Coal-Gasification/MHD/ Steam-Turbine Combined- Cycle (GMS) Power Generation

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November 1980

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ABSTRACT

The coal-gasification/MHD/steam-turbine combined cycle (GMS) refers to magnetohydrodynamic (MHD) systems in which coal gasification is used to supply a clean fuel (free of mineral matter and sulfur) for combustion in an MHD electrical power plant. Advantages of a clean-fuel system include the elimination of mineral matter or slag from all components other than the coal gasifier and gas cleanup system; reduced wear and corrosion on components; and increased seed recovery resulting from reduced exposure of seed to mineral matter or slag. Efficiencies in some specific GMS power plants are shown to be higher than for a comparably sized coal-burning MHD power plant. The use of energy from the MHD exhaust gas to gasify coal (rather than the typical approach of burning part of the coal) results in these higher efficiencies.

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INTRODUCTION

The combination of magnetohydrodynamics (MHD) and a conventional steam-turbine generator offers promise for a high thermal-to-electrical efficiency and for low pollution emissions. The MHD generator yields a thermal-to-electrical efficiency of 21% to 27% (AVCO 1979) and also provides a high-quality waste heat that may be fed to a steam generator with an efficiency of 42% (AVCO 1979). The MHD and steam-generator efficiencies quoted do not reflect decreases resulting from power plant auxiliary power and gas compression requirements. Consequently, detailed calculations for specific MHD and steam-generator systems yield efficiencies in the range of 41% to 45% (AVCO 1979).

MHD technology in the U.S. has emphasized the direct combustion of coal, which introduces significant amounts of mineral matter and sulfur into MHD components at temperatures up to 3000K (Figure 1). The resulting slag or ash formed by mineral matter and the sulfur-based compounds influence the performance of the entire power plant. In addition, sulphur and slag compositions and properties vary within a coal seam and from seam to seam, thus complicating the influence on performance. The slag can be beneficial to some MHD components by providing a protective coating that reduces erosion and thermal losses; however, these positive effects are minor when compared to the negative effects slag has on the MHD system. For example, slag increases electrochemical corrosion, reduces the amount of seed recovered, and increases erosion in air

FIGURE 1. Coal-Fired/MHD/Steam-Turbine Power Generation

preheaters, boilers, and other downstream components. These chemical interactions that result from direct coal combustion appear to represent critical limitations to component longevity.

Consequently, the use of a clean fuel (a fuel free of mineral matter and sulfur) reduces many of the material and system problems and simplifies both the MHD and steam-generator components. Although natural gas and oil would be possible fuels, they are not being considered in this study because of our interest in developing a practical and efficient method for using coal. Coal gasification provides a clean fuel, thus allowing us to use our most plentiful domestic fossil fuel resource--coal. A coal-gasification/MHD/steam-turbine combined cycle (GMS), then, is a reasonable alternative to an MHD/steam-turbine cycle with direct coal combustion.

COAL-GASIFICATION/MHD INTERFACING

Coal gasification has been pursued on a worldwide commercial scale to produce end products such as hydrogen, carbon monoxide, gasoline, ammonia and methanol. Consequently, many coal gasification processes have been developed (Table 1). Most of the gasifiers listed in Table 1 require fuel-gas cleanup of sulfur compounds and mineral matter before the gas is introduced into the combustor. Notable exceptions to the sulfur cleanup requirement are: 1) the Exxon process, which uses large amounts of potassium that will react with sulfur; 2) the Westinghouse process that circulates crushed dolomite as a getter for the sulfur; and 3) the atmospheric-pressure gasifiers that circulate potassium, which is supplied by the MHD exhaust gas and reacts with sulfur.

Table 2 shows several sulfur-cleanup processes. All of the cleanup processes require gas-cooling. The sensible heat from cooling can be partially recovered by heat exchangers.

Advantages attributed to a GMS that makes use of fuel gas which is free of sulfur and mineral matter are:

- Coal gasification technology is presently available and is being improved.
- MHD combustor development is simplified because gas is combusted instead of coal; gas burns more rapidly and coal requires coal feed and slag removal systems.
- MHD generator operation and maintenance is expected to be less complicated because of the absence of slag and sulfur, which both erode and corrode; the corresponding absence of the adherent slag coating will make replacement and repair of channel components less complicated and will diminish the potential for electrode and insulator breakup caused by thermal-expansion differences.
- MHD component size can be reduced by the elimination of slag coatings that restrict mass flow, heat transfer and electrical conductivity.

TABLE 1. Summary of Gasification Processes (Wall 1973; Dravo 1976; Teggers and Falkenheim 1977; Furlong and Nahas 1978)

Gasifier	Fuel	Oxidant	Efficiency		Gas, vol%					Temperature of exit gas, K	Pressure, MPa
			Cold Gas, %	Overall, %	CO	H ₂	CH ₄	CO ₂	N ₂ +Ar		
Babcock & Wilcox	Pittsburgh #8	O ₂	74	68	65.3	27.9	--	5.0	1.2	1255	0.10-2.22
		Air	--	--	23.3	8.4	--	4.6	63.5	1255	
Bi-Gas	Pittsburgh Seam	O ₂	69	~65	29.3	32.0	15.7	21.5	0.7	1088	3.62-10.67
Combustion Engineering	Kentucky Bituminous	Air	69	N/A	22.1	17.0	0.03	7.0	53.3	1144	0.10
Foster Wheeler	Illinois #6	-	45	--	29.3	14.5	3.5	3.3	48.7	1255-1422	2.56
Koppers-Totzek	Eastern Coal	O ₂	75	68	52.5	36.0	--	10.0	1.1	1755	>0.10
Texaco	Illinois #6	O ₂	--	--	37.6	39.0	0.5	20.8	0.6	477-533	2.22-8.55
Battelle/Carbide	--	--	--	--	0.0 to 38.6	47.9 to 66.2	1.1 to 6.3	3.3 to 28.2	--	1144-1255	0.81
BCR Low-Btu	Eastern Coal	Steam-Air	88	--	25.7	23.4	--	5.2	45.5	588-922	1.76
CO ₂ Acceptor	Lignite	--	77	--	15.5	58.8	13.7	9.1	2.9	1089	1.16
COGAS	Illinois #6	--	48	79	31.2	57.9	4.0	6.6	0.3	1144	0.21-0.42
Hydrane	Pittsburgh #8	--	84	77.8	6.0	21.7	68.2	1.7	1.4	811-1089	7.15
HYGAS	Montana Sub-Bitum.	--	--	74	26.1	30.7	16.6	24.1	0.2	1283	8.37
	Pittsburgh #8	--	--	68	23.8	30.2	18.6	24.5	0.1	1283	8.37
Synthane	Illinois #6	O ₂	N/A	65 to 70	13.2	32.3	15.0	36.2	--	1033	7.15
		Air	--	--	10.1	21.5	5.6	17.9	43.5	1033	7.15
U-Gas	Bituminous	Air	79	79	19.6	17.5	3.4	9.9	48.9	1116-1311	0.46-2.57
Westinghouse	Eastern Coal	Air	97(a)	94	19.2	14.4	2.7	9.3	54.3	1144-1255	1.02-1.52

(a) Hot Gas

TABLE 1. contd

Gasifier	Fuel	Oxidant	Efficiency		Gas, vol%				N ₂ +Ar	Temperature of exit gas, K	Pressure, MPa
			Cold Gas, %	Overall %	CO	H ₂	CH ₄	CO ₂			
Winkler	Lignite	O ₂			48.2	35.3	1.8	13.8	0.9	894	0.10
	Western U.S. Sub-Bitum. Illinois #6	Air	72	69	22.0	14.0	1.0	7.0	56.0	1061	0.10
ERDA-MERC Stirred-Bed	West Virginia	Air	79	--	20.4	15.5	2.4	8.7	52.5	922	0.10-2.11
	Pittsburgh Bed New Mexico Sub-Bitum.	Air			16.0	19.0	3.8	12.6	48.4	922	
Lurgi	Pittsburgh #8	O ₂	63	76	16.9	39.4	9.0	31.5	1.6	644-811	2.56-3.27
Wellman-Galusha	Bituminous	Air	75	81	28.6	15.0	2.7	3.4	50.3	867-922	near 0.10
	Anthracite	Air	--	--	27.1	16.6	0.5	5.0	50.8	700-811	near 0.10
Woodall Duckham/ Gas Integrale	HVCB	O ₂	--	--	37.5	38.4	3.5	18.0	2.2	922-2200	0.10
	HVCB	Air	77	88	28.3	17.0	2.7	4.5	47.2	922	0.10
Al Molten Salt	Kentucky #9	Air	78	--	29.7	13.2	1.5	3.5	48.0	1200	0.10-2.08
Otto-Rummel	Bituminous	O ₂	72	85	53.6	30.7	0.5	14.0	0.7	1089-1200	0.10-2.64
Bergbau-Forschung	Lignite & Peat	H ₂ O heat	--	70	6.2	58.6	31.2	1.7	--	1033-1144	4.11
Exxon	--	O ₂								977	3.62

TABLE 2. Summary of Sulfur and Carbon Dioxide Removal Systems
(Wall 1973; Dravo 1976)

Process	Pressure Range of Gas in Absorber, MPa	Pressure, MPa	Temperature, K	Fuel Gas, vol%		Product, ppm H ₂ S	Gas, vol% CO ₂
				H ₂ S	CO ₂		
Adip	0.10->7.15	2.01	--	10	2.5	2	0.2
Alkazid	0.10-7.15	7.85	298	0.7	30	5	--
Carl Still	High	--	--	0.6	--	560	--
Claus	0.10-0.21	--	--	40	60	≤37,900	--
Hot Carbonate (Benfield)	High (≥0.28)	4.43	394	1.5	5.4	2	0.01
MDEA	0.10-7.14	0.53	313	0.6	10	50	3.3
Purisol	Low (7.15)	7.64	--	6	15	2	13.6
Rectisol	2.22-14.19	4.93	--	1	5-6	<0.1	0.1
SCOT	Low	0.13	433	1-3	-	200-500	-
Selexol Solvent	3.62-7.15	3.63		0.5	35	<0.1	11
Stretford	0.10-0.81	--	--	0.03 to 95	Any amount	up to 1	None
Sulfiban	0.10-7.15	0.39	-	1.7	9.7	2	(a)
Sulfinol	0.10->7.15	2.89	296	0.46	4.9	3	0.05
Catacarb CO ₂ Removal	1.51-7.15	--	--	--	21.4	--	0.1
Fluor Econamine	-	--	--	--	--	5	--
Fluor Solvent	>0.63	--	--	--	--	5	--
SNPA-DEA	4.32-7.85	--	--	--	--	5	2
Giommarco- Vetrocoke	up to 7.87	--	--	0.001	48	--	3
Takahax	--	--	--	Low	High	99.9% removal	

(a) Negligible

- Corrosive and erosive effects of the slag and sulfur compounds are eliminated on components downstream of the coal gasifier/gas-cleanup system.
- High-temperature gas-combustion development is more advanced than is high-temperature coal combustion.
- MHD component development is expected to be simplified, because the absence of slag in the GMS process eliminates all removal requirements except for those associated with coal gasification.
- Combustion exit temperatures are higher with fuel gas than with coal because flame temperatures are higher with carbon monoxide and hydrogen than with coal and because energy in the combustor is not required to heat coal mineral matter and moisture.
- Seed recovery and regeneration are not complicated by the seed-slag and sulfur reactions in the MHD combustor and generator channel. In these gasifiers in which seed is added with hot MHD exhaust gas, the interactions will be less extensive than in an MHD combustor and channel because of lower operating temperatures in the gasifier, where the seed is in contact with the coal mineral matter.
- Fuel gas can be preheated by the MHD exhaust gas.

In each of the gasification processes, energy must be supplied to the coal gasifier to support the endothermic steam-carbon and carbon dioxide-carbon reactions. Whether or not a gasification process is applicable to a specific GMS power plant (Figures 2 through 4) depends on the method of energy transfer to the gasifier.

ENERGY-TRANSFER METHODS

Energy may be supplied to the coal gasifier by several energy-transfer methods (ETMs):

- a fixed-heat-exchanger method using a ceramic- or metallic-walled heat exchanger operating in the regenerative or recuperative mode;

FIGURE 2. Coal-Gasification/MHD/Steam-Turbine Combined-Cycle Power Generation with Partial-Oxidation ETM

FIGURE 3. Coal-Gasification/MHD/Steam-Turbine Combined-Cycle Power Generation with Partial-Oxidation ETM and Energy Recycle Using Direct-Mixing ETM

FIGURE 4. Coal-Gasification/MHD/Steam-Turbine Combined-Cycle Power Generation with Energy Recycle Using All EMTs Except Partial-Oxidation

- a nonreactive, moveable-burden method that has a non-chemically reactive burden being exchanged between the MHD exhaust gas and the gasifier;
- a reactive moveable-burden method that has a chemically reactive burden being exchanged between the exhaust gas and the gasifier. [The chemically reactive burden can be nonregenerative (e.g., char in the COGAS process) or regenerative (e.g., CaO-CaCO_3 in the CO_2 Acceptor process). In the regenerative process reversible reactions occur, with the exothermic reactions taking place in the gasifier and the endothermic reactions taking place in the MHD exhaust gas.];
- a direct-mixing method that has the hot MHD exhaust gas being mixed directly with the coal in the gasifier; and

- a partial-oxidation method that has air or oxygen-enriched air oxidizing some of the coal, supplying the heat by the exothermic oxidation reaction. (This method is generally used in commercial gasifiers.)

ETM Selection

The selection of an individual ETM or ETM combination for the gasifier is based on technological, environmental and economic considerations. In this brief study the field of choices in available gasifiers was narrowed and suggestions for gasifier modifications were made. In all the ETMs except direct-mixing, seed is not in contact with the slag, ash or coal unless added to increase the gasification reaction rate. In the direct-mixing ETM, seed from the hot combustion gas will be in contact with slag, ash and coal in the gasifier. Seed is not expected to react as extensively with slag, ash and coal in the gasifier as in an MHD channel and combustor, due to the lower temperature in a gasifier.

For the GMS in Figure 2, the ETM is the partial-oxidation method. For the GMS in Figure 3, the ETM is a combination of the direct-mixing and the partial-oxidation methods. The ETM in Figure 4 is a combination of heat exchangers, moveable-burden and direct-mixing, but not partial-oxidation.

COAL-GASIFICATION/MHD INTERFACING OPTIONS

In this section three combinations of ETMs are discussed:

1. partial-oxidation ETM
2. direct-mixing and partial-oxidation ETM
3. ETM combinations excluding partial-oxidation.

Coal Gasifier with Partial-Oxidation ETM

The GMS power plant depicted in Figure 2 has the greatest potential for rapid development because the gasifier can be used without modification. All gasifiers listed in Table 1 except Exxon's use partial-oxidation ETM and are therefore candidates for the GMS; however, advantages of specific gasifiers are apparent from the fuel-gas composition information of Table 1. For instance, low concentrations of CO₂ and N₂-Ar and high concentrations of CO and H₂ are desirable.

The low overall power plant efficiency is a major disadvantage of the partial-oxidation GMS. If coal gasification is assumed to have an overall efficiency of 75%, the GMS overall power plant efficiency would be reduced from a 41% to 45% range down to a range of about 31% to 34% (neglecting the effect of added or subtracted plant components).

Coal Gasifier with Direct-Mixing and Partial-Oxidation ETM

The overall GMS power plant efficiency may be improved by energy recycle through the MHD generator. The most convenient way to recycle energy is to use the hot MHD exhaust gas to supply hot CO_2 and H_2O for reaction with carbon-- thereby transferring heat to the coal gasifier by the direct-mixing ETM.

Heat transfer by the direct-mixing ETM may be applied to near-atmospheric-pressure gasifiers, provided a convenient method of introducing combustion gas into the gasifier can be devised. The energy gained for gasification from this step is dependent on the amount of combustion gas injected into the gasifier, on the temperature of the combustion gas, and on the temperature of the gasifier. The pressure of a gasifier using heat transfer by the direct-mixing ETM must be nearly atmospheric because of the low pressure of the MHD exhaust gas and the difficulty in compressing hot gases. Only gasifiers using the direct-mixing ETM have the requirement of near-atmospheric-pressure operation. Among the gasifiers listed in Table 1, several operate at near-atmospheric pressures; four of these are commercial: Koppers-Totzek, Winkler, Wellman-Galusha and Woodall-Duckham/Gas Integrale. The Koppers-Totzek has the highest-temperature gasifier and lowest carbon-to-gas conversion percentage. Carbon-to-gas conversion for the Wellman-Galusha and Woodall-Duckham gasifiers is nearly 100%, and is 95% or greater for the Winkler gasifier (Dravo 1976). When using the commercial gasifier for GMS, only enough combustion gas is fed into the gasifier to supply the oxygen that steam normally supplies. The combustion gas also provides some of the energy for gasification because of its high temperature. The additional energy needed for gasification is supplied by the partial-oxidation ETM, as shown in Figure 3.

Partial oxidation is required, since the transfer of enough heat by direct-mixing ETM would dilute the fuel gas excessively with carbon dioxide

and/or nitrogen. Increased concentrations of either carbon dioxide or nitrogen will have the end effect of decreasing combustion temperature and increasing nitrous oxide formation at any given temperature.

The Wellman-Galusha gasifier can be modified to use hot MHD exhaust gas as the oxidant in place of the conventional steam oxidant. Hot MHD exhaust gas may be fed into the gasifier in a position corresponding roughly to the oxidant inlet. An upper limit may exist for the temperature of the hot MHD exhaust gas. Two gasifier modifications may be necessary: 1) a refractory lining at the combustion gas inlet, and 2) alternate grate cooling using either cool combustion gas or water-cooling through a rotating seal. Waste heat from water-cooled gasifier walls and sensible heat of fuel gas can be recovered, but viscous tar formation from bituminous coals fouls heat-exchanger walls. Currently, gasifiers with waste-heat recovery are limited to sub-bituminous or lignite coals. Use of bituminous coals would require modifications in the design of the waste-heat recovery system.

Coal Gasifier with ETM Combinations Excluding Partial-Oxidation

The overall GMS power plant efficiency is improved when the gasifier is extensively modified to use any ETM combinations excluding partial-oxidation to supply the energy for gasification. Using a fixed-heat-exchanger ETM is particularly difficult because the limitations of heat-exchanger technology require low-temperature operation. Two gasifiers that appear to be adaptable to the fixed-heat-exchanger ETM are the German Bergbau-Forschung (Teggars and Falkenhaim 1977) and the U.S. Exxon (Furlong and Nahas 1978). These gasifiers use low gasification temperatures. In the German process, low gasification temperature is achieved at the expense of gasification rate; in the Exxon process the gasification rate is increased to acceptable levels by the addition of up to 25 wt% potassium catalyst. When applied to a GMS plant, the presence of potassium as catalyst on one side and as seed on the other side of a heat exchanger results in particularly difficult material problems. However, if gasification rates are increased in the German process and if heat-exchanger technology advances, modified forms of both the German and Exxon processes are candidates for combination with MHD.

A method of increasing the reactivity of coal at gasification conditions is to first pyrolyze it, which is the basis of the COGAS process (Dravo 1976, Bloom and Malakoff 1977). Initial pyrolysis of the coal increases the rate of the gasification reaction and produces a high-Btu pyrolysis gas along with light and heavy distillates. The subsequent gasification yields a medium-Btu gas. After scrubbing, all of these products may be burned in the MHD combustor or may be treated as high-value byproducts. The pyrolysis gasification approach still requires heat-exchanger development work. As envisioned in the COGAS process, heat is transferred to the gasifier by a reactive moveable-burden ETM. The reactive burden in this case is char, which is heated by oxidation in a combustor and then transferred hot to the gasifier to supply heat. Another gasification process, which first pyrolyzes and then gasifies the coal is the TOSCO-DYNE process being developed by Hydrocarbon Research Institute and Oil Shale Corporation (Carlson, Yardumian and Atwood 1972). In this process, ceramic balls or similar burden are used as the nonreactive moveable-burden ETM. For GMS, the ceramic balls would be heated by the hot MHD exhaust gas.

An additional process of interest using the nonreactive moveable-burden ETM is the Battelle-Columbus Agglomerating-Burner Coal Gasifier (Mink, Steedman and Tewksbury 1978). In this process, part of the coal is burned in a combustor using the Agglomerating Burner. The hot combustion gas, low in particulate matter because of the Agglomerating Burner, is cycled directly to a gas turbine for electric power production. The hot, agglomerated ash (nonreactive burden) from the combustor is then transferred to the coal gasifier. The gasification products would be available for use in an MHD system.

The CO₂ Acceptor process from Conoco Development Company transfers heat to the gasifier using a regenerative reactive-burden ETM. Calcium oxide is converted to calcium carbonate in the presence of carbon dioxide (an exothermic reaction) in the gasifier, thus releasing heat for the endothermic steam-carbon reaction. The calcium oxide is regenerated (an endothermic reaction) at a higher temperature and returned to the gasifier. The energy required for this step is supplied by burning char that has collected on the calcium carbonate. If the energy is instead supplied by hot MHD exhaust gas, the CO₂ Acceptor concept applies to GMS.

SYSTEM DESIGN

A detailed example using a modified commercial gasifier with both direct-mixing ETM and partial-oxidation ETM is shown in Figure 5. This example is intended to be a system that is attainable on a short-term basis, requiring only moderate development. The proposed system does not include a separate sulfur-removal step, which may be added if necessary. It is expected, however, that the seed introduced into the gasifier with the exhaust gas will be effective in removing most of the sulfur. The oxygen from the oxygen plant is necessary to increase the combustion temperature. Details of the steam plant are not included because of the common nature of the technology.

DIRECT-MIXING/PARTIAL-OXIDATION ETM DESIGN DETAILS

MHD exhaust gas is divided, with a greater portion going to the steam plant; consequently, a greater portion of the seed will remain uncontaminated by either coal slag/ash or sulfur. Hence, the seed recovery will be simplified, resulting in high yield. The lesser portion of the seed will be in contact with the coal in the gasifier and will have a lower yield for seed recovery. The overall seed recovery is expected to be higher than in a coal-fired MHD plant. The MHD combustor design is simplified, in that the combustion only burns a gas and is not required to reject slag or ash. The MHD channel design is also simplified, because the MHD plasma does not contain coal slag or ash. The fuel gas from the gasifier is cooled prior to compression. The gas cleanup will be done prior to compression to reduce wear on compressor parts. The heat exchanger recovers most of the heat from the gas-cooling.

PLANT EFFICIENCY

Figure 6 shows the detailed energy and mass balances for the system in Figure 5. The oxidant preheat temperature is 900K. The carbon conversion in the gasifier is assumed to be 85%, although it is understood that some commercial gasifiers attain 98% or greater carbon conversion (Dravo 1976). The combustion takes place with 80% of the amount of air or oxidant theoretically required for complete combustion ("theoretical air") to control nitrogen oxide

FIGURE 5. A Block Diagram of the Coal-Gasification/MHD/Steam-Turbine Combined-Cycle Power Plant with Partial-Oxidation ETM and Energy Recycle Using Direct-Mixing ETM

FIGURE 6. Heat and Mass Balances for the Coal-Gasification/MHD/Steam-Turbine Combined-Cycle Power Plant with Partial-Oxidation ETM and Energy Recycle Using Direct-Mixing ETM

emissions. The size of the oxygen plant may be reduced by increasing the oxidant preheat temperature, the fuel-gas preheat temperature and the percentage of theoretical air. The calculations are based on the assumption that the gasifier makes use of waste-heat recovery, water-cooled grate, hot MHD exhaust gas feed, and tar-byproduct gasification.

The calculated efficiency for a GMS power plant of the same size (2123 MJ/s thermal input) as the coal-fired plant described in reference plant #3, parametric point #1 (AVCO 1979) has an efficiency comparable to that of the reference plant (43%). The GMS efficiency calculation was based on an 85% carbon conversion in the gasifier, ~80% theoretical air, and fuel gas and oxidant preheat of 900K. The GMS plant will gain efficiency advantage over the coal-burning MHD plant with 1) increased preheat temperatures (>900K) for fuel gas, 2) increased carbon conversion (>85%), and 3) increased theoretical air percent (>80%) for combustion.

For a modified GMS power plant that uses only the direct-mixing ETM, that maintains a fuel-gas and oxidant preheat temperature range of 1100K to 1650K, and that has near-100% values for carbon conversion and theoretical oxygen levels, the calculated efficiencies range between 43% and 55% (Braun and Pudlik 1980; Zinko, Linder and Ravensborg 1975). All of the energy needed for the endothermic coal gasification reactions comes from the hot MHD exhaust gas. More CO_2 than is needed for gasification is supplied to the gasifier because of the gasifier energy requirements. Consequently, the fuel-gas stream is rich in CO_2 (32% to 50%). The high CO_2 content of the fuel gas requires oxygen-enriched air for adequate combustion temperatures. This modified GMS power plant uses 98% pure oxygen at about 100% theoretical air for combustion. In a system that does not use oxygen enrichment but that is otherwise similar, the calculated efficiency is 56.4% (Bergman et al. 1973).

For a GMS plant in which all ETM may be used except partial-oxidation, efficiencies range from 48% to 58%, depending on the preheat temperature of the fuel gas and oxidant. The efficiency calculations were made assuming 85% carbon conversion in the gasifier and 90% theoretical oxygen in the combustor.

CONCLUSIONS/RECOMMENDATIONS

The combination of a coal gasifier and an MHD/steam-turbine combined-cycle system (GMS) results in a power-generation arrangement that increases efficiency and makes component interfacing more practical. The GMS systems offer solutions to several technological problems related to the development of MHD--especially in the areas of corrosion, erosion, electrochemical degradation of components and seed/slag interaction. The GMS technology has the potential to lengthen the lifetime of MHD components by allowing removal of coal mineral matter and sulfur from the system before combustion takes place.

The GMS increases the overall plant efficiency by the following means:

- recycling heat to the MHD channel
 - by the endothermic $C-CO_2$ and $C-H_2O$ reactions
 - by providing a gaseous fuel stream that may be preheated before combustion;
- reducing the amount of seed in contact with the slag and consequently the complexity of seed regeneration;
- increasing combustion temperature.

Based on increased efficiency and improved overall component interfacing, it is recommended that research and development of GMS systems commence so that the technology may be demonstrated. The research and development will include: 1) power plant design and analysis (efficiency, economics); 2) proof-of-principle verification tests, including operation performance data on a pilot-plant scale (the pilot plant includes a gasifier, a combustor and an MHD generator channel); and 3) development of components for higher efficiency.

The GMS power-generation concept is sound, and the means of demonstrating the concept are available. A clean fuel (sulfur- and slag-free) is provided by coal gasification and gas cleanup. The combustor in the GMS plant is a gas burner that would require little additional development. Corrosion and erosion of heat exchangers, MHD generator, radiant boiler and combustor are expected to be less severe than would be the case if coal were burned directly in an MHD plant, and a slag-free environment is attractive for reducing the problems of seed recovery.

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