

MODELING OF A COAL CARBONIZER

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ABSTRACT

A computer model has been developed, using data currently available in the literature, to simulate air-blown pyrolysis of coal in a carbonizer. A sorbent (limestone or dolomite) can also be added to the carbonizer to capture in-situ sulfur released into the gas. The sorbent, besides reacting with sulfur, also influences the product yields by cracking some tar to gases and soot, and hence like temperature and pressure, forms an independent parameter of the system. The char, soot, tar, spent sorbent, sulfur capture, air feed, and product gas flow rates and their compositions are determined by the computer model. This model has been used to predict carbonizer performance for Pittsburgh No. 8 bituminous coal at different operating conditions.

INTRODUCTION

A team of companies, led by Foster Wheeler Development Corporation and consisting of Gilbert/Commonwealth, Institute of Gas Technology (IGT), Combustion Turbine Operations Division of Westinghouse Electric Corporation, and Research and Development Division of Westinghouse Electric Corporation, has embarked upon a three-phase 5-year program with the Department of Energy (DOE) to develop an advanced second-generation Pressurized Fluidized Bed (PFB) Combustion system. The targeted goals of this second-generation PFB combustion plant are a 45% efficiency and a cost of electricity that is at least 20% lower than conventional pulverized-coal-fired plants with stack gas scrubbers. In addition, the plant emissions should be within New Source Performance Standards and it should have high availability, be able to process different ranks of coal, and incorporate modular construction technologies. These goals are achieved by shifting power generation to the more efficient gas turbine cycle and away from the steam cycle while maintaining sulfur capture by the sorbent, and by providing significantly higher gas turbine inlet temperatures without increasing the bed temperature through the incorporation of a topping combustor in the system. In this arrangement, a carbonizer generates a coal-derived low-Btu fuel gas at approximately 1500°F which is mixed with flue gases from a PFB combustor operating at 1500° to 1600°F and is burned in a topping combustor to increase the gas turbine inlet temperature to approximately 2100° to 2200°F. The combustion air to the topping combustor is provided by high excess air present in the flue gas from the PFB combustor. The carbonizer thus, is an essential element of this system. The coal is primarily fed to the carbonizer. The coal char residue from the carbonizer is burned in the PFB combustor along with the balance of the plant coal, if there is any left. Calcium-based sorbent is injected into the carbonizer and PFB combustor to minimize carbonizer tar yield and

desulfurize the gases from both units. The targeted efficiency is dependent upon the performance of the carbonizer.

The coal carbonizer, depending upon the coal properties, can be designed as a bubbling or a fast fluidized-bed reactor, each having its own characteristics with respect to the coal and air injection and product recovery. These constraints associated with the carbonizer design were recognized and therefore a highly generalized model was developed to accommodate various coal carbonizer configurations. The model can simulate a bubbling or a fast fluidized-bed reactor with or without fines recycle in which the coal and sorbent can be introduced into the fluidized-bed region and/or into the freeboard region of the carbonizer. Later, the model was tailored specifically for the three most practical configurations of the carbonizer.

LITERATURE SEARCH AND DATA CORRELATIONS

An extensive literature search was conducted and correlations were developed for yields of various species as a function of coal properties and carbonizer operating parameters. Out of numerous data available on the subject of pyrolysis, only a handful of data were applicable for the type of coal processing used here. Much of the data for coal pyrolysis were obtained in a heated grid reactor where the coal is subjected to the desired temperature from a fraction of a second to about 2 seconds yielding only a fraction of the pyrolysis product. On the other hand, in a fluidized-bed reactor, coal is subjected to a sufficiently long residence time (a gas residence time of over 5 seconds and a solids residence time of several minutes) so that the maximum yield is typically obtained. The data available in this category were used to develop the correlations for the coal carbonization product yields and their compositions. These correlations have been developed for bituminous coals as well as for lignites to cover a wide range of feedstock properties.

The details of the literature findings and correlations development are beyond the scope of this paper. However, as an example, the effects of various parameters on the tar yield from bituminous coals are given below.

In Figure 1, the tar yield at 1 atm of inert pressure expressed as a fraction of feed carbon is plotted against temperature. The tar yield increases up to about 1250°F after which it decreases because of the increased activity of the secondary reactions of tar cracking. With respect to the effect of pressure, Suuberg *et al.* (1978) and Arendt and van Heek (1981) conducted experiments with bituminous coals and reported a considerable reduction in the carbon conversion to tar with an increase in pressure from 1 atm to 100 atm, as shown in Figure 2. The data indicate that the tar yield decreases logarithmically with pressure. A similar effect on the tar yield has been shown by Eklund and Wanzl (1981) with a subbituminous coal at 1472°F. Regarding the effect of limestone or dolomite addition, Yeboah *et al.* (1980) and Longwell *et al.* (1985) have reported an appreciable decrease in the tar yield when limestone or dolomite was added during the pyrolysis of coal (Figure 3). Simultaneously, an increase in the hydrocarbon gases, along with some soot formation on the surface of the limestone, was noticed. The effect of CaO on the char yield and other gases was very little. These observations led to a conclusion that the addition of limestone or dolomite during coal pyrolysis causes some of the evolved tar to crack into hydrocarbon gases and

soot. The effect of oxygen feed on tar yield is shown in Figure 4. The oxygen reacts with tar as well as char [Howard and Essenhig (1967), Boley and Fegley (1977), and Saito *et al.* (1987)] yielding primarily CO and CO₂. However, the yields of methane, ethylene, and ethane are also higher in the presence of oxygen than those in the absence of oxygen. The increased yields are attributed to tar cracking. It should be recognized that the amount of tar and char reacting with the oxygen will depend on the amount of oxygen fed to the carbonizer, which is dictated by the reactor energy balance.

MODEL DESCRIPTION

The primary function of the model developed in this program is to make an estimate, for a given coal, of the product yields from a coal carbonizer operating at a specified temperature and pressure. In addition, sorbent (limestone or dolomite) may be added to capture *in-situ* sulfur released into the gas. The sorbent, besides reacting with sulfur, also influences the product yields from the coal carbonization and hence like temperature and pressure, forms distinctly an independent parameter of the system. The coal carbonizer, depending upon the coal properties, can take many forms from a bubbling fluidized bed to an entrained-flow reactor, each having its own peculiarities associated with the coal and air introduction and product recovery. These constraints were recognized and as a result a highly generalized model has been developed to accommodate different features that may be found in a coal carbonizer. Later, the model was tailored specifically to consider three practical configurations of the carbonizer.

General Description

For modeling purposes, and to accommodate various carbonizer configurations, the reactor has been divided into two sections, namely, the upper zone and the lower zone. The various streams leaving and entering these zones are shown in Figure 5.

The coal (stream S1) and sorbent (stream S2) are fed into the upper zone along with the transport gas (stream G4). The transport gas could be an inert gas, recycled gas, and/or air. Two additional gas streams (secondary gas streams G2 and G3) can also enter this zone, if needed. The product gas stream from the lower zone (stream G9) also enters this upper zone. Basically, the coal devolatilization takes place in the upper zone. If the air is fed to this zone (stream G1 or G4), then the oxygen present in the air will also react in this zone. The combustion in the upper zone and the sensible heat of the solids/gas from the lower zone provide the heat required for the coal devolatilization. The sulfur in the gas is captured by the sorbent present in this zone. The solids elutriated from this zone (stream S8) are captured by a cyclone and returned to the solids splitter (stream S7). The gas leaving this zone (stream G8) is the gas yield from the carbonizer. The carbonizer product gas also contains some char/sorbent fines (stream S4) and evolved tars (stream T1). The coal devolatilization temperature could be specified differently from the exit product gas temperature. Furthermore, the tar cracking occurs when sorbent is added to the system, producing soot and hydrocarbon gases. The soot formed in the carbonizer leaves the upper zone (stream S13) and enters the cyclone. The soot produced in the carbonizer may deposit on the char and the sorbent particles and thus leave the gasification system along with various solids

discharge streams (such as streams S4, S5, S6, and S12). However, for modeling purposes, this stream is assumed to be withdrawn from the cyclone (stream S14) along with the cyclone fines. The composition and flow rate of streams S13 and S14 are identical; however, they may differ in temperature.

The combustion air (stream G5) enters the lower zone along with the recycled char and reacted sorbent (stream S9) from the upper zone. The primary reaction in the lower zone is the char combustion reaction. If the temperature of this zone is high enough, then some slow rate gasification reactions will also take place. However, at present no such gasification reactions have been considered in the model. The solids stream containing char and spent sorbent (stream S5) can leave the carbonizer system from this zone. Alternatively, a part of the solids stream captured by the cyclone which contains char and spent sorbent (stream S7), may be removed from the system (stream S6). The sorbent (stream S3) can also be fed into this lower zone along with the transport gas (stream G7). For modeling purposes, it is assumed that the sorbent fed to the lower zone is calcined, if thermodynamically permitted, in this zone and transferred into the upper zone (stream S11). An additional gas stream (secondary gas stream G6) may also enter this zone, if needed. The gas produced in this lower zone enters the upper zone (stream G9).

The sorbent can be fed into the upper zone or the lower zone or into both the zones simultaneously. This will depend upon its sulfur capture capability and the system energy balance requirements for each zone. Furthermore, the temperature in each zone is assumed to be uniform, but not necessarily the same as the gas leaving the zone.

As shown in Figure 5, there are:

- Fourteen solids streams, 10 of which are unknown. Each solids stream can contain up to 15 species (C, H, O, N, S, Cl, Ash, Moisture, CaCO_3 , MgCO_3 , CaO, MgO, CaS, CaSO_4 , Inert).
- Nine gas streams, four of which are unknown. Each gas stream can contain up to 22 species (CO , CO_2 , H_2 , H_2O , CH_4 , C_2H_6 , O_2 , N_2 , H_2S , COS, NH_3 , HCN, HCl, C_2H_4 , C_2H_2 , C_3H_8 , C_3H_6 , C_4H_{10} , C_6H_6 , C_7H_8 , C_{10}H_8 , $\text{C}_6\text{H}_5\text{OH}$).
- One tar stream which is unknown (this stream is actually part of the product gas; however, for modeling purposes, it has been represented separately).

The above two zone model is an appropriate description of a fluidized-bed reactor or a fast fluidized-bed reactor in which the coal is fed into the reactor above the bed, that is, in the freeboard region. The model would also accommodate a carbonizer in which coal, sorbent, and air are fed in a single zone.

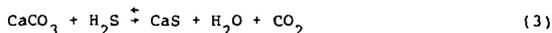
Yield Determination

The method employed for the determination of the product yields in the carbonizer is illustrated in Figure 6. Basically, complete information is available for the coal pyrolysis as a function of temperature at 1-atm pressure in inert atmosphere. The individual effects of pressure, sorbent

(limestone or dolomite), and oxygen on these product yields are also available. However, the literature lacks information about the combined effects of these factors on the product yields. The model has been constructed by superimposing effects of these factors (Figure 6) to yield information about the products of coal pyrolysis as a function of temperature, pressure, sorbent, and oxygen.

As illustrated in Figure 6, the product yields are determined in four steps. In the first step, a complete product slate is determined for coal carbonization at 1-atm pressure in an inert atmosphere and at specified carbonizer temperature. In the second step, the yields are adjusted for pressure. In the third step, using the information derived for the effect of oxygen on pyrolysis yield at 1-atm pressure, and assuming the same effect to hold at pressure, the yields obtained in the second step are adjusted for the effect of oxygen feed. Finally in the fourth step, the effect of sorbent is integrated into the above third step. When doing so, it is again assumed that the relationships derived at 1-atm pressure between products of pyrolysis with and without the addition of sorbent in the inert atmosphere are also valid at elevated pressure in the presence of oxygen. The yields and compositions obtained in the fourth step are thus considered to have accounted for all the process parameters namely, temperature, pressure, sorbent, and oxygen.

Depending upon the partial pressure of CO_2 in the carbonizer, the CaCO_3 in the sorbent will either exist as CaCO_3 or get calcined to CaO . This will also determine whether the H_2S will react with CaCO_3 or CaO . The extent of the sulfur capture by sorbent will be determined by its approach to the appropriate reaction equilibrium. The following reactions show the calcination of CaCO_3 , the reaction of H_2S with CaO , and the reaction of H_2S with CaCO_3 , respectively.



Determining equilibrium decomposition pressures of calcite (Equation 1) has proved a durable problem, and dubious values have appeared in the literature. The following correlation (Squires, 1967) has been used here:

$$\log_{10} (P_{\text{CO}_2}) = -8799.7/\text{TK} + 7.521 \quad (4)$$

where --

P_{CO_2} = equilibrium decomposition partial pressure of CO_2 in gas, atm

TK = temperature, °K

The equilibrium for the above reactions 2 and 3 are given by the following equations (Squires *et al.*, 1971):

$$\log_{10} \{(\text{H}_2\text{O})/(\text{H}_2\text{S})\} = 3519.2/\text{TK} - 0.268 \quad (5)$$

$$\log_{10} [(H_2O)(CO_2)(P)/(H_2S)] = 7.253 - 5280.5/TK \quad (6)$$

where --

- P = total system pressure, atm
- (H₂O) = mole fraction of H₂O in gas
- (CO₂) = mole fraction of CO₂ in gas
- (H₂S) = mole fraction of H₂S in gas
- TK = temperature, °K

The product gas is also considered to be at water-gas shift equilibrium at the carbonizer exit temperature.

MODEL PREDICTIONS

Carbonizer Configuration

The computer model has been kept as general as possible to accommodate various possible carbonizer configurations. However, for the current study the simple configuration for the carbonizer shown in Figure 7 is considered. Here, coal and dolomite (sorbent) are fed into the fluidized bed, and the fines captured by the cyclone are not recycled to the reactor, instead they are directed to the combustor. The bed is fluidized primarily using air. A model representation for this case is also given in this figure. The carbonizer is essentially represented by a single stage (upper zone) configuration. The solids stream S7 is equal to the solids stream S6, while the solids streams S3, S5, S9, S10, and S11 are zero. Furthermore, the gas stream G9 is also equal to zero.

Model Predicted Carbonizer Performance at 14-atm Pressure

The model predicted carbonizer performance at 14-atm pressure for several cases is given here. Besides the base case at 14-atm pressure and 1500°F temperature for the Pittsburgh No. 8 bituminous coal containing 2.5% moisture, the other cases have accounted for the effect of using as-received coal without drying (6% moisture), operating the carbonizer at 1600°F, and using coal/water slurry instead of dried feed. The operating conditions and the results of the model predictions are summarized in Table 1. This table is based on a 1000 pounds of moisture-free coal feed to the carbonizer. The results on the moisture-free coal feed basis provide a better comparison of yields at different operating conditions. A detailed material balance for the base case at 14-atm pressure and 1500°F temperature is given in Figure 8.

The char, soot, spent dolomite, tar, air feed, and product gas flow rates and their compositions are determined by the computer model. The air feed requirement is based on the energy balance around the carbonizer. The heat losses from the carbonizer are assumed to be negligible. The relative humidity of the air is 50% at 70°F, which is equivalent to 1.235 mole percent moisture in the air. The H₂S in the product gas is based on 92% approach to the equilibrium concentration, that is, the ratio of calculated equilibrium H₂S

content in the product gas (using Equation 5 or 6) to the actual H_2S content in the product gas is 0.92. The dolomite feed rate to the carbonizer is based on feed Ca/S molar ratio of 1.75. It is also assumed that $CaSO_4$ formation does not take place in the carbonizer. The product gas is in water-gas shift at the carbonizer exit gas temperature. The fines leaving the carbonizer have been included in the discharged solids stream. The computer model allows the formation of acetylene (C_2H_2), naphthalene ($C_{10}H_8$), and hydrogen cyanide (HCN). However, due to the lack of literature information, amounts of these species have been assumed to be zero in all the balances.

Model Predicted Carbonizer Performance at 10-atm Pressure

To determine the effect of pressure on the carbonizer performance, four balances were prepared under conditions similar to those of 14-atm pressure cases given above, except the pressure was reduced to 10 atm. These balances include carbonizer operation at 1500°F with the Pittsburgh No. 8 bituminous coal containing 2.5% moisture, and the effect of using as-received coal without drying (6% moisture), operating the carbonizer at 1600°F, and using coal/water slurry instead of dry feed. The operating conditions and the results of the model predictions are summarized in Table 2. The basis of these balances are the same as used for 14-atm cases.

CONCLUSIONS

The mathematical model has been used to predict carbonizer performance for Pittsburgh No. 8 bituminous coal at different operating conditions. The following conclusions are derived from this study.

- An increase in pressure results in a decrease in the amount of tar and soot, but somewhat reduced sulfur capture at a specified temperature.
- An increase in temperature results in a reduction in the amount of tar and soot as well as an improvement in the sulfur capture at a specified pressure.
- An increase in feedstock moisture or the use of slurry requires additional air, which in turn results in reduced amounts of tar and soot and lower quality product gas. Also, the sulfur capture is reduced due to higher steam partial pressure in the product gas.

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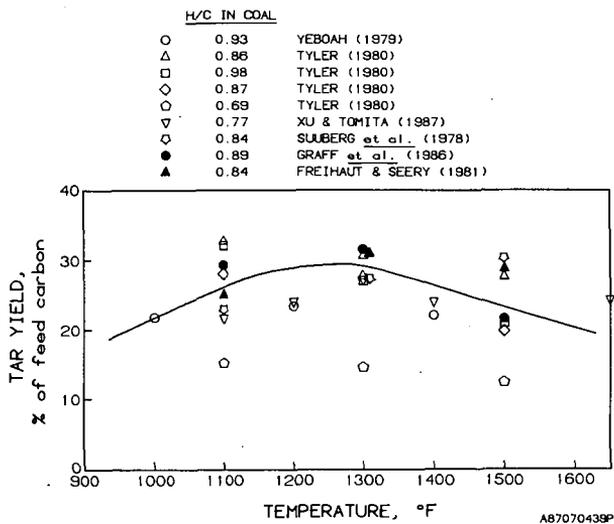


Figure 1. TAR YIELD AS A FUNCTION OF TEMPERATURE FOR BITUMINOUS COALS (Inert Atmosphere, 1 atm Pressure)

32WP/PAP/agpaper

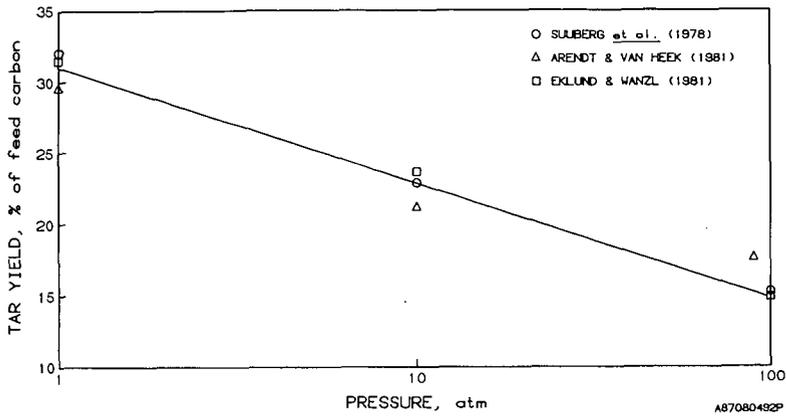


Figure 2. EFFECT OF PRESSURE ON TAR YIELD DURING PYROLYSIS OF BITUMINOUS COALS (Inert Atmosphere)

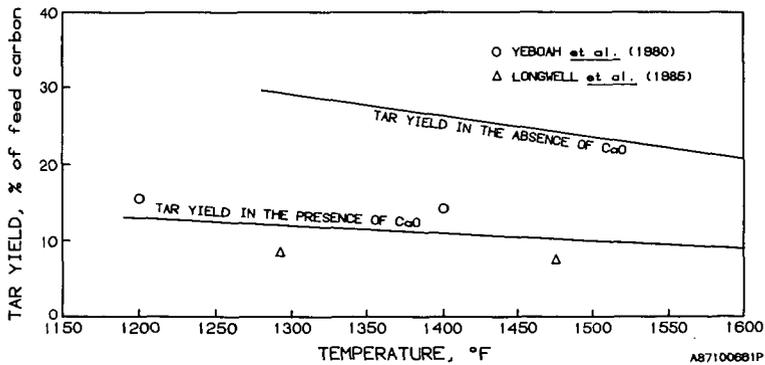


Figure 3. EFFECT OF LIME ADDITION ON TAR YIELD FOR BITUMINOUS COALS (Inert Atmosphere, 1 atm Pressure)

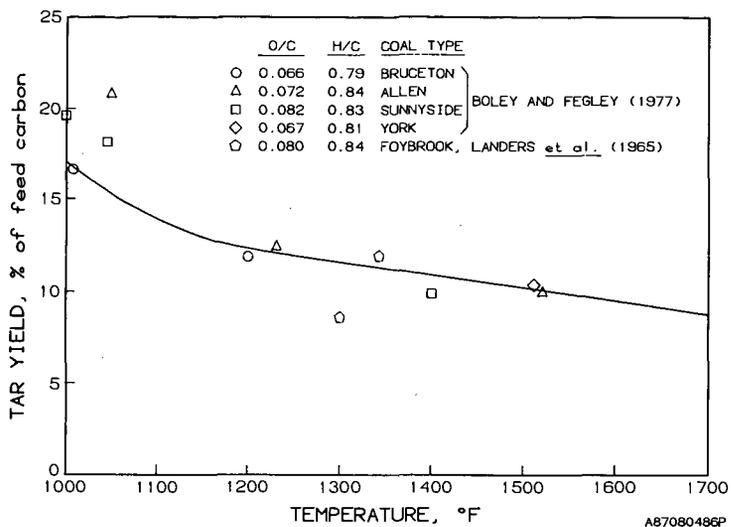


Figure 4. TAR YIELD BITUMINOUS COALS PYROLYSIS IN THE PRESENCE OF OXYGEN (1 atm Pressure)

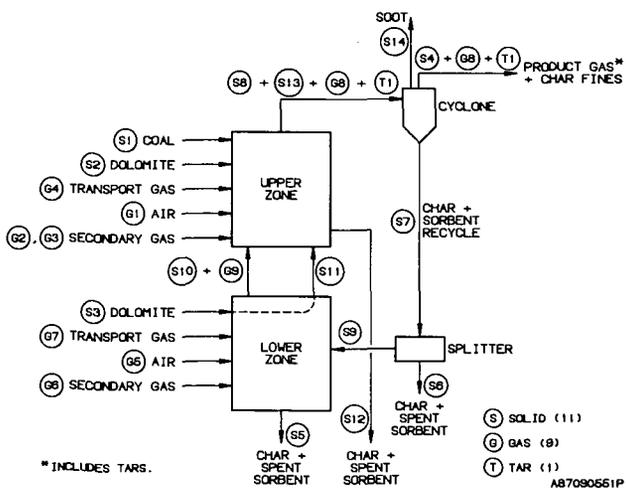


Figure 5. SCHEMATIC OF CARBONIZER MODEL

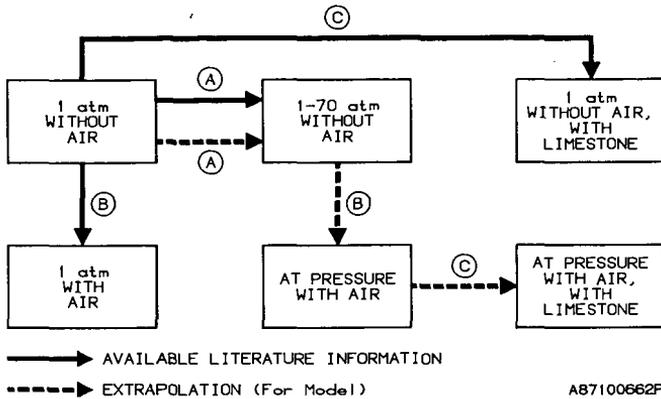


Figure 6. METHODOLOGY FOR CARBONIZER PRODUCT YIELD DETERMINATION

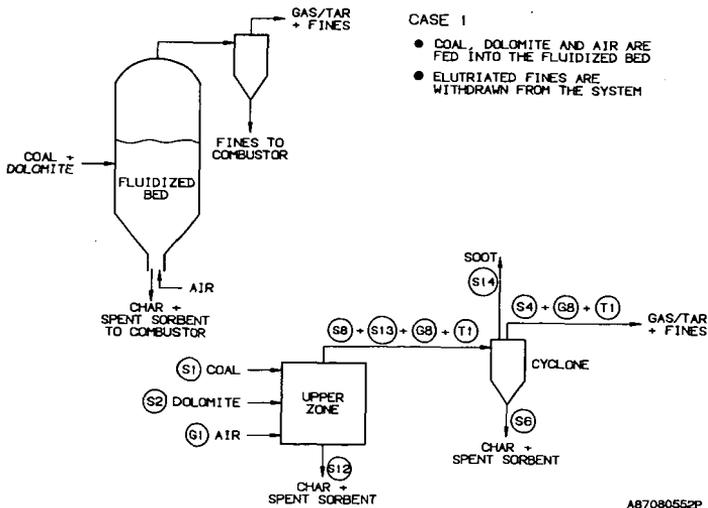


Figure 7. CARBONIZER CONFIGURATION FOR MODEL PREDICTIONS

Fuel Gas Flow (lb/h) 1489.42
 HHV (Btu/lb) 3139
 LHV (Btu/lb) 2917
 LHV (Btu/SCF) 207.2 (Gas Only)

Char-Sorbent (Flow = 846.9 lb/h)			
	Char	Soot	Spent Dolomite
Carbon	462.89	10.58	63.73
Hydrogen	7.67	0.04	129.73
Sulfur	16.77	0.07	27.45
Nitrogen	8.34	0.03	5.23
Oxygen	8.25	0.01	--
Moisture	--	--	--
Ash	105.70	--	--
Total	609.62	10.73	226.14
HHV (Btu/lb)	11830	14568	
LHV (Btu/lb)	11711	14536	

Tar
(Flow Rate = 28.71 lb/h)

Gas*
(Flow Rate = 1460.71 lb/h,
54.54 mol/h)

MW = 13.0449

Atomic Composition:

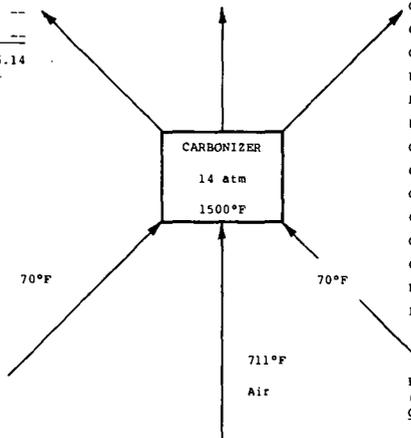
CH_{0.462}O_{0.018}N_{0.0076}S_{0.0053}

HHV (Btu/lb) 15485

LHV (Btu/lb) 15147

wt % mol %

CO	11.26	10.77
CO ₂	20.47	12.46
H ₂ O	5.80	8.63
H ₂	0.54	7.20
CH ₄	3.60	6.00
C ₂ H ₆	0.957	0.852
C ₂ H ₄	2.975	2.840
NH ₃	0.204	0.321
H ₂ S	0.082	0.065
N ₂	52.36	50.06
COS	0.020	0.009
C ₃ 's	0.787	0.495
C ₄ 's	0.134	0.062
C ₆ H ₆	0.192	0.066
C ₇ H ₈	0.374	0.109
C ₆ H ₅ OH	0.244	0.069
HHV (Btu/lb)	2896	
LHV (Btu/lb)	2677	



Plum Run Dolomite
(Flow Rate = 307.9 lb/h;
Ca/S = 1.75)

Pittsburgh Coal
(Flow Rate = 1025.64 lb/h)

Carbon	737.90
Hydrogen	48.10
Sulfur	30.70
Nitrogen	12.90
Oxygen	64.70
Moisture†	25.64
Ash	105.70
HHV (Btu/lb)	12913
LHV (Btu/lb)	12469*

(Flow Rate = 1002.37 lb/h)

(Relative Humidity: 50% at 70°F)

O ₂	231.65 lb/h
N ₂	762.95
Moisture	7.77
	1002.37

wt % lb/h

CaCO ₃	54.5	167.81
MgCO ₃	43.3	133.32
Moisture	0.5	1.54
Inerts	1.7	5.23
Total	100.0	307.90

*Excludes Tar.

**92% Approach to H₂S/Sorbent Reaction Equilibrium.

†After Drying.

Figure 8. CARBONIZER BALANCE FOR PITTSBURGH COAL AT 14 atm, 1500°F, and 2.5% MOISTURE (Base Case)

Table 1. SUMMARY OF CARBONIZER MATERIAL BALANCES AT 14-atm PRESSURE
(Basis: 1000 lb Moisture-Free Coal Feed)

Case Description	Base Case	6% Moisture	1600°F	30% Slurry
Carbonizer Temperature, °F	1500	1500	1600	1500
Coal Feed (moisture-free), lb	1000	1000	1000	1000
Moisture in Coal Feed, %	2.5	6.0	2.5	30.73*
Coal Feed (as-fed), lb	1025.6	1063.8	1025.6	1443.6
Sorbent (Dolomite) Feed, lb	307.9	307.9	307.9	307.9
Air Feed, lb	1002.4	1069.5	1102.0	1765.8
Char in Solids Discharged From Carbonizer, lb	609.6	605.1	598.5	558.4
Spent Sorbent in Solids Discharged From Carbonizer, lb	226.1	226.4	225.0	228.9
Soot Leaving Carbonizer System, lb	10.7	10.0	0.0	2.8
Product Gas (tar-free) Leaving Carbonizer, lb	1460.7	1572.8	1592.7	2719.6
Tars Leaving Carbonizer, lb	28.7	26.9	19.3	7.6
Product Gas (tar-free) HHV, Btu/lb	2896	2709	2917	1685
Tars HHV, Btu/lb	15485	15485	15462	15485
Feedstock HHV, Btu/lb (MF)	13244	13244	13244	13244
Total (product gas + tars) HHV/Feedstock HHV, %	35.3	35.3	37.3	35.5
Total (product gas + tars) LHV/Feedstock LHV, %	34.0	33.9	35.9	33.6
Product Gas (tar-free) HHV, Btu/SCF	224.2	212.8	227.5	146.7
Feedstock Carbon Conversion to Gas, %	32.25	33.14	35.93	42.31
Feedstock Carbon Conversion to Gas + Tars, %	35.84	36.49	38.33	43.26
MAF Coal Conversion to Gas, %	39.24	40.03	42.74	48.21
MAF Coal Conversion to Gas + Tars, %	42.45	43.03	44.89	49.06
Ca/S Feed Molar Ratio	1.75	1.75	1.75	1.75
Approach to H ₂ S/Sorbent Reaction Equilibrium, %	92.0	92.0	92.0	92.0
Sulfur Captured by Sorbent, % of Coal Sulfur	39.73	38.85	43.82	29.51
Sulfur Appearing in Product Gas + Tars, % of Coal Sulfur	5.40	6.79	3.42	21.34

* Includes slurry water.

Table 2. SUMMARY OF CARBONIZER MATERIAL BALANCES AT 10-atm PRESSURE
(Basis: 1000 lb Moisture-Free Coal Feed)

Case Description	2.5% Moisture	6% Moisture	1600°F	30% Slurry
Carbonizer Temperature, °F	1500	1500	1600	1500
Coal Feed (moisture-free), lb	1000	1000	1000	1000
Moisture in Coal Feed, %	2.5	6.0	2.5	30.73*
Coal Feed (as-fed), lb	1025.6	1063.8	1025.6	1443.6
Sorbent (Dolomite) Feed, lb	307.9	307.9	307.9	307.9
Air Feed, lb	1000.8	1068.2	1100.3	1767.9
Char in Solids Discharged From Carbonizer, lb	606.4	602.1	596.5	557.4
Spent Sorbent in Solids Discharged From Carbonizer, lb	225.9	226.0	224.9	227.4
Soot Leaving Carbonizer System, lb	11.3	10.5	0.0	2.9
Product Gas (tar-free) Leaving Carbonizer, lb	1460.7	1573.2	1592.2	2724.2
Tars Leaving Carbonizer, lb	30.1	28.2	20.2	7.7
Product Gas (tar-free) HHV, Btu/lb	2907	2718	2927	1682
Tars HHV, Btu/lb	15485	15485	15462	15485
Feedstock HHV, Btu/lb (MF)	13244	13244	13244	13244
Total (product gas + tars) HHV/Feedstock HHV, %	35.6	35.6	37.6	35.5
Total (product gas + tars) LHV/Feedstock LHV, %	34.3	34.2	36.2	33.6
Product Gas (tar-free) HHV, Btu/SCF	225.4	213.8	228.6	146.6
Feedstock Carbon Conversion to Gas, %	32.42	33.30	36.08	42.44
Feedstock Carbon Conversion to Gas + Tars, %	36.18	36.81	38.59	43.40
MAF Coal Conversion to Gas, %	39.38	40.17	42.86	48.32
MAF Coal Conversion to Gas + Tars, %	42.76	43.32	45.12	49.17
Ca/S Feed Molar Ratio	1.75	1.75	1.75	1.75
Approach to H ₂ S/Sorbent Reaction Equilibrium, %	92.0	92.0	92.0	92.0
Sulfur Captured by Sorbent, % of Coal Sulfur	40.70	40.22	44.31	35.07
Sulfur Appearing in Product Gas + Tars, % of Coal Sulfur	4.42	5.39	2.84	15.58

* Includes slurry water.