DOE/ET/10205--T1-Vol.19



A minerals and materials contract report
DECEMBER 1985

# FIXED-BED GASIFICATION RESEARCH USING U.S. COALS, VOLUME 19 EXECUTIVE SUMMARY



Contract H0222001
Black, Sivalls, and Bryson, Incorporated

BUREAU OF MINES
UNITED STATES DEPARTMENT OF THE INTERIOR

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16. Abstract (Limit: 200 words)

A single-staged, fixed-bed, Wellman-Galusha gasifier coupled with a hot, raw gas combustion system and scrubber has been used to gasify numerous coals from throughout the United States. The gasification test program is organized as a cooperative effort under the Mining and Industrial Fuel Gas Group (MIFGA).

This report is the nineteenth volume in a series of reports describing the atmospheric pressure, fixed-bed gasification of U.S. coals. This volume briefly summarizes the results of eighteen different gasification tests in which fourteen different fuels were gasified from May 1982 to August 1985. The design gasification performance of all coals evaluated are summarized. In addition, summary design and economic data for industrial coal gasification systems are presented.

17. Document Analysis a. Descriptors

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## FOREWORD

This report was prepared by Black, Sivalls, and Bryson, Inc., Houston, Texas under USBM contract number H0222001. The contract was administered under the technical direction of the Twin Cities Research Center with Mr. Robert Zahl acting as Technical Project Officer. Mr. Frank Pavlich was the contract administrator for the Bureau of Mines. This report is a partial summary of the work completed as a part of this contract during the period June 1982 to December 1985. This final report was submitted by the authors on December 15, 1985.

Funding for this contract was through USBM/USDOE Interagency Agreement DE-A121-7ET10205.

The University of Minnesota, Particle Technology Laboratory, Minneapolis, Minnesota, a subcontractor to Black, Sivalls, and Bryson, Inc., participated in the preparation of this report.

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## INTRODUCTION

The United States Department of Interior, Bureau of Mines, Twin Cities Research Center, Minneapolis, Minnesota is the site of a 6.5 foot diameter Wellman-Galusha gasifier, installed in 1977-78. This gasifier, combustor/incinerator, and flue gas scrubber system in the past had been operated jointly by Bureau of Mines personnel, personnel from member companies of the Mining and Industrial Fuel Gas Group (MIFGa), and United States Department of Energy (DOE) personnel and consultants. Numerous tests using a variety of coals have to date been performed.

In May of 1982, Black, Sivalls & Bryson, Incorporated (BS&B) was awarded the contract to plan, execute, and report gasification test performance data from this small industrial fixed-bed gasification test facility. BS&B is responsible for program administration, test planning, test execution, and all documentation of program activities and test reports. The University of Minnesota, Particle Technology Laboratory (UMPTL) is subcontractor to BS&B to monitor process parameters, and provide analysis for material inputs and outputs.

This report is the nineteenth volume in a series of reports describing the fixed-bed gasification of U.S. coals at the Bureau of Mines, Twin Cities Research Center. This report is an executive summary of the program which summarizes the design performance of the 18 fuels gasified from May 1982 through August 1985. In addition to the design performance data, the design considerations and general economics of industrial sized coal gasification plants utilizing the single-stage fixed-bed gasifier used in this program is summarized.

Section 1 of this report summarizes the Mining and Industrial Fuel Gas (MIFGA) Program Objectives and Results. The specific Program Summary and Conclusions are presented in Section 2. An overview of the facility and process description is presented in Section 3. Sections 4 and 5 summarize the fuels gasified and the design performance of each fuel gasified. Finally, Sections 6 and 7 present an overview and discussion of the issues to be considered when planning an industrial coal gasification facility and the nominal economics of industrial coal gasification facilities utilizing the single-stage fixed-bed coal gasification process.

## SECTION 1

## PROGRAM OBJECTIVES & RESULTS

Although the United States possesses a long history of operating fixed-bed coal gasifiers, it does not include operation with low rank coals as feedstock. In order to gain fundamental performance data relating to the fixed-bed gasification of sub-bituminous coals, lignites, and peat, plus the use of coal gas in kiln operations, the Mining and Industrial Fuel Gas Group (MIFGA) was formed to cooperatively address these issues.

A single-stage fixed-bed Wellman-Galusha gasifier was installed at the Bureau of Mines, Twin Cities Research Center. The objectives of the coal gasification research program, performed by Black, Sivalls & Bryson, Incorporated, under contract to the Bureau of Mines are listed below:

(1) Identify the limitations to throughput for fixed-bed gasification and the overall conversion efficiencies.

(2) Investigate the influence of coal properties on gasifier operation.

(3) Characterize the total gasifier product for various operating conditions.

(4) Identify retort and control design changes that can reduce downtime and operational requirements.

(5) Provide a source of coal gas for processing and utilization studies.

(6) Provide an opportunity for "hands on" gasifier operation experience for cooperators.

(7) Evaluate environmental impacts of fixed-bed gasifiers.

Program results are briefly summarized in this volume, Sections 2 through 5. Program details are reported in Volumes 1 through 18. Volume 1 of the report series presents the TCRC gasification test facility plus operating and data handling/reduction procedures. Volumes 2 through 17 are detailed reports summarizing individual tests. These volumes present the operational logs, data, performance results, and discussions pertaining to the gasification performance of a specific fuel. Volume 18 presents an overall compilation of the gasification performance data generated on this program and correlations of these results with coal properties.

## SECTION 2

## SUMMARY AND CONCLUSIONS

This program succeeded in accomplishing the stated objectives, delineated in Section 1. The eighteen different fuels gasified in the 6.5 foot diameter single-stage Wellman-Galusha gasifier produced the following results:

(1) Most U.S. coals can be effectively gasified in the single-stage Wellman-Galusha gasifier.

(2) The single-stage fixed-bed gasifier is highly efficient. Hot raw coal gas conversion efficiencies in the range of 92 to 94 percent are easily achieved. Cold gas plus distillate efficiencies in the range of 82 to 85 percent are readily achieved.

(3) Coals with free-swelling indexes (FSI) greater than or equal to 6 are questionable feedstock for the Wellman-Galusha gasifier with an agitator.

(4) Coals with free-swelling indexes (FSI) less than or equal to 4 are manageable feedstock for the Wellman-Galusha gasifier with an agitator.

(5) Low rank coals (subbituminous and lignites), despite their friability (tendency to break down into fines in the retort), in general performed well in the single-stage retort.

(6) Cleaning the hot raw gas from a single-stage gasifier can be achieved by first removing the particulate and subsequently condensing and collecting the distillate with an electrostatic precipitator.

(7) The coal distillate generated in the relatively thick bed Wellman-Galusha gasifier is high quality, lower in sulfur than the original coal, with the yield accurately predicted from the coal proximate analysis (Volume 18, Thimsen, Maurer, et. al.) The coal distillate yield can be over 20 percent of the input coal energy.

(8) The majority of the sulfur in the coal is recovered in the product gas. In this form the sulfur is amenable to recovery by existing gas phase desulfurization processes.

# SECTION 3

## FACILITY AND PROCESS DESCRIPTION

The gasifier installed at the Bureau of Mines, Twin Cities Research Center (USBM/TCRC) is a single-stage, Wellman-Galusha gas producer as shown in Figure 3-1. The gas producer operates near atmospheric pressure. The gasification process as operated at USBM/TCRC is briefly described here. A more detailed discussion is presented in Volume 1.

Coal is choke fed from an overhead lock hopper down two feed pipes into the retort. As the coal descends to the grate, it is dried, devolatilized, gasified, and finally the char residue is burned in a layer just above the ash. The coal ash insulates the rotating, step-type grate. Ash is removed through this grate as a dry, granular solid.

Moving counter to the coal flow is the gas flow. Blast air is saturated with water vapor at a controlled temperature, and moves up through the ash layer where it is partially preheated. Variations in blast saturation temperature (steam/air ratio) are used to optimize the combustion zone temperature below the level at which ash fusing becomes a problem. In this combustion zone above the ash layer, oxygen in the blast is consumed and replaced by carbon monoxide and carbon dioxide. As these gases move upward from the combustion zone, the high temperature steam and carbon dioxide in the blast react with the incandescent char to produce carbon monoxide and hydrogen. These endothermic reduction reactions cool the gas but more than enough sensible heat is present to preheat, devolatize, and dry the fresh coal feed. This counterflow arrangement makes for relatively low product gas temperatures (400-900 F) and very efficient operation.

A process flow schematic for the USBM/TCRC facility is given in Figure 3-2.

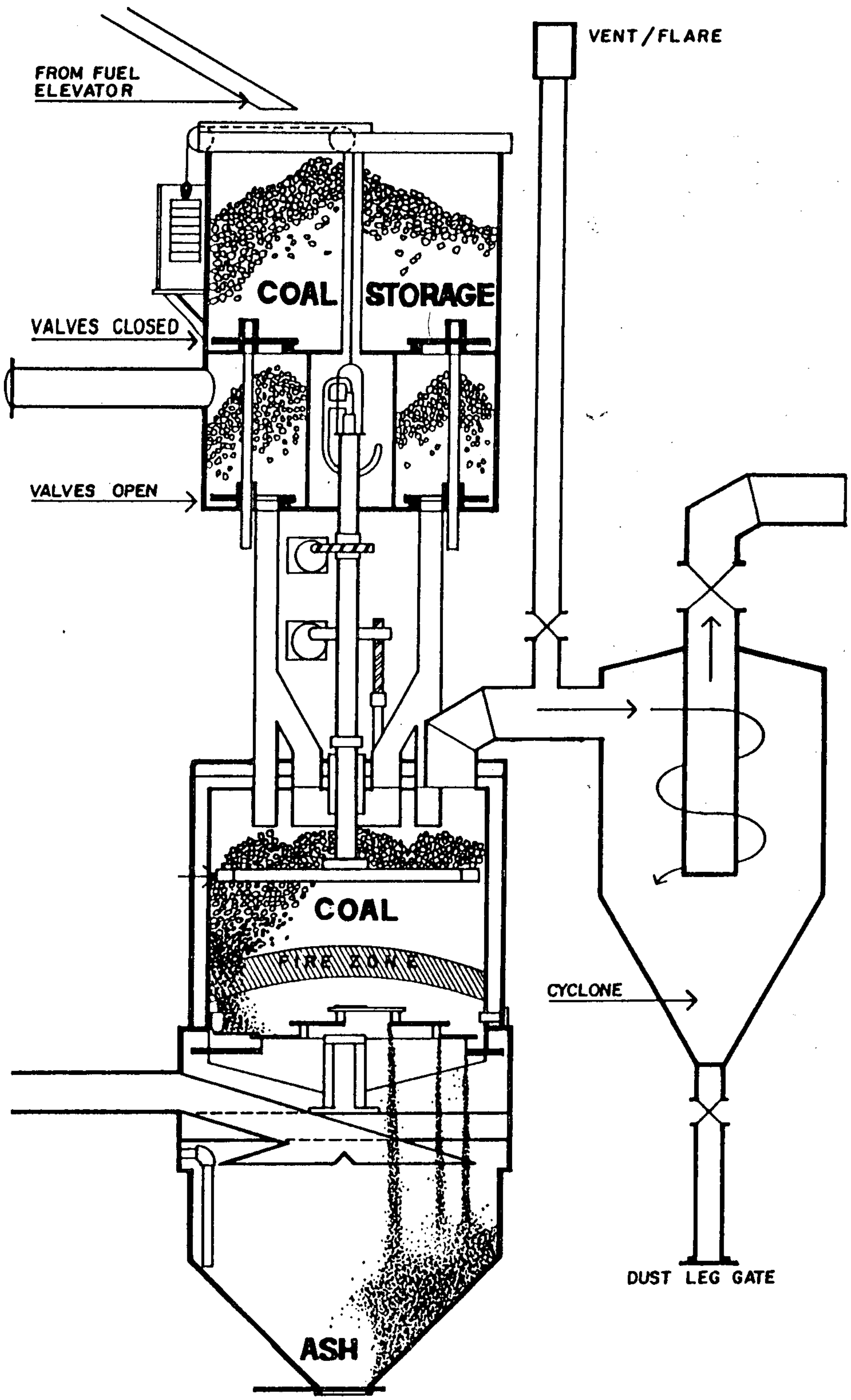
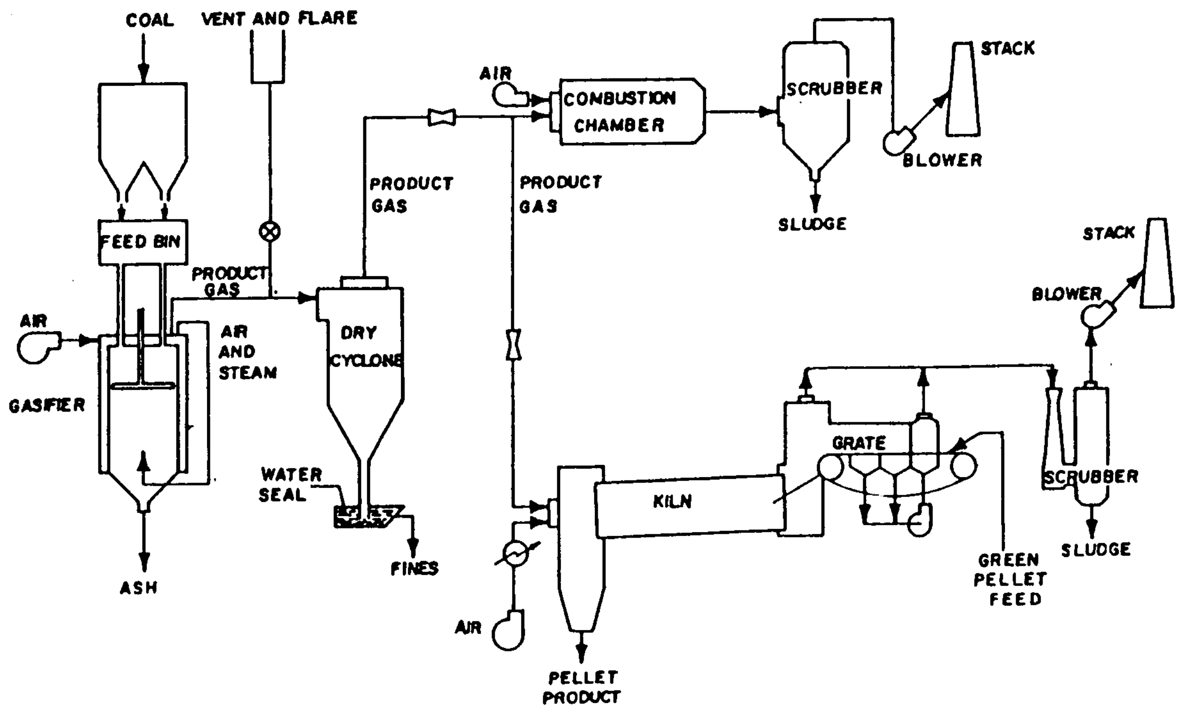



Figure 3-1

Schematic of Wellman-Galusha Gasifier

Figure 3-2

USBM/TCRC Gasifier Process Flow Schematic



## SECTION 4

## SUMMARY OF FUELS GASIFIED

During the tenure of Black, Sivalls & Bryson, Incorporated as contractor with the Bureau of Mines (Contract H0222001) on the Mining and Industrial Fuel Gas Group (MIFGA) program, a total of eighteen separate gasification tests were performed. The period of performance during which these tests were conducted spanned from May 1982 to August 1985.

Table 4-1 summarizes the fuels gasified during the program, including the dates and duration of each test and the reference in which the test results are documented.

Table 4-2 summarizes the average analyses of each fuel gasified.

The fuels gasified spanned the range from "green" delayed petroleum coke on the high rank end to four different physical forms of Minnesota peat on the low rank (or biomass) end.

Eight different bituminous coals were gasified with five different subbituminous coals tested. Two different lignites were tested, one from the Wilcox seam in Arkansas, the other from the Indianhead seam in North Dakota.

Table 4-1

Fixed-Bed Gasification Tests Conducted
USBM Contract HO222001

| Test Number | Fuel | Test Dates | Duration (days) | Report(** |
|---|---|---|---|---|
| Bituminous: | | | | |
| BOM/FGT-001 | Jetson Bituminous | 08/18 - 08/25/82 | | |
| | continued | 10/29 - 11/02/82 | 13 | Volume 2 |
| BOM/FGT-004 | Stahlman Stoker | 04/30 - 05/04/83 | 4 | Volume 5 |
| BOM/FGT-006 | Piney Tipple Bit. | 07/18 - 07/24/83 | 7 | Volume 7 |
| BOM/FGT-007 | River King Bit. | 07/28 - 08/10/83 | | |
| | continued | 08/15 - 08/19/83 | 19 | Volume 8 |
| BOM/FGT-008 | Elkhorn Bit. | 09/13 - 10/13/83 | 31 | Volume 9 |
| BOM/FGT-014 | Blind Canyon Bit. | 07/31 - 08/11/84 | 12 | Volume 13 |
| BOM/FGT-018 | Hiawatha Bit. | 07/25 - 07/28/85 | 4 | Volume 17 |
| BOM/FGT-018 | SUFCO Bituminous | 07/17 - 07/21/85 | 4 | Volume 17 |
| BOM/FGT-018 | River King Bit. | 07/16 - 07/17/85 | 2 | Volume 17 |
| Subbituminous: | | | | |
| BOM/FGT-002 | Rosebud Subbit. | 11/02 - 11/20/82 | 19 | Volume 3 |
| BOM/FGT-003 | Leucite Hills Sub. | 04/11 - 04/30/83 | 20 | Volume 4 |
| BOM/FGT-012 | Absaloka Subbit. | 06/18 - 06/30/84 | 13 | Volume 12 |
| BOM/FGT-015 | Kemmerer Subbit. | 08/11 - 08/15/84 | 4 | Volume 14 |
| BOM/FGT-016 | Rosebud Subbit. | 06/17 - 06/24/85 | 8 | Volume 15 |
| Lignite: | | | | |
| BOM/FGT-009 | Benton Lignite | 11/01 - 11/08/83 | 8 | Volume 10 |
| BOM/FGT-018 | Indianhead Lignite | 07/22 - 07/24/85 | 3 | Volume 17 |
| Peat: | | | | |
| BOM/FGT-010 | Peat Pellets | 11/09/83 | 1 | Volume 11 |
| BOM/FGT-011 | Peat Sods | 06/05 - 06/10/84 | 6 | Volume 11 |
| BOM/FGT-013 | Peat Pellets | 07/16 - 07/19/84 | 4 | Volume 11 |
| BOM/FGT-017 | Peat Sods | 06/24 - 06/27/85 | 4 | Volume 16 |
| Coke: | | | | |
| BOM/FGT-005 | Delayed Pet. Coke | 06/01 - 06/17/83 | 17 | Volume 6 |

(**) Complete report titles are given in the References.

Table 4-2 (a)

Average Physical and Chemical Analyses of Fuels Gasified

| Test Number (BOM/FGT- ) | -001 Jetson Bituminous | -002 Rosebud Subbitum | -003 Leucite Hills | -004 Stahlman Stoker Bit. | -005 Petroleum Coke | -006 Piney Tipple Bit. | -007 River Kng Bit. | -008 Elkhorn Bituminous | -009 Benton Lignite | -010,013 Peat Pellets |
|---|---|---|---|---|---|---|---|---|---|---|
| Proximate Analysis (wt %) | | | | | | | | | | |
| Moisture | 7.1 | 23.0 | 16.8 | 3.2 | 2.7 | 1.9 | 10.3 | 4.4 | 32.8 | 34.4 |
| Volatile Matter | 38.8 | 29.1 | 29.6 | 31.7 | 9.1 | 37.7 | 35.3 | 37.2 | 34.9 | 42.2 |
| Fixed Carbon | 48.9 | 35.3 | 45.6 | 56.9 | 87.9 | 51.0 | 45.1 | 51.5 | 25.9 | 16.1 |
| Ash | 5.2 | 12.6 | 8.1 | 8.1 | 0.3 | 9.4 | 9.3 | 6.9 | 6.4 | 7.3 |
| Ultimate Analysis (wt %) | | | | | | | | | | |
| Hydrogen | 4.2 | 3.3 | 3.8 | 5.0 | 3.5 | 5.2 | 4.6 | 5.1 | 3.7 | 3.5 |
| Carbon | 71.9 | 48.9 | 58.7 | 74.2 | 85.8 | 73.6 | 63.1 | 73.7 | 44.8 | 34.3 |
| Nitrogen | 1.6 | 0.7 | 1.4 | 1.5 | 1.4 | 1.3 | 1.1 | 1.5 | .6 | 1.6 |
| Oxygen | 8.7 | 10.5 | 10.7 | 6.6 | 1.1 | 5.6 | 8.2 | 7.7 | 11.1 | 18.7 |
| Sulfur | 1.4 | 1.1 | 0.6 | 1.0 | 5.3 | 3.0 | 3.4 | .8 | .6 | .2 |
| Moisture | 7.1 | 23.0 | 16.8 | 3.2 | 2.7 | 1.9 | 10.3 | 4.4 | 32.8 | 34.4 |
| Ash | 5.2 | 12.6 | 8.1 | 8.1 | 0.3 | 9.4 | 9.3 | 6.9 | 6.4 | 7.3 |
| Heating Value (Btu/lb) | 12845 | 8354 | 10209 | 13355 | 14699 | 13427 | 11389 | 13137 | 8081 | 6092 |
| Free Swelling Index | 2 | 0 | 0 | 8 1/2 | 0 | 6 1/2 | 3 1/2 | 3 1/2 | 1/2 | 0 |
| Ash Fusion Temperatures (deg F) | | | | | | | | | | |
| (Oxidizing Atmosphere) | | | | | | | | | | |
| Initial Deformation | 2520 | 2280 | 2700 | 2790 | - | 2545 | 2390 | +2800 | 2320 | 2135 |
| Softening | 2570 | 2300 | 2800 | +2800 | - | 2565 | 2450 | +2800 | 2365 | 2155 |
| Hemispherical | 2610 | 2320 | +2800 | +2800 | - | 2580 | 2480 | +2800 | 2410 | 2205 |
| Fluid | 2715 | 2380 | +2800 | +2800 | - | 2615 | 2580 | +2800 | 2465 | 2220 |
| (Reducing Atmosphere) | | | | | | | | | | |
| Initial Deformation | 2210 | 2220 | 2700 | 2725 | - | 2120 | 2040 | +2800 | 2350 | 2050 |
| Softening | 2335 | 2270 | +2800 | +2800 | - | 2235 | 2105 | +2800 | 2395 | 2085 |
| Hemispherical | 2415 | 2280 | +2800 | +2800 | - | 2330 | 2180 | +2800 | 2410 | 2100 |
| Fluid | 2485 | 2300 | +2800 | +2800 | - | 2430 | 2297 | +2800 | 2430 | 2135 |

Table 4-2 (b)

Average Physical and Chemical Analyses of Fuels Gasified

| Test Number (BOM/FGT- ) | -011 Peat Sods | -012 Absoloka Subbitum | -014 Blnd Cnyn Bituminous | -015 Kemmerer Subbitum | -016 Rosebud Subbitum | -017 Peat Sods | -018-1 River King Bituminous | -018-2 SUFCO Bituminous | -018-3 Indianhead Lignite | -018-4 Hiawatha Bituminous |
|---|---|---|---|---|---|---|---|---|---|---|
| **Proximate Analysis (wt %)** | | | | | | | | | | |
| Moisture | 42.5 | 23.46 | 6.10 | 16.76 | 21.25 | 36.45 | 9.56 | 7.06 | 28.21 | 5.17 |
| Volatile Matter | 31.4 | 29.56 | 38.92 | 35.13 | 26.81 | 41.89 | 35.47 | 37.35 | 31.52 | 40.06 |
| Fixed Carbon | 13.8 | 40.72 | 43.88 | 42.44 | 40.12 | 15.43 | 44.83 | 47.88 | 29.11 | 44.21 |
| Ash | 12.3 | 6.26 | 11.10 | 5.67 | 11.82 | 6.23 | 10.14 | 7.71 | 11.17 | 10.57 |
| **Ultimate Analysis (wt %)** | | | | | | | | | | |
| Hydrogen | 2.44 | 3.60 | 5.09 | 4.37 | 3.31 | 3.47 | 4.65 | 4.81 | 3.02 | 5.17 |
| Carbon | 26.9 | 53.59 | 66.52 | 60.11 | 52.70 | 32.71 | 62.49 | 67.52 | 42.60 | 67.53 |
| Nitrogen | 1.23 | .54 | .96 | .90 | .71 | 1.58 | 1.00 | 1.02 | .43 | 1.20 |
| Oxygen | 14.4 | 12.22 | 9.72 | 11.40 | 9.35 | 19.36 | 7.91 | 11.36 | 13.16 | 9.77 |
| Sulfur | .24 | .31 | .52 | .79 | .87 | .20 | 4.25 | .52 | 1.40 | .60 |
| Moisture | 42.5 | 23.46 | 6.10 | 16.76 | 21.25 | 36.45 | 9.56 | 7.06 | 28.21 | 5.17 |
| Ash | 12.3 | 6.26 | 11.10 | 5.67 | 11.82 | 6.23 | 10.14 | 7.71 | 11.17 | 10.57 |
| **Heating Value (Btu/lb)** | 4403 | 9187 | 11926 | 10513 | 8881 | 5573 | 11344 | 11837 | 7117 | 12058 |
| **Free Swelling Index** | 0 | 0 | 1 1/2 | 0 | 0 | 0 | 4 | 0 | 0 | 1 1/2 |
| **Ash Fusion Temperatures (deg F)** | | | | | | | | | | |
| (Oxidizing Atmosphere) | | | | | | | | | | |
| Initial Deformation | 2120 | 2135 | 2345 | 2245 | 2290 | 2140 | 2365 | 2125 | 2315 | 2390 |
| Softening | 2170 | 2175 | 2450 | 2330 | 2350 | 2165 | 2440 | 2190 | 2340 | 2425 |
| Hemispherical | 2270 | 2195 | 2490 | 2410 | 2380 | 2205 | 2480 | 2310 | 2355 | 2465 |
| Fluid | 2505 | 2230 | 2660 | 2535 | 2455 | 2390 | 2555 | 2525 | 2380 | 2515 |
| (Reducing Atmosphere) | | | | | | | | | | |
| Initial Deformation | 2065 | 2070 | 2250 | 2205 | 2140 | 2070 | 1975 | 2070 | 2420 | 2275 |
| Softening | 2120 | 2105 | 2370 | 2300 | 2210 | 2100 | 2015 | 2140 | 2455 | 2390 |
| Hemispherical | 2150 | 2120 | 2450 | 2380 | 2245 | 2125 | 2070 | 2185 | 2490 | 2415 |
| Fluid | 2320 | 2175 | 2495 | 2465 | 2310 | 2195 | 2175 | 2320 | 2510 | 2470 |

## SECTION 5

## DESIGN PERFORMANCE OF FUELS GASIFIED

Eighteen different fuels were gasified in a small (6.5 foot diameter) industrial single-stage gasifier. Fifteen of the fuels were evaluated as successful, based on their overall performance in the single-stage gasifier, despite the fact that the fuels ranged from highly friable low rank lignites and subbituminous coals to moderate and high swelling bituminous coals.

Three fuels were judged not to be suitable feedstock for fixed-bed gasifiers. These fuels are listed below:

| | |
|---|---|
| BOM/FGT-004 | Stahlman Stoker Bituminous |
| BOM/FGT-006 | Piney Tipple Bituminous |
| BOM/FGT-002/016 | Rosebud Subbituminous |

The two Pennsylvania coals (Stahlman Stoker and Piney Tipple) from Clarion county, both had free swelling indexes above 6.5. The swelling and agglomerating characteristics of these coals could not be effectively managed by the agitator in the Wellman-Galusha gasifier used throughout this program. The carbon conversion was extremely low (poor gas quality) with a limited throughput achievable.

On the low rank end of the spectrum, two different forms of Rosebud subbituminous coal (Powder River Basin, Montana) were gasified and demonstrated excessive friability and decrepitation which severely limited the gasifier capacity. Details of these tests are available in Volumes 3, 5, 7, and 15 (Thimsen, Maurer, et. al.).

The design performance data for each fuel gasified is presented in Table 5-1. The data presented herein summarizes detailed gasification performance tests spanning a total of 203 days of gasifier operation. These and other data are correlated with coal properties in Volume 18.

Table 5-1 (a)

## Design Point Characteristics for Gasification of Jetson Bituminous Coal

Coal Throughput - 1.60 tons/hour (96.4 lb/hr/sq ft grate)

| | | |
|---|---|---|
| Air/Coal | 2.96 | lb/lb |
| Steam/Coal | 0.49 | lb/lb |
| Blast Saturation Temperature | 142 | deg. F |
| Gas Offtake Temperature | 800 | deg. F |
| Wet Gas/Coal | 125 | scf/lb |
| Gas Dewpoint | 113 | deg. F |
| Tar Yield | 13.0 | lb/100 lb coal |
| Tar Analysis | | |
| HHV (dry) | 16200 | Btu/lb |
| Pourpoint | 70 | deg. F |
| Viscosity (210 F) | 107 | SUS |
| Specific gravity (60/60 F) | 1.09 | |
| Dry Gas Composition (mol %) | | |
| Hydrogen | 17.20 | |
| Carbon monoxide | 24.70 | |
| Methane | 1.60 | |
| Ethane | 0.179 | |
| Ethylene | 0.140 | |
| Carbon Dioxide | 5.67 | |
| Nitrogen + Argon | 50.20 | |
| Total Gas Sulfur | 2800 | ppm |
| Water | 4.4 | lb/1000 dscf |
| Dry Gas HHV | 158 | Btu/dscf |
| Dry Gas LHV | 148 | Btu/dscf |
| Thermal Efficiencies | | |
| Hot, raw | 92 | percent |
| Cold, with tar | 83 | percent |
| Cold, without tar | 69 | percent |

Table 5-1 (b)

Design Point Characteristics for Gasification of Rosebud Subbituminous Coal

Coal Throughput - 1.1 tons/hour (66.3 lb/hr/sq ft grate)

| | | |
|---|---|---|
| Air/Coal | 1.55 | lb/lb |
| Steam/Coal | 0.29 | lb/lb |
| Blast Saturation Temperature | 146 | deg. F |
| Gas Offtake Temperature | 533 | deg. F |
| Wet Gas/Coal | 44.3 | scf/lb |
| Gas Dewpoint | 137 | deg. F |
| Tar Yield | 5.2 | lb/100 lb coal |
| Tar Analysis | | |
| HHV (dry) | 17050 | Btu/lb |
| Pourpoint | 85 | deg. F |
| Viscosity (210 F) | 128 | SUS |
| Specific gravity (60/60 F) | 1.0746 | |
| Dry Gas Composition (mol %) | | |
| Hydrogen | 18.10 | |
| Carbon monoxide | 28.40 | |
| Methane | 1.63 | |
| Ethane | 0.13 | |
| Ethylene | 0.85 | |
| Carbon Dioxide | 5.97 | |
| Nitrogen + Argon | 44.00 | |
| Water | 10.3 | lb/1000 dscf |
| Dry Gas HHV | 184 | Btu/dscf |
| Dry Gas LHV | 172 | Btu/dscf |
| Thermal Efficiencies | | |
| Hot, raw | 98 | percent |
| Cold, with tar | 89 | percent |
| Cold, without tar | 79 | percent |

## Table 5-1 (c)

### Design Point Characteristics for Gasification of Leucite Hills Coal

Coal Throughput - 1.60 tons/hour (96.4 lb/hr/sq ft grate)

| | | |
|---|---|---|
| Air/Coal | 1.78 | lb/lb |
| Steam/Coal | 0.332 | lb/lb |
| Blast Saturation Temperature | 146 | deg. F |
| Gas Offtake Temperature | 565 | deg. F |
| Wet Gas/Coal | 49.4 | scf/lb |
| Gas Dewpoint | 128 | deg. F |
| Tar Yield | 6.6 | lb/100 lb coal |
| Tar Analysis | | |
| HHV (dry) | 15430 | Btu/lb |
| Pourpoint | 90 | deg. F |
| Viscosity (210 F) | 73 | SUS |
| Specific gravity (60/60 F) | 1.075 | |
| Dry Gas Composition (mol %) | | |
| Hydrogen | 19.40 | |
| Carbon monoxide | 28.80 | |
| Methane | 1.67 | |
| Ethane | 0.152 | |
| Ethylene | 0.051 | |
| Propylene | 0.038 | |
| Propane | 0.037 | |
| Carbon Dioxide | 5.96 | |
| Nitrogen + Argon | 43.20 | |
| Water | 7.73 | lb/1000 dscf |
| Dry Gas HHV | 178 | Btu/dscf |
| Dry Gas LHV | 166 | Btu/dscf |
| Thermal Efficiencies | | |
| Hot, raw | 93 | percent |
| Cold, with tar | 85 | percent |
| Cold, without tar | 75 | percent |

Table 5-1 (d)

Design Point Characteristics for Gasification of Stahlman Stoker Bituminous Coal

Coal Throughput - 0.49 tons/hour (29.5 lb/hr/sq ft grate)

| | | |
|---|---|---|
| Air/Coal | 4.44 | lb/lb |
| Steam/Coal | 0.721 | lb/lb |
| Blast Saturation Temperature | 141 | deg. F |
| Gas Offtake Temperature | 1033 | deg. F |
| Wet Gas/Coal | 92.9 | scf/lb |
| Gas Dewpoint | 135 | deg. F |
| Tar Yield | 4.4 | lb/100 lb coal |
| Tar Analysis | | |
| HHV (dry) | 12905 | Btu/lb |
| Pourpoint | 45 | deg. F |
| Viscosity (210 F) | 91.0 | SUS |
| Specific gravity (60/60 F) | 1.1033 | |
| Dry Gas Composition (mol %) | | |
| Hydrogen | 12.40 | |
| Carbon monoxide | 13.40 | |
| Methane | 1.28 | |
| Ethane | 0.081 | |
| Ethylene | 0.162 | |
| Propane | 0.020 | |
| Propylene | 0.030 | |
| Carbon Dioxide | 12.57 | |
| Nitrogen + Argon | 59.10 | |
| Water | 9.65 | lb/1000 dscf |
| Dry Gas HHV | 102 | Btu/dscf |
| Dry Gas LHV | 94 | Btu/dscf |
| Thermal Efficiencies | | |
| Hot, raw | 82 | percent |
| Cold, with tar | 63 | percent |
| Cold, without tar | 59 | percent |

Table 5-1 (e)

Design Point Characteristics for Gasification of Delayed Petroleum Coke

Coal Throughput - 0.91 tons/hour (54.9 lb/hr/sq ft grate)

| | | |
|---|---|---|
| Air/Coke | 3.697 | lb/lb |
| Steam/Coke | 0.599 | lb/lb |
| Blast Saturation Temperature | 141 | deg. F |
| Gas Offtake Temperature | 877 | deg. F |
| Wet Gas/Coke | 80.4 | scf/lb |
| Gas Dewpoint | 92 | deg. F |
| Tar Yield | 1.3 | lb/100 lb coke |
| Tar Analysis** | | |
| HHV (dry) | 11931 | Btu/lb |
| Dry Gas Composition (mol %) | | |
| Hydrogen | 16.60 | |
| Carbon monoxide | 23.30 | |
| Methane | 0.51 | |
| Ethane | 0.044 | |
| Ethylene | 0.031 | |
| Carbon Dioxide | 8.39 | |
| Nitrogen + Argon | 51.30 | |
| Water | 2.49 | lb/1000 dscf |
| Dry Gas HHV | 140 | Btu/dscf |
| Dry Gas LHV | 130 | Btu/dscf |
| Thermal Efficiencies | | |
| Hot, raw | 83 | percent |
| Cold, with tar | 73 | percent |
| Cold, without tar | 72 | percent |

** Insufficient "Tar" was collected from the petroleum coke gasification test to characterize.

Table 5-1 (f)

Design Point Characteristics for Gasification of Piney Tipple Bituminous Coal

Coal Throughput - 0.67 tons/hour (40.4 lb/hr/sq ft grate)

| | | |
|---|---|---|
| Air/Coal | 3.309 | lb/lb |
| Steam/Coal | 0.610 | lb/lb |
| Blast Saturation Temperature | 145 | deg. F |
| Gas Offtake Temperature | 987 | deg. F |
| Wet Gas/Coal | 71.7 | scf/lb |
| Gas Dewpoint | 119 | deg. F |
| Tar Yield | 8.5 | lb/100 lb coal |
| Tar Analysis | | |
| HHV (dry) | 15672 | Btu/lb |
| Pourpoint | 75 | deg. F |
| Viscosity (210 F) | 116 | SUS |
| Specific gravity (60/60 F) | 1.1521 | |
| Dry Gas Composition (mol %) | | |
| Hydrogen | 14.30 | |
| Carbon monoxide | 20.70 | |
| Methane | 1.12 | |
| Ethane | 0.108 | |
| Ethylene | 0.160 | |
| Propane | 0.028 | |
| Propylene | 0.064 | |
| Carbon Dioxide | 8.98 | |
| Nitrogen + Argon | 53.90 | |
| Water | 5.84 | lb/1000 dscf |
| Dry Gas HHV | 134 | Btu/dscf |
| Dry Gas LHV | 125 | Btu/dscf |
| Thermal Efficiencies | | |
| Hot, raw | 83 | percent |
| Cold, with tar | 71 | percent |
| Cold, without tar | 61 | percent |

Table 5-1 (g)

Design Point Characteristics for Gasification of River King Illinois No. 6 Bituminous Coal

Coal Throughput - 2.07 tons/hour (125 lb/hr/sq ft grate)

| | | |
|---|---|---|
| Air/Coal | 2.172 | lb/lb |
| Steam/Coal | 0.371 | lb/lb |
| Blast Saturation Temperature | 143 | deg. F |
| Gas Offtake Temperature | 902 | deg. F |
| Wet Gas/Coal | 52.5 | scf/lb |
| Gas Dewpoint | 125 | deg. F |
| Tar Yield | 13.7 | lb/100 lb coal |
| Tar Analysis | | |
| HHV (dry) | 15352 | Btu/lb |
| Pourpoint | 65 | deg. F |
| Viscosity (210 F) | 122 | SUS |
| Specific gravity (60/60 F) | 1.1544 | |
| Dry Gas Composition (mol %) | | |
| Hydrogen | 16.50 | |
| Carbon monoxide | 23.70 | |
| Methane | 1.62 | |
| Ethane | 0.183 | |
| Ethylene | 0.171 | |
| Propane | 0.050 | |
| Propylene | 0.065 | |
| Carbon Dioxide | 7.22 | |
| Nitrogen + Argon | 49.50 | |
| Water | 6.94 | lb/1000 dscf |
| Dry Gas HHV | 160 | Btu/dscf |
| Dry Gas LHV | 149 | Btu/dscf |
| Thermal Efficiencies | | |
| Hot, raw | 92 | percent |
| Cold, with tar | 81 | percent |
| Cold, without tar | 63 | percent |

## Table 5-1 (h)

### Design Point Characteristics for Gasification of Elkhorn Bituminous Coal

Coal Throughput - 2.0 tons/hour (121 lb/hr/sq ft grate)

| | | |
|---|---|---|
| Air/Coal | 2.162 | lb/lb |
| Steam/Coal | 0.320 | lb/lb |
| Blast Saturation Temperature | 138 | deg. F |
| Gas Offtake Temperature | 838 | deg. F |
| Wet Gas/Coal | 52.8 | scf/lb |
| Gas Dewpoint | 104 | deg. F |
| Tar Yield | 14.5 | lb/100 lb coal |
| Tar Analysis | | |
| HHV (dry) | 16450 | Btu/lb |
| Pourpoint | 75 | deg. F |
| Viscosity (210 F) | 29.5 | SUS |
| Specific gravity (60/60 F) | 1.1095 | |
| Dry Gas Composition (mol %) | | |
| Hydrogen | 18.90 | |
| Carbon monoxide | 26.30 | |
| Methane | 1.76 | |
| Ethane | 0.20 | |
| Ethylene | 0.21 | |
| Propane | 0.05 | |
| Propylene | 0.08 | |
| Carbon Dioxide | 6.12 | |
| Nitrogen + Argon | 46.00 | |
| Water | 3.6 | lb/1000 dscf |
| Dry Gas HHV | 175 | Btu/dscf |
| Dry Gas LHV | 163 | Btu/dscf |
| Thermal Efficiencies | | |
| Hot, raw | 87 | percent |
| Cold, with tar | 80 | percent |
| Cold, without tar | 62 | percent |

Table 5-1 (i)

Design Point Characteristics for Gasification of Benton Lignite

Coal Throughput - 2.6 tons/hour (157 lb/hr/sq ft grate)

| | | |
|---|---|---|
| Air/Coal | 1.067 | lb/lb |
| Steam/Coal | 0.302 | lb/lb |
| Blast Saturation Temperature | 158 | deg. F |
| Gas Offtake Temperature | 292 | deg. F |
| Wet Gas/Coal | 38.4 | scf/lb |
| Gas Dewpoint | 160 | deg. F |
| Tar Yield | 11.2 | lb/100 lb coal |
| Tar Analysis | | |
| HHV (dry) | 18953 | Btu/lb |
| Pourpoint | 90 | deg. F |
| Viscosity (210 F) | 49.5 | SUS |
| Specific gravity (60/60 F) | 1.0461 | |
| Dry Gas Composition (mol %) | | |
| Hydrogen | 21.40 | |
| Carbon Monoxide | 23.00 | |
| Methane | 1.76 | |
| Ethane | 0.112 | |
| Ethylene | 0.219 | |
| Propane | 0.086 | |
| Propylene | 0.072 | |
| Carbon Dioxide | 10.60 | |
| Nitrogen + Argon | 42.50 | |
| Water | 21.8 | lb/1000 dscf |
| Dry Gas HHV | 172 | Btu/dscf |
| Dry Gas LHV | 158 | Btu/dscf |
| Thermal Efficiencies | | |
| Hot, raw | 99 | percent |
| Cold, with tar | 89 | percent |
| Cold, without tar | 54 | percent |

Table 5-1 (j)

Design Point Characteristics for Gasification of Peat Pellets

Peat Throughput - 1.8 tons/hour (108 lb/hr/sq ft grate)

| | | |
|---|---|---|
| Air/Peat | 1.29 | lb/lb |
| Steam/Peat | 0.19 | lb/lb |
| Blast Saturation Temperature | 139 | deg. F |
| Gas Offtake Temperature | 251 | deg. F |
| Wet Gas/Peat | 41.5 | scf/lb |
| Gas Dewpoint | 153 | deg. F |
| Tar Yield | 7.9 | lb/100 lb peat |
| Tar Analysis | | |
| HHV (dry) | 15552 | Btu/lb |
| Pourpoint | +110 | deg. F |
| Viscosity (210 F) | 56.9 | SUS |
| Specific gravity (60/60 F) | 1.0491 | |
| Dry Gas Composition (mol %) | | |
| Hydrogen | 17.20 | |
| Carbon monoxide | 28.40 | |
| Methane | 1.46 | |
| Ethane | 0.100 | |
| Ethylene | 0.087 | |
| Propane | 0.024 | |
| Propylene | 0.040 | |
| Carbon Dioxide | 7.97 | |
| Nitrogen + Argon | 44.30 | |
| Water | 17.1 | lb/1000 dscf |
| Dry Gas HHV | 168 | Btu/dscf |
| Dry Gas LHV | 158 | Btu/dscf |
| Thermal Efficiencies | | |
| Hot, raw | 92 | percent |
| Cold, with tar | 82 | percent |
| Cold, without tar | 66 | percent |

Table 5-1 (k)

Design Point Characteristics for Gasification of Absaloka/Robinson Subbituminous Coal

Coal Throughput - 2.0 tons/hour (121 lb/hr/sq ft grate)

| | | |
|---|---|---|
| Air/Coal | 1.80 | lb/lb |
| Steam/Coal | 0.415 | lb/lb |
| Blast Saturation Temperature | 152 | deg. F |
| Gas Offtake Temperature | 635 | deg. F |
| Wet Gas/Coal | 48.0 | scf/lb |
| Gas Dewpoint | 132 | deg. F |
| Tar Yield | 4.2 | lb/100 lb coal |
| Tar Analysis | | |
| HHV (dry) | 16995 | Btu/lb |
| Pourpoint | 85 | deg. F |
| Viscosity (210 F) | 9.7 | SUS |
| Specific gravity (60/60 F) | 1.0454 | |
| Dry Gas Composition (mol %) | | |
| Hydrogen | 18.6 | |
| Carbon monoxide | 28.8 | |
| Methane | 1.41 | |
| Ethane | 0.100 | |
| Ethylene | 0.059 | |
| Propane | 0.028 | |
| Propylene | 0.034 | |
| Carbon Dioxide | 5.15 | |
| Nitrogen + Argon | 45.7 | |
| Water | 8.84 | lb/1000 dscf |
| Dry Gas HHV | 171 | Btu/dscf |
| Dry Gas LHV | 160 | Btu/dscf |
| Thermal Efficiencies | | |
| Hot, raw | 90 | percent |
| Cold, with tar | 81 | percent |
| Cold, without tar | 73 | percent |

Table 5-1 (1)

Design Point Characteristics for Gasification of Blind Canyon Bituminous Coal

Coal Throughput - 1.8 tons/hour (108 lb/hr/sq ft grate)

| | | |
|---|---|---|
| Air/Coal | 2.09 | lb/lb |
| Steam/Coal | 0.384 | lb/lb |
| Blast Saturation Temperature | 145 | deg. F |
| Gas Offtake Temperature | 800 | deg. F |
| Wet Gas/Coal | 52.8 | scf/lb |
| Gas Dewpoint | 117 | deg. F |
| Tar Yield | 14.2 | lb/100 lb coal |
| Tar Analysis | | |
| HHV (dry) | 17157 | Btu/lb |
| Pourpoint | 92 | deg. F |
| Viscosity (210 F) | 62.2 | SUS |
| Specific gravity (60/60 F) | 1.0394 | |
| Dry Gas Composition (mol %) | | |
| Hydrogen | 18.30 | |
| Carbon monoxide | 27.00 | |
| Methane | 1.84 | |
| Ethane | 0.181 | |
| Ethylene | 0.151 | |
| Propane | 0.054 | |
| Propylene | 0.057 | |
| Carbon Dioxide | 6.30 | |
| Nitrogen + Argon | 45.90 | |
| Water | 5.4 | lb/1000 dscf |
| Dry Gas HHV | 174 | Btu/dscf |
| Dry Gas LHV | 162 | Btu/dscf |
| Thermal Efficiencies | | |
| Hot, raw | 93 | percent |
| Cold, with tar | 84 | percent |
| Cold, without tar | 66 | percent |

Table 5-1 (m)

Design Point Characteristics for Gasification of Kemmerer Subbituminous Coal

Coal Throughput - 1.54 tons/hour (92.8 lb/hr/sq ft grate)

| | | |
|---|---|---|
| Air/Coal | 1.966 | lb/lb |
| Steam/Coal | 0.304 | lb/lb |
| Blast Saturation Temperature | 140 | deg. F |
| Gas Offtake Temperature | 752 | deg. F |
| Wet Gas/Coal | 51.7 | scf/lb |
| Gas Dewpoint | 131 | deg. F |
| Tar Yield | 9.3 | lb/100 lb coal |
| Tar Analysis | | |
| HHV (dry) | 16200 | Btu/lb |
| Pourpoint | 95 | deg. F |
| Viscosity (210 F) | 63.7 | SUS |
| Specific gravity (60/60 F) | 1.079 | |
| Dry Gas Composition (mol %) | | |
| Hydrogen | 16.3 | |
| Carbon monoxide | 29.7 | |
| Methane | 1.72 | |
| Ethane | 0.157 | |
| Ethylene | 0.119 | |
| Propane | 0.033 | |
| Propylene | 0.041 | |
| Carbon Dioxide | 4.98 | |
| Nitrogen + Argon | 46.6 | |
| Water | 8.44 | lb/1000 dscf |
| Dry Gas HHV | 173 | Btu/dscf |
| Dry Gas LHV | 163 | Btu/dscf |
| Thermal Efficiencies | | |
| Hot, raw | 95 | percent |
| Cold, with tar | 84 | percent |
| Cold, without tar | 70 | percent |

Table 5-1 (n)

Design Point Characteristics for Gasification of "Fresh Mined" Rosebud Subbituminous Coal

Coal Throughput - 0.70 tons/hour (42.2 lb/hr/sq ft grate)

| | | |
|---|---|---|
| Air/Coal | 1.87 | lb/lb |
| Steam/Coal | 0.28 | lb/lb |
| Blast Saturation Temperature | 138 | deg. F |
| Gas Offtake Temperature | 507 | deg. F |
| Wet Gas/Coal | 48.3 | scf/lb |
| Gas Dewpoint | 130 | deg. F |
| Tar Yield | 4.7 | lb/100 lb coal |
| Tar Analysis | | |
| HHV (dry) | 16573 | Btu/lb |
| Pourpoint | 75 | deg. F |
| Viscosity (210 F) | 201 | SUS |
| Specific gravity (60/60 F) | 1.0472 | |
| Dry Gas Composition (mol %) | | |
| Hydrogen | 16.40 | |
| Carbon monoxide | 30.00 | |
| Methane | 1.60 | |
| Ethane | 0.12 | |
| Ethylene | 0.06 | |
| Carbon Dioxide | 4.47 | |
| Nitrogen | 46.50 | |
| Water | 8.24 | lb/1000 dscf |
| Dry Gas HHV | 172 | Btu/dscf |
| Dry Gas LHV | 162 | Btu/dscf |
| Thermal Efficiencies | | |
| Hot, raw | 94.5 | percent |
| Cold, with tar | 86.0 | percent |
| Cold, without tar | 78.0 | percent |

Table 5-1 (o)

Design Point Characteristics for Gasification of 2-Inch Peat Sods

Throughput - 2.6 tons/hour (155 lb/hr/sq ft grate)

| | | |
|---|---|---|
| Air/Peat | 1.03 | lb/lb |
| Steam/Peat | 0.24 | lb/lb |
| Blast Saturation Temperature | 152 | deg. F |
| Gas Offtake Temperature | 171 | deg. F |
| Wet Gas/Peat | 39.1 | scf/lb |
| Gas Dewpoint | 167 | deg. F |
| Tar Yield | 5.0 | lb/100 lb peat |
| Tar Analysis | | |
| HHV (dry) | 15659 | Btu/lb |
| Pourpoint | 110 | deg. F |
| Viscosity (210 F) | 158.8 | SUS |
| Specific gravity (60/60 F) | 1.0369 | |
| Dry Gas Composition (mol %) | | |
| Hydrogen | 18.80 | |
| Carbon monoxide | 21.60 | |
| Methane | 1.61 | |
| Ethane | 0.220 | |
| Ethylene | 0.001 | |
| Propane | 0.095 | |
| Propylene | 0.039 | |
| Carbon Dioxide | 12.65 | |
| Nitrogen + Argon | 44.82 | |
| Water | 29.39 | lb/1000 dscf |
| Dry Gas HHV | 154 | Btu/dscf |
| Dry Gas LHV | 142 | Btu/dscf |
| Thermal Efficiencies | | |
| Hot, raw | 93.2 | percent |
| Cold, with tar | 78.6 | percent |
| Cold, without tar | 64.8 | percent |

## SECTION 6

## PLANNING FOR AN INDUSTRIAL COAL GAS PLANT

The major areas of an industrial coal gas plant are listed below:

- Area 1. Coal Receiving/Handling
- Area 2. Gasification
- Area 3. Physical Gas Cleanup
- Area 4. Gas Desulfurization
- Area 5. Ash, Dust, Pyrolysis Liquids Handling/Storage/Disposal
- Area 6. Utilities

Each of these areas is discussed in detail below.

### Area 1 - Coal Receiving/Handling.

Coal leaving Area 1 and fed to the gasifier lock hopper must meet a size distribution specification. This program has demonstrated that coal fed to the gasifier lock hopper with a size less than 2 inches and greater than 1/4 inch (no more than 10% less than 1/4 inch) can be gasified with acceptable throughput and gas quality. If double-screened coal is specified for purchase, care should be taken in Area 1 to insure that there is not excessive production of -1/4 inch coal on site prior to its delivery to the gasifier lock hopper.

If run-of-mine coal is specified for the gas plant, Area 1 processes must remove the -1/4 inch coal to acceptable levels and provide for disposal of the -1/4 inch coal. In most cases this will mean removing the coal off-site, or utilizing the -1/4 inch coal on-site in another process. In a few cases it may mean inclusion of coal briquetting or other agglomerating equipment in Area 1 to prepare an acceptable feedstock for the gasification area.

Area 1 will include the following for most installations:

1. Coal Receiving - Coal will generally be received by truck, train, or, in some cases, barge. The coal receiving facilities may include a scale for weighing the coal into the plant. Coal may be transported to storage by belt conveyor, or may be unloaded directly into storage.

2. Coal Storage - The amount of coal storage required will depend on plant size, critical dependence on coal gas, and reliability of coal delivery. Long term storage of 30 days supply will generally be adequate. Short term storage under cover of 1 to 3 days' supply is typical.

3. Coal Screening - If run-of-mine coal is delivered, facilities must be included to remove the undersize and oversize coal prior to conveying the coal to the gasifier lock hopper. Oversize coal may be crushed and returned to the unscreened inventory. If double screened coal is delivered, a small polishing screen may be included just prior to the gasifier lock hopper to remove excessive amounts of undersize coal in the delivery, or undersize coal generated during handling and storage.

   Provisions must be made here to dispose of the undersize material rejected by the screening process. These provisions may include truck or rail loadouts, conveyance to another process that can use the undersize coal, or pelletizing/agglomeration of the coal for use as gasifier feed.

4. Coal Conveying - The coal must be conveyed between the various Area 1 operations. Belt or drag-flight conveyors are preferred as they abuse the coal the least. Bucket elevators and low speed augers may be used, but pneumatic conveying systems and high speed augers are discouraged. Care should be taken to minimize the height of fall from the end of the conveyors.

5. Coal Metering - At some point in Area 1 the coal should be metered. It is helpful if coal is metered to each gasifier lock hopper.

Area 2 - Gasification

This area includes the lock hoppers for pressurizing the coal to retort operating pressure, the retort and its support machinery, the grate and lock hopper for ash discharge, and the blast metering and supply.

The number of gasifiers included in Area 2 will depend on the coal specified, the gas output requirement, and the retort size selected. If detailed test results are available for the coal specified, the design capacity of each retort can be arrived at as a result of these tests. If no test data is available, a design throughput of 45 lb fixed carbon/hr/sq ft grate may be used with a reasonable expectation that fundamental limits to fixed-bed gasifier performance will occur at higher throughputs than this (Volume 18, Thimsen, Maurer et al, 1985). For selected bituminous coals this design throughput may be increased to 50 lb fixed carbon/hr/sq ft grate. These design throughputs allow operation at up to 125% of design capacity for short periods of time (<24 hours). Typical retort sizes are 6.5 feet and 10 feet inner diameter.

Each gasifier in Area 2 will be essentially identical to the other gasifiers in the area. The details of each portion of Area 2 will differ according to the equipment supplier, but the following should be general characteristics of each part of the area:

1. Lock Hopper - The most important feature of the lock hopper is the method by which fugitive emissions of gas are controlled during normal operation and during depressurizing to replenish the lock hopper with fresh coal. The coal entry valve on the lock hopper should not allow excessive amounts of gas to leak out or air leak into the lock hopper during normal operation. Similarly, during depressurization of the lock hopper to feed additional fresh coal into it, care should be taken to insure that the gas that escapes the lock hopper is handled in an environmentally acceptable manner. Explosion relief has been a common part of most lock hoppers. Coal must be fed evenly into the retort from the lock hopper to minimize gas quality fluctuations.

2. Retort - The retorts are essentially shaft furnaces with appurtenances to insure that coal is evenly distributed over the cross section, and that ash is removed evenly into the ashpit. If agglomerating coals are to be gasified, the retort must be equipped with a device to manage the coal agglomeration in the upper 12 inches of the coal bed. The retorts generally also include ports on the top that allow access to the interior for monitoring of the ash zone thickness, ash conditions, and coal inventory. These ports should be equipped with devices to preclude gas leaking into the operator work space when they are open. The gasifier retort (Wellman-Galusha) used during this test program is water jacketed, as shown in Figure 3-1. The retorts may or may not include a water jacket for blast steam generation.

3. Ash Grate, Ashpit,and Lock Hopper - Ash must be removed evenly from the retort into the ashpit to insure that gas flow through the coal bed is approximately uniform across the retort, and that the grate remains cool enough to maintain its structural strength. The grate must be strong enough to support the coal inventory. The grate must also be able to respond to changes in gasifier throughput.

   The ash lock hopper must depressurize to remove the accumulated ash. Water sprays or other such devices should be included to insure that the ashpit and lock hopper can be cleared of ash. Sealing of ash lock hopper valves is not as critical as sealing of coal lock hopper valves as the gas that leaks out is generally not hazardous. During start-up, shut-down and gasifier banking there is some danger of gas moving from the coal bed into the ashpit and forming a combustible mixture with oxygen in the blast. For this reason, explosion relief is usually included in the ashpit.

4. Blast Metering and Supply - The blast consists of mixture of air and steam. The air is usually supplied by a high pressure fan. The air required is approximately 4.7 lb/lb fixed carbon (Volume 18, Thimsen, Maurer et al, 1985).

   Some or all of the steam requirements may be supplied by a water jacket around the retort. Any steam not supplied by the water jacket must be supplied by Area 3 (Gas Clean-Up) or be imported. If detailed test data is available for the fuel to be gasified, this data will include design steam/air ratio. If no test data is available, a design steam flow of 0.181 lb steam/lb air may be used with reasonable assurance that ash clinkering will occur at a lower steam/air ratio (Volume 18, Thimsen, Maurer et al, 1985).

Area 3 - Physical Gas Cleanup

The extent of physical gas cleanup will depend on several factors most important of which are the anticipated end use of the gas and the extent of chemical gas cleanup required. If no chemical gas cleanup is required, and the gas is being sent to a nearby gas burner, particulate removal may be all that is required. The opposite extreme is supplying detarred, dry gas to an engine, or extensive gas distribution system. This would require particulate removal, gas cooling, coal pyrolysis liquids removal, water removal and perhaps compression.

Physical gas cleaning systems for fixed-bed gasifiers are not standardized. Several schemes have been proposed and installed. Two schemes were investigated on a pilot scale as part of this program. They differ primarily in the method chosen for cooling the gas. The first scheme investigated was cooling the gas by evaporation of water sprayed directly into the gas. This scheme complicates the water vapor removal step if this is required. The second scheme was indirect cooling of the gas in a shell and tube heat exchanger. Further work is required to identify the optimum scheme for application at full scale. Both gas cooling schemes are strongly affected by the dust removal step.

The components of the gas cleaning system that could be included in Area 3 are listed below:

1. Particulate Removal - When the retorts operate at high throughput, significant quantities of dust are blown out of the retort along with the product gas. Characterizations of this dust were performed as part of this program. These characterizations indicate that the

dust is coarse particulate with mass median diameter exceeding 50 microns. This dust is relatively easy to remove in properly designed inertial dust collection devices such as cyclones. If the dust is dry (free of condensed tar) this removal step is relatively straightforward.

2. Gas Cooling - It is important that the gas cooling be conducted after dust removal. During cooling the coal pyrolysis liquids in the gas condense as a fog. If dust removal is not effective, the dust is mixed with the coal pyrolysis liquids which complicates their handling.

   If the gas is cooled by indirect contact heat exchange, this may be accomplished in stages making steam available from Area 3 for the blast in Area 2.

   If direct contact water sprays are used only to cool the gas, there will be no aqueous discharge from Area 3. This method of gas cooling, however, produces a gas with high water vapor content. Typical gas temperatures achieved by this method are 160 F to 170 F (saturated). If lower gas temperatures or lower gas water dew points are required, additional cooling either by indirect contact or scrubbing with cold water is required. This cooling produces an aqueous discharge which may be recycled, or may have to be treated to reduce dissolved organic material before it leaves the plant site.

3. Pyrolysis Condensate Removal - The pyrolysis condensate fog generated during gas cooling has significant material less than 5 microns (Liu, et al, 1984). Particles this small are very difficult to remove by inertial means (cyclones, scrubbers, etc.). This program has shown that electrostatic precipitation is an effective means of achieving high pyrolysis condensate removal efficiencies (Volume 18, Thimsen, Maurer et al, 1985).

4. Gas Compression - The gas may be compressed to desired pressure after the pyrolysis condensate removal stage. There may be a small aqueous discharge from the gas compression after cooler since the gas fed to the compressor is typically saturated with water.

Area 4 - Gas Desulfurization

Environmental or process considerations may require that the gas be cleaned of sulfur species prior to final use. Stretford acid gas removal was investigated on a pilot scale as part of this program (Volume 3, Thimsen, Maurer et al, 1983). This technology, as well as other similar liquid phase hydrogen sulfide oxidation technologies, appear to be able to accomplish hydrogen sulfide removals of +95%. Limited commercial experience with these desulfurization technologies exist, although commercial Stretford systems are installed at the Caterpillar Tractor coal gasification plant in York, PA, and at the Great Plains Coal Gasification facility in Beulah, North Dakota.

The gas produced during fixed-bed coal gasification also includes significant amounts of carbonyl sulfide and higher order sulfur species that are not removed by the liquid phase hydrogen sulfide oxidation technologies. The carbonyl sulfide can be converted to hydrogen sulfide by reaction with steam. The hydrogen sulfide can then be removed by the liquid phase hydrogen sulfide oxidation technologies.

Care must be exercised in planning and designing for gas desulfurization. Data for the distribution of gas phase sulfur was collected during this program, but the data is not well correlated. There will be a solid sulfur stream leaving Area 4.

Area 5 - Ash, Dust, Pyrolysis Liquids Handling/Storage/Disposal

Ash disposal is relatively straightforward. The analyses of one of the ashes produced during this program indicates that it is a non-hazardous solid waste (Volume 4, Thimsen, Maurer et al, 1985). A previous evaluation of North Dakota lignite ash reached the same conclusion (Kilpatrick, M.P., R. A. Mage, and T. E. Emel. Environmental Assessment: Source Test and Evaluation Report, Wellman-Galusha (Fort Snelling) Low-Btu Gasification. Radian Corp. Final Report, U.S. EPA contract 68-02-2147, Exhibit A, DCN 80-218-143-116, 1980). It is likely that most coal ash may be disposed of in non-hazardous landfills.

The dust may leave the dust removal device at a relatively high temperature. It must be cooled prior to exposure to air to avoid burning. The dust collected during this program has a relatively high heating value (> 10,000 Btu/lb) and may be suitable for burner fuel. If no suitable use for the dust can be found, it is likely that it can be disposed of in a non-hazardous landfill (Volume 4, Thimsen, Maurer et al, 1985).

The pyrolysis liquids generation during fixed-bed gasification is substantial, particularly for bituminous coals. The yield can be predicted from the proximate analysis (Volume 18, Thimsen, Maurer et al, 1985). During this program the physical properties of these liquids have been characterized, and selected liquids have been burned. The coal distillates have heating values generally in the range 16,000 - 17,000 Btu/lb, and viscosity characteristics similar to those of No. 6 fuel oil. Heated piping and tanks will be required to handle and store these liquids. On-site storage of 3 days is probably adequate. Previous analyses of coal distillates (see previous reference, Kilpatrick, et. al.) show that they generally contain organic compounds suspected and/or listed as carcinogens. Therefore, the storage and handling of coal distillate would require the appropriate permits to be obtained and handling procedures established. If the value of the coal distillate is equal to or above that of No. 6 fuel oil, the overall economics of a fixed-bed coal gasification system is significantly enhanced.

Area 6 - Utilities

The utilities required for operation of coal gasification facility may include compressed air for instruments and valve operators, electrical power for instruments and motors, cooling water or boiler feedwater for the retort and gas cooler, and import steam (if required). There may be a chemical and catalyst requirement if desulfurization is included.

## SECTION 7

## ECONOMIC ANALYSIS PARAMETERS

An economic analysis of a coal gas plant supplying fuel gas and coal pyrolysis liquids is similar to many other plant or process analyses. The two important cost components are the capital cost of the plant and the cost to supply and operate the plant. The components of these costs are described below.

Capital costs:

The capital costs associated with a fixed-bed coal gasification facility can be divided into two groups: (1) The direct costs of engineering, equipment, site acquisition and preparation, installation of the equipment, start-up costs, and working capital, and (2) Indirect capital costs including license fees, royalties, interest on funds used during construction, permitting costs, etc.

Table 7-1 shows capital cost estimates for three different sized plants: (1) One 10 foot diameter retort, (2) Four 10 foot diameter retorts, and (3) Sixteen 10 foot diameter retorts. The assumptions used in arriving at these capital costs are listed in Table 7-1.

Operating Costs:

The costs associated with operating a fixed-bed coal gas plant are primarily acquisition of the coal. Other costs include operating labor, maintenance of the equipment, purchase of utilities, and purchase of catalysts and chemicals. These costs are listed in Table 7-2 for the three plants whose capital costs were estimated in Table 7-1 along with the unit requirements for each operating component.

Labor and Maintenance Costs:

Single Gasifier Retort:

Generally, when one gasifier retort supplies the fuel gas required for the process (i.e. kiln, furnace, etc.), the operation of the gasification system becomes an integral part of the process operation.

The labor required to operate one gasifier retort amounts to approximately two (2) hours per shift. The gasifier, under normal operation, is automatic and only requires periodic monitoring. Monitoring tasks routinely performed by the operators include:

(1) Fire tests (generally performed twice per shift) to measure the ash depth and thereby maintain a 10 to 12-inch ash depth.

(2) Logging the operational data (automatic data logging systems would preclude the manual logging of data in many industrial plants, although others would still manually log the process temperatures, pressures, and flows).

(3) Feeding coal to the upper storage bin from ground storage.

Multiple Gasifier Operation:

Multiple gasifier retort operation achieves the maximum labor efficiency when at least four (4) retorts are installed and online. The routine operating labor tasks require two full-time operators on each of the three shifts. One extra laborer is required on the day shift to assist with the materials handling and routine maintenance of the gasifier facility.

The labor requirements (Full Time Employees, FTE) are summarized along with the other operational costs in Table 7-2 (a through c) for the single and multiple gasifier installations, including a standard desulfurization system.

ECONOMIC SUMMARY:

The economic data presented in Tables 7-1 and 7-2 assumed specific coal costs, operating labor costs, and other utility costs. There are obviously a wide range of coal costs, and to a certain extent, labor costs associated with the operation of an industrial coal gasification facility.

Table 7-3 provides an overall summary of the three principal cost components with ranges of costs associated with each constituent. In 1985 dollars, sized coal costs will range from $1.00 to $2.00/MM Btu. The economics in Table 7-2 assumed coal cost in the range of $1.68 to $1.80/MM Btu.

Operating costs (labor, chemicals, and utilities) will range from $1.00 to $2.00/MM Btu. A significant variable in these costs is the requirement for desulfurization and the chemicals required for desulfurization. In Table 7-2, chemical costs contributed approximately $0.45/MM Btu.

Capital recovery assuming a simple 25 percent return, add from $.50 to $1.00/MM Btu. As the facility increases in size above a single gasifier installation, the impact of capital costs

Table 7-1

Capital Costs For Three Fixed-Bed Gas Plants

| | 1 Retort | 4 Retorts | 16 retorts |
|---|---|---|---|
| DIRECT CAPITAL COSTS | | | |
| Area 1<br>Coal Receiving/Handling | 250,000 | 760,000 | 2,300,000 |
| Area 2<br>Gasification | 700,000 | 2,450,000 | 8,490,000 |
| Area 3<br>Physical Gas Cleanup | 350,000 | 1,060,000 | 3,220,000 |
| Area 4<br>Gas Desulfurization | 550,000 | 1,670,000 | 5,050,000 |
| Area 5<br>Ash, Dust, Pyrolysis Liquids Handling/ Storage/Disposal | 300,000 | 740,000 | 1,820,000 |
| Area 6<br>Utilities | 150,000 | 345,000 | 1,110,000 |
| TOTAL, DIRECT CAPITAL COSTS | 2,300,000 | 7,025,000 | 21,990,000 |
| INDIRECT CAPITAL COSTS | 207,000 | 775,000 | 3,300,000 |
| TOTAL CAPITAL COSTS | 2,507,000 | 7,800,000 | 25,290,000 |

Assumptions:

1. 12 to 18 month fabrication and construction period (1 to 4 retorts).
2. 24 month fabrication and construction period (16 retorts).
3. No land acquisition costs.
4. Minimal site preparation costs.
5. Coal received by truck (1 to 4 retors), by rail (16 retorts).
6. 30 day coal storage.
7. 3 day ash, dust, pyrolysis liquids, and sulfur cake storage.
8. Gas leaves Area 3 limits at 7 psig.
9. All utilities generated offsite.
10. Carbonyl sulfide shifting included in Area 4.
11. +- 25% accuracy.

Table 7-2a

Yearly Fixed-Bed Gasifier Operating Costs
1 Retort

| Component | Unit Requirements | Unit Price | Yearly Cost |
|---|---|---|---|
| Coal @ $45/ton (12,500 Btu/lb) | 691,000 MM Btu | 1.80/MM Btu | 1,244,000 |
| Operating Labor @ $20/hr | 5 FTE | 30,000/FTE | 150,000 |
| Maintenance | 3%/yr of Direct Capital | | 68,000 |
| Utilities: | | | |
| Steam @ 15 psig | 4,500 lb/hr | $4.00/1000 lb | 151,000 |
| Cooling Water | 2,000 gpm | $0.1/1000 gal | 101,000 |
| Electricity | 600 kwh | $0.4/kwh | 202,000 |
| Boiler Feed Water | 26 gpm | $1.0/1000 gal | 14,000 |
| Catalysts/Chemicals (for desulfurization) | | | 265,000 |
| Total yearly costs | | | $2,195,000 |

Total Yearly Output (MM Btu) = 587,350
(gas + pyrolysis liquid)

Cost Breakdown:

Coal and Operational Cost = $3.74/MM Btu
Coal Cost = $1.80/MM Btu
Operational Cost = $1.94/MM Btu

Assumptions:

1. Design throughput of 1.1 MM Btu/hr/sqft grate
2. 8000 hrs operation at design throughput
3. Carbonyl sulfide shifting included in Area 4
4. 85% Conversion efficiency to gas + pyrolysis liquids

## Table 7-2b

### Yearly Fixed-Bed Gasifier Operating Costs
### 4 Retorts

| Component | Unit Requirements | Unit Price | Yearly Cost |
|---|---|---|---|
| Coal $45/ton (12,500 Btu/lb) | 2,764,000 MM Btu | $1.80/MM Btu | 4,975,000 |
| Operating Labor | 10 FTE | $30,000/FTE | 300,000 |
| Maintenance | 2.5%/yr of Direct Capital | | 195,000 |
| Utilities: | | | |
| Steam @ 15 psig | 18,000 lb/hr | $4.00/1000 lb | 605,000 |
| Cooling Water | 8,000 gpm | $0.1/1000 gal | 403,000 |
| Electricity | 2,400 kwh | $0.04/kwh | 806,000 |
| Boiler feed water | 104 gpm | $1.00/1000 gal | 53,000 |
| Catalysts/Chemicals (for desulfurization) | | | 1,060,000 |
| Total yearly costs | | | 8,397,000 |

Total Yearly Output (MM Btu) = 2,349,400
(gas + pyrolysis liquid)

Cost Breakdown:

Coal and Operational Cost = $3.56/MM Btu
Coal Cost = $1.80/MM Btu
Operational Cost = $1.76/MM Btu

Assumptions:

1. Design throughput of 1.1 MM Btu/hr/sqft grate
2. 8000 hrs operation at design throughput
3. Carbonyl sulfide shifting included in Area 4
4. 85% conversion efficiency to gas + pyrolysis liquids

Table 7-2c

Yearly Fixed-Bed Gasifier Operating Costs
16 Retorts

| Component | Unit Requirements | Unit price | Yearly Cost |
|---|---|---|---|
| Coal $42/ton (12,500 Btu/lb) | 11,056,000 MM Btu | $1.68/MM Btu | 18,575,000 |
| Operating Labor | 38 FTE | $30,000/FTE | 1,140,000 |
| Maintenance | 2%/yr of Direct Capital | | 506,000 |
| Utilities: | | | |
| Steam @ 15 psig | 72,000 lb | $4.00/1000 lb | 2,420,000 |
| Cooling Water | 32,000 gpm | $0.10/1000 gal | 1,613,000 |
| Electricity | 9,600 kwh | $0.04/kwh | 3,226,000 |
| Boiler feed water | 416 gpm | $1.00/1000 gal | 210,000 |
| Catalysts/Chemicals (for desulfurization) | | | 4,240,000 |
| Total yearly costs | | | $31,930,000 |

Total Yearly Output (MM Btu) = 9,397,600
(gas + pyrolysis liquid)

Cost Breakdown:

Coal and Operational Cost = $3.39/MM Btu
Coal Cost = $1.68/MM Btu
Operational Cost = $1.71/MM Btu

Assumptions:

1. Design throughput of 1.1 MM Btu/hr/sqft grate
2. 8000 hrs operation at design throughput
3. Carbonyl sulfide shifting included in Area 4
4. 85% conversion efficiency to gas + pyrolysis liquids

TABLE 7-3

COAL GAS GENERATION ECONOMICS SUMMARY
GREENFIELD PLANT

| | |
|---|---|
| COAL | 1.00 - 2.00* |
| OPERATING | 1.50 - 2.00* |
| CAPITAL RECOVERY | 0.50 - 1.00* |
| | 3.00 - 5.00* |

* Dollars per million Btu recoverable energy.

decreases.

Industrial fuel gas from coal (including desulfurization) will cost between $3.00 to $5.00 per million Btu, delivered to the burner.

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