PREDICTING PERFORMANCE OF A COAL-FIRED AIR-BLOWN GASIFIER

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Recent reviews of available energy sources to meet our rapidly escalating needs for electric power over the next 2-3 decades conclude that fossil fuel must supply a major portion. Furthermore, these reviewers stress that coal must be the major source. However, government restrictions on stack emissions (particulates, sulfur and NO_x) severely tax present day approaches. As these restrictions become more binding, it becomes obvious that some new approach to generating electric power by the use of coal must be found. One such approach involves cycles employing coal gasification. Basically two types of cycles have been proposed as near term solutions. The simplest of these employs a conventional steam cycle as illustrated schematically by Figure 1. The second involves operation under pressure using a combination of steam and gas turbines.

Inherent in cycles of these types are:

1. Smaller gas quantities to cleanup.
2. Conversion of the sulfur to H_2S, a more reactive and readily removable form.
3. Two-stage combustion which results in reduced NO_x production.

The combined turbine cycle (Figure 2) also has the potential of improved efficiency over the conventional steam cycle. However, if either of these approaches is to find acceptance in the power industry it must, in addition to meeting limits on stack emissions, also have:

1. Good thermal efficiency
2. Reliability
3. Favorable economics

The key to the success of these cycles is most likely the coal gasifier with gas cleaning running a close second. The ability to accurately predict gasifier performance is essential to designing and locating the various heat absorbers for maintaining a high cycle efficiency. A simple analysis of either cycle leads to the conclusion that the gasifier must be air blown (oxygen would be prohibitively expensive). Not quite as obvious is the lower cycle efficiency attained when steam is used as the gasifying medium. In this case heat is lost because this medium enters as water at ambient temperature and exits as steam at stack temperature.

Figure 3 diagrams the performance of a gasifier. If the three outputs at the bottom of the diagram are assumed to be relatively constant then the relationship between the chemical heating value of the gas (expressed as Btu/scf) and the sensible heat in the gas (expressed as gas temperature) can be calculated based on a given set of inputs. This relationship is shown in Figure 4 for a specific set of assumptions as given in the figure. Using the coal analysis specified in Figure 4 the heating value of the product gas can be calculated as a function of the fuel heat input per unit of air fed to the gasifier. This is illustrated in Figure 5, where the fuel to air ratio is expressed as Btu input from the fuel per lb of air, and gas heating value is expressed as Btu/scf.

From an analysis of Figures 4 and 5 it becomes apparent that given a specific coal analysis, the preheated air temperature. the amount of heat loss to the enclosure, the unconsumed fuel (solids) heating value and the sensible heat in the discharge residue, the gasifier performance can be reasonably well defined if the heating value of the product gas is known. However, here is where the difficulty exists. Although the concept of air-blown coal gasification is quite old a good theoretical treatment was presented by Gumz[1] in 1950 - no experimental data is given. Limited data has been presented by Lowry[2] and in a review of gas generators conducted by Bituminous Coal Research, Inc., on an Office of Coal Research project.[3] However, this data is very sketchy, incomplete, and in most cases involves the use of saturated air at about 140°F (0.15 lb. steam per lb of dry air).

During the period 1960-1963 the Babcock & Wilcox Company in cooperation with the General Electric Company conducted an intensive test program to develop a combined cycle concept involving coal gasification.[4] This work covered limited testing of 1-ft diameter suspension and 3 ft x 4 ft fixed bed gasifiers and very extensive testing of a larger 5-ft diameter suspension involving many major modifications of the gasification chamber. All three gasifiers were air-blown using preheated air and all were operated at atmospheric pressure. However, due to limitations of gas cleaning equipment complete gasification was not attained. Essentially complete gasification is considered necessary for the two cycle concepts described earlier. The gasifier arrangement tested is shown schematically on Figure 6 with the equipment arrangement for the larger test unit shown on Figure 7.

Some of the pertinent features of this test unit were the division of the gasifier into separately water-cooled sections for assessment of heat losses. Gas cleanup for solids was accomplished by twin single stage cyclone separators which permitted some carbon carryover with the product gas. However, solids removal was reasonably complete permitting extrapolation to obtain an estimate of the product gas at complete gasification. Also, in an actual process, complete gasification implies total recycling, for a practical gas cleanup system some solid carbon will be entrained in the product gas.

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[1] Wilhelm Gumz, D. Eng. "Gas Producers and Blast Furnaces", 1950, John Wiley & Sons Inc., N.Y.

[2] H.H. Lowry "Chemistry of Coal Utilization" Supplementary volume 1963, John Wiley and Sons.

[3] "Gas Generator Research & Development" BCR Report L-156 prepared for Office of Coal Research under Contract No. 14-01-0001-324, March 1965.

[4] E.A. Pirsh and W.L. Sage "Combined Steam Turbine - Gas Turbine Super Charged Cycles Employing Coal Gasification" American Chemical Society, Division of Fuel Chemistry Vol. 14, No. 2. at the Symposium of Coal Combustion in Present and Future Power Cycles Toronto, Canada May 1970.

Based on the results of the above test program it was concluded that the most important factor in determining high quality product gas was the heat available for promoting gasification and that this heat available (h_a) can be calculated as follows:

h_a (btu/lb air) = heat of combustion of fuel at stoichiometric conditions + sensible heat in the air and fuel stream above 80°F minus the heat losses to the gasification zone.

One problem arises in defining what portion of the gasification zone should be included in defining heat losses. Since gasification reactions are believed to be very rapid, it is believed that only the surface up to or shortly after the start of the gasification zone should be included. Table I lists typical data obtained on the 5 ft diameter gasifier and Figure 8 shows the gasifier configuration. pertaining to the test points.

Figure 9, similar to Figure 5, shows the heat available (h_a) lines based on a correlation of about 150 data points obtained on various gasifier configurations. This data is directly applicable to an air-blown suspension type gasifier only. However, with the proper definition of terms, it should be useful for predicting the performance of fluidized or fixed bed gasifiers, but actual experimental data is lacking to verify this.

Figure 9 serves to define operational limits of an air-blown suspension gasifier. For example, assume a gasifier operating with the coal analysis indicated on figure 4, preheated air temperature of 1000°F, a char recycle rate equal to 50% of coal input heating value, and designed to hold heat losses to 10% of input. Then:

Chemical heat @stoichiometric is (1)	1270 Btu/lb air
Sensible heat in air (1000°F)	230 Btu/lb air
	1500
Less 10% heat loss	150
	1350
Gasifier fuel input is (2)	3750
Predicted product gas HHV (2)	94 Btu/scf

(1) based on coal @1320 Btu/# air and char (C_8H) at 1220 Btu/# air
(2) point located on Figure 9.

Based on these operating conditions the coal feed rate to the gasifier is fixed for a 100% gasification. If the coal feed rate drops then the gas quality drops, or if the coal feed rate is increased then excess char is produced. For the sample cited the exit gas temperature without heat removal would be 3500°F. Hence, steam generating surface must be incorporated in the gasifier and gasifier exit zone to cool the gases to the desired temperature for gas cleanup and sulfur removal.

The case shown has been that somewhat simplified with regard to char recycle rate. Figure 9 indicated that a higher recycle rate would increase product gas quality. However, in actual practice a high excess of char recycle decreases h_a and also imposes a greater heat loss on the gasification zone, since the char has been cooled before collection and recycle. At moderate recycle rates this loss has a major effect on product gas quality but if very high recycle rates are used gas quality will drop.

Figure 9 implies that product gas quality is kinetically and not equilibrium controlled, at least for this gasification process. If the basic reaction is

$$\text{Coal} + \text{air} \longrightarrow \text{product gas heating value } (h_v)$$

then

$$\frac{d(h_v)}{dt} = k\ (\text{coal})\ (\text{air})$$

where K is the apparent rate constant of the form to $Ae^{-E/RT}$

This indicates that the most important factor in increasing product gas heating value is temperature (T). Actually h_a is very closely related to T. However, the above relationship also indicates that high char recycle rate or the use of steam addition to the gasification zone will lower T and hence lower product gas quality. Limited data obtained during this test program verified this prediction.

Figure 10 shows the basic components of a combined cycle including both the steam turbine and gas turbine. However, if a forced draft fan were substituted for the turbine compressor then the same basic configuration applies to the conventional steam cycle. Although the overall cycle efficiency is not affected by the gasifier product gas quality provided the same boundary conditions are maintained, the location of the various heat traps does have considerable bearing on the gas qualities, and it is essential that the details of such a cycle enable accurate prediction of this value.

Although electric power generation from coal gasification to meet atmospheric pollution limits may have considerable merit, it also creates problems. To cite two of these:

1. Because there are few heat sinks where low level heat can be economically recovered, gas cleanup and sulfur removal should be accomplished at the highest feasible temperature leading to the needs for developing a high temperature gas cleaning system.

2. To obtain the low level heat sinks, regenerative feed-water heating which is essential to high steam cycle efficiency may have to be sacrificed to some degree.

TABLE I

Test	8	27	41	51	53	74	76	121	124
Coal Feed lb/hr	5500	5480	4600	4980	2560	3900	4340	4650	4460
Air Flow lb/hr	22860	24260	21370	24010	15930	19740	22180	25820	19410
Heat in Btu/lb Air	1471	1461	1501	1525	1490	1485	1497	1425	1430
Heat Losses Btu/lb Air	182	162	218	241	325	223	298	181	177
h_a Btu/lb Air	1289	1299	1283	1284	1165	1262	1199	1244	1253
Fuel Input Btu/lb Air	4034	3880	3325	3147	2535	2550	2525	3050	2920
(4) Solids/lb hr	2805	1975	1800	1495	990	1805	1670	3180	2830
(5) Product Gas (Dry)/lb hr	25590	26765	23330	26235	17005	21680	24220	28230	21480
Solids lb/hr	1035	1240	865	680	480	585	620	430	1110
Gas Composition (Vol. %)									
H_2	8.5	7.8	6.9	5.4	3.8	6.7	5.5	5.5	8.6
CO	16.5	15.9	14.4	14.8	9.0	15.5	13.6	15.0	16.6
CH_4	0.58	0.45	0.18	0.04	0.2	0	0	0	0.06
CO_2	8.2	9.2	10.0	9.8	13.3	8.9	10.4	8.9	8.0
N_2	66.3	66.8	68.6	70.0	73.6	8.1	9.0	8.0	7.5
H_2O (% Vol. - Wet)	8.5	9.1	9.4	10.5	8.6	8.1	9.0	8.0	7.5
HHV Btu/Scf Dry	86.7	80.9	70.4	65.6	43.6	71.7	66.2	72.7	82.0

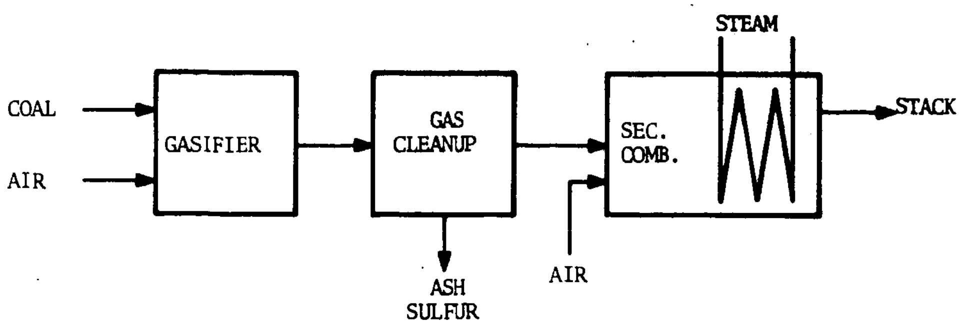

FIGURE 1. STEAM CYCLE

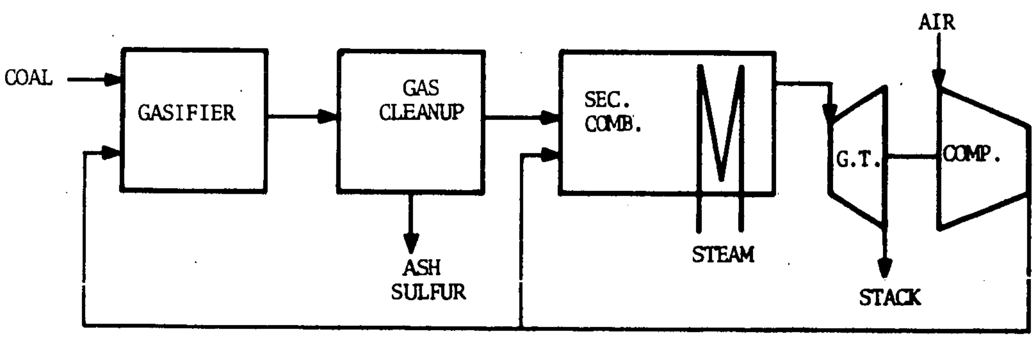

FIGURE 2. COMBINED CYCLE

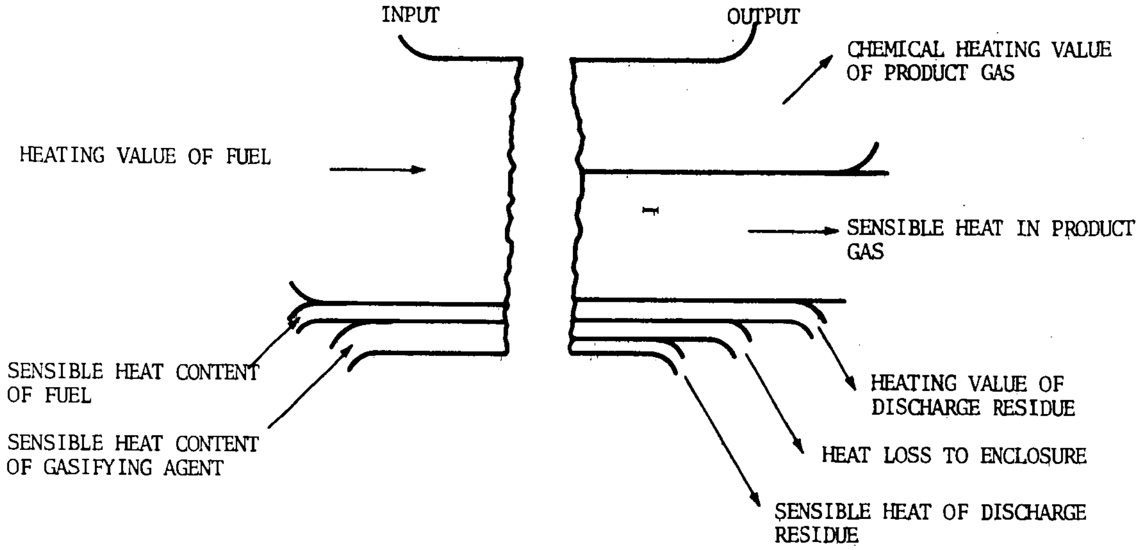

FIGURE 3. GASIFIER HEAT FLOW DIAGRAM

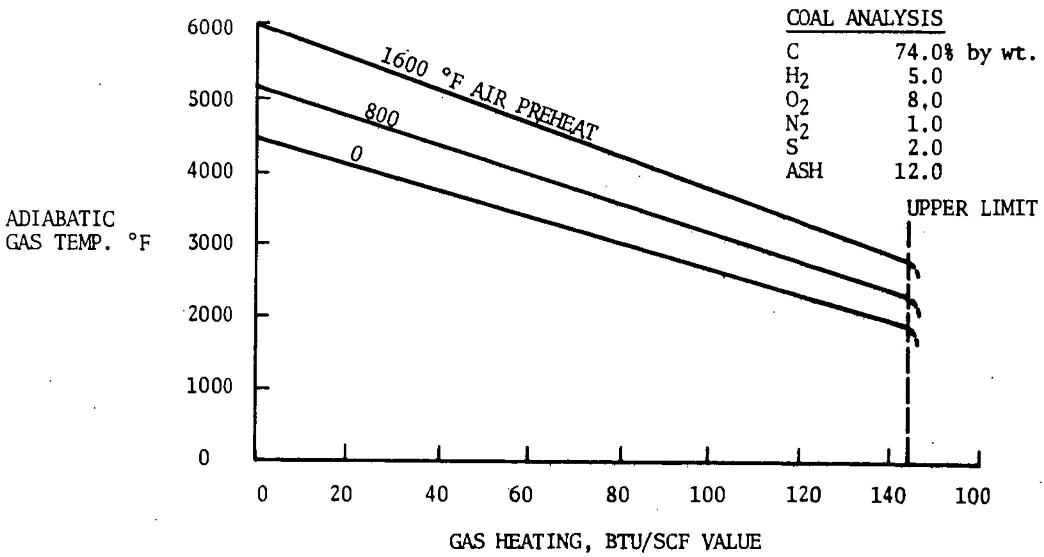

FIGURE 4. GASIFIER ADIABATIC FLAME TEMPERATURE VS. GAS HIGHER HEATING VALUE

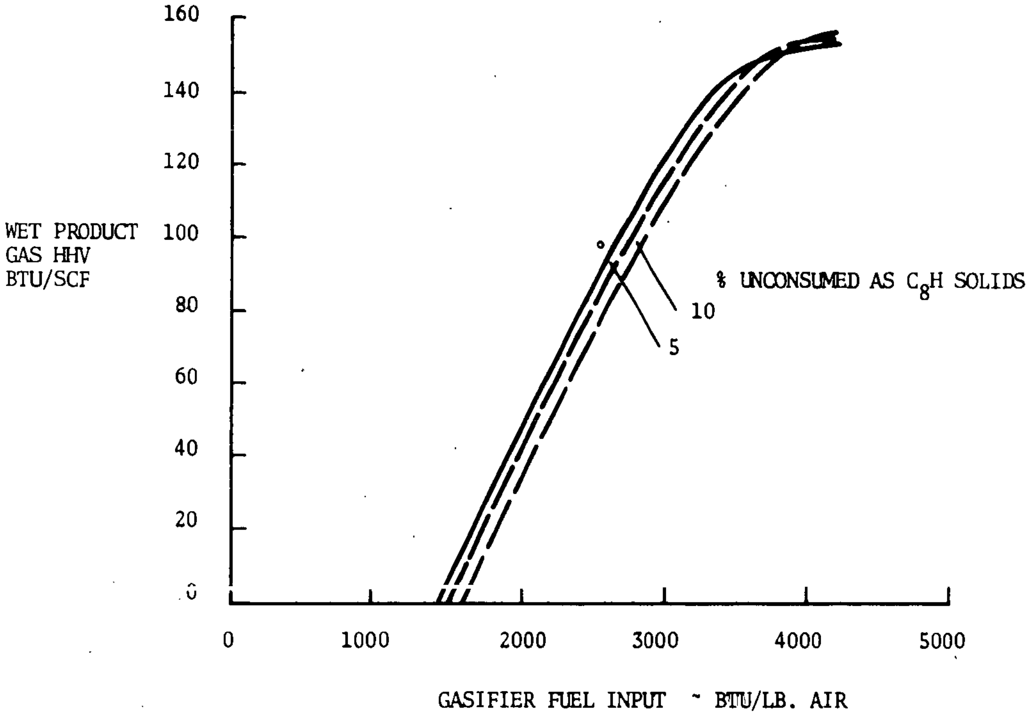

FIGURE 5. PRODUCT GAS HEATING VALUE VS. GASIFIER FUEL INPUT

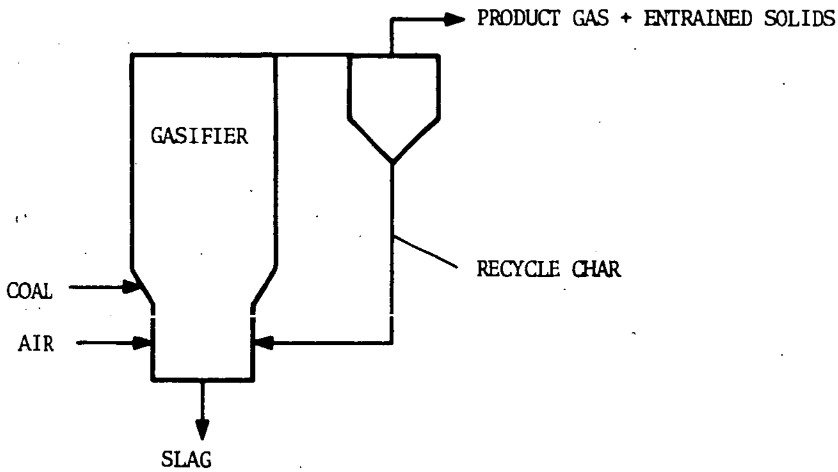

FIGURE 6. AIR-BLOWN SUSPENSION GASIFIER ARRANGEMENT

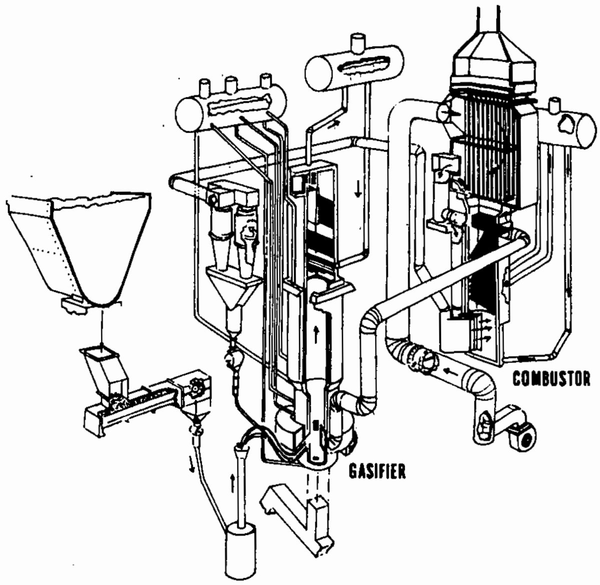

FIGURE 7. ALLIANCE LARGE SCALE GASIFIER

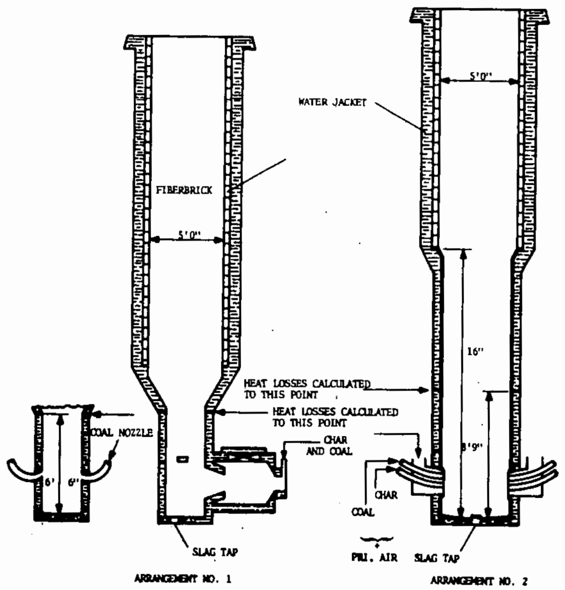

FIGURE 8. GASIFIER ARRANGEMENTS

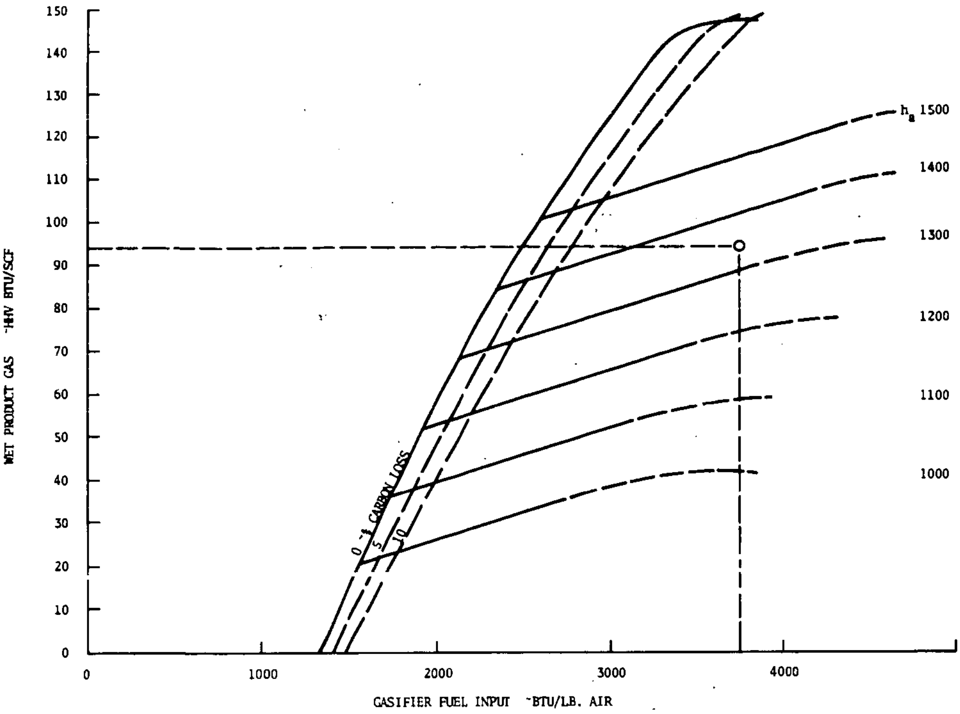

FIGURE 9. PRODUCT GAS HEATING VALUE

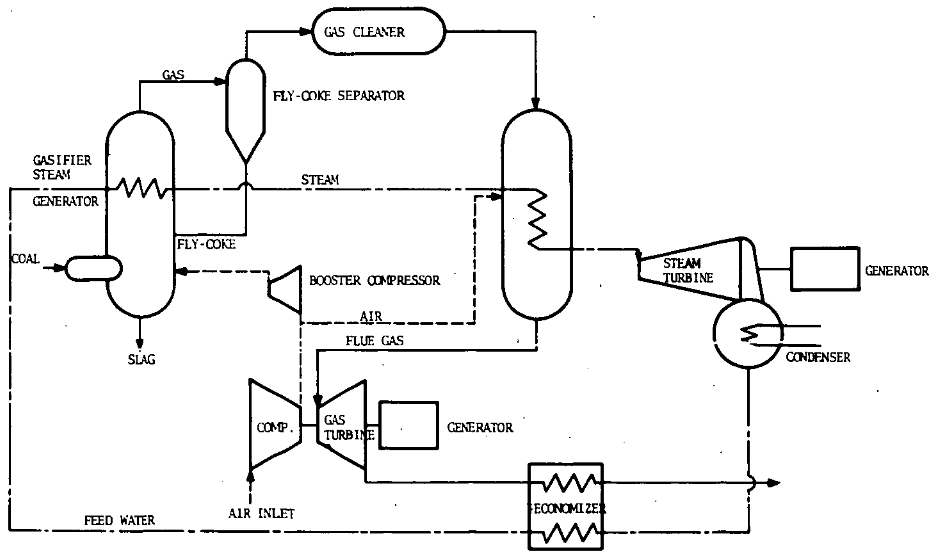

FIGURE 10. COMBINED CYCLE COMPONENT ARRANGEMENT