Seed Regeneration Integration Options For Commercial MHD/Steam Power Plants

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SEED REGENERATION INTEGRATION OPTIONS FOR COMMERCIAL MHD/STEAM POWER PLANTS

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ABSTRACT

This paper reports the results of a study that evaluated methods of integrating the TRW Econoseed seed regeneration process with the power generation systems of an MHD/steam power plant. This analysis was based on a 220 MWe-class early commercial MHD/steam power plant. Performance and economics were compared for different methods of integrating the two systems, and technical issues arising from the process integration were identified. In parallel with the study of methods of integrating the seed regeneration and power generation systems, an ASPEN model of the seed regeneration process was prepared to assist with analysis of the seed regeneration process in future studies.

The results of the study indicate that integration of the seed regeneration systems with the MHD/steam power plant will increase the net electrical output of the power plant, and can reduce the cost of electricity by about 3.8 percent.

INTRODUCTION

One characteristic of coal-fired magnetohydrodynamic (MHD) power generation is that SO_2 emissions can be controlled by chemical reactions that occur within the MHD combustor between sulfur and the potassium salts that are added as a "seed" material to enhance ionization. If potassium oxide, formate, or carbonate is selected as the seed material, it will combine with the sulfur contained in the coal to form potassium sulfate (K_2SO_4), which may be removed in a solid form by a particulate control system downstream of the heat recovery equipment.

Previous studies of MHD power plants have shown that it is more economical to produce potassium carbonate (K_2CO_3) or potassium formate (KCOOH) seed by regenerating the K_2SO_4 collected by the Heat and Seed Recovery System (HRSR) than by continually purchasing fresh seed. The U.S. Department of Energy has supported the study of several seed regeneration processes, and has selected the Econoseed process[1], developed by TRW, for further study and for the construction of a pilot seed recovery plant.

This paper reports the results of a study[2] that evaluated the integration of the Econoseed process with an MHD power plant. The study examined three means of fully integrating the Econoseed seed regeneration process to the MHD power plant, and one means of partial integration. The performance and economics of these integrated plants were then compared with those of a non-integrated baseline plant.

ECONOSEED PROCESS

The Econoseed process uses a partial oxidation reactor, fired by oxygen and a fuel such as natural gas or coal, to generate carbon monoxide. The carbon monoxide then reacts with slaked lime to produce calcium formate, which in turn reacts with potassium sulfate to produce potassium formate. The potassium formate may be used as seed, or it may be oxidized to produce potassium carbonate, which is the form of seed that has generally been used in MHD testing up to this time.

In this study, the Econoseed process was assumed to use natural gas as its fuel. Coal is a potential fuel for larger Econoseed plants, but an Econoseed system sized for a 220 MWe power plant considered by this study would have a coal feed rate of about 100 tons/day. Modern coal gasifier designs are being developed in the 1000 ton/day and larger class. Since commercial coal gasifiers will be an order of magnitude larger than the size required for this study, it is probable that natural gas would be the more economical fuel for small systems due to the high specific cost of small-scale coal gasifiers.

BASELINE PLANT

This study was based on an early-commercial, oxygen-enriched MHD/steam plant configuration with a net output rating of 220 MWe. The plant uses Illinois No. 6 coal, a high-sulfur bituminous coal, as its fuel. The seed was assumed to be provided as potassium carbonate, and the seed/coal ratio was set to provide 90 percent sulfur capture, which is the sulfur capture level required by the present New Source Performance Standards (NSPS) for this type of coal.

A conceptual design for a non-integrated baseline plant was prepared; this plant design was very similar to the National Aeronautics and Space Administration (NASA) Engineering Test Facility[3] design developed by Gilbert/Commonwealth (G/C). In the baseline plant, the Econoseed unit used purchased consumables (except for electrical energy), provided regenerated seed to the MHD power plant, and exported its byproduct steam for sale to third parties. The electrical power consumed by the Econoseed plant was charged as an auxiliary loss to the power plant, so that the net output quoted for the baseline plant represents energy that is available for sale to other customers.

INTEGRATION OPTIONS

Table 1 shows a listing of flow rates and economic values of consumables and byproducts for the Econoseed seed regeneration process, when sized to meet the needs of the 220 MWe baseline plant. The Econoseed process and the MHD power plant can be integrated in the following three areas:

Table 1

ECONOSEED PROCESS CONSUMABLES AND BY-PRODUCTS

	Flow Quantity	Nominal Cost, $/hr
Basis (Mixed Seed Flow Rate), lb/hr	29,488	
Consumables Costs		
Natural Gas, Millions Btu/hr	204.06	459
175 psia Saturated Steam, lb/hr	*89,416*	*326*
Lime, lb/hr	10,108	291
Oxygen, (pure oxygen basis), lb/hr	*7,292*	*277*
Makeup K_2SO_4, lb/hr	1,492	134
Electrical Energy, kW	*1,144*	*69*
150 psia Saturated Steam, lb/hr	*6,499*	*24*
Boiler-Quality Feedwater, lb/hr	*27,150*	*19*
Process Water, lb/hr	160,055	8
By-product Credits		
600 psia Saturated Steam, lb/hr	*25,994*	*143*
Partial Oxidation Reactor Offgas, Millions Btu/hr	*102.2*	*??*
Formate Reactor Offgas, Millions Btu/hr	*25.65*	*??*

Notes:

a. *Italicized Lines* Denote Streams with Integration Potential

b. Flow Quantities Based on 532 MWt (220 MWe) MHD/Steam Power Plant

c. Value of offgases is site-specific, but, if they are sold as a fuel, their value will be less than that of natural gas (2.25 $/million Btu).

1. The air separation unit (ASU) of the power plant can supply oxygen to the seed regeneration plant;
2. Steam and feedwater interfaces to the seed regeneration plant may be provided by the steam bottoming cycle of the power plant; and
3. Combustible offgases produced by the Econoseed process may be burned in the power plant.

Oxygen can be readily supplied to the Econoseed plant, since the oxygen-enriched plant configuration selected for this study would have an ASU in place. Steam and feedwater interfaces can also be provided between the seed regeneration system and the power plant; Figure 1 shows the steam and feedwater interfaces that were selected for this integration study.

The primary design freedom in integration of the Econoseed and power plant systems is the disposition of combustible offgases that are produced by the seed regeneration system. One byproduct offgas is produced by the partial oxidation reactor that generates carbon monoxide from natural gas and oxygen; the fuel content of this gas is 102.2 million Btu/hr for the 220 MWe nominal rating of the baseline plant. The other offgas is produced by the calcium formate reactor that reacts CO with lime to produce calcium formate; this stream contains 25.6 million Btu/hr in fuel value. Figure 2 depicts the composition and relative flow rates of these two offgases.

Due to their high hydrogen content, both the specific gravity and the heating value per cubic foot of the offgases are low compared to natural gas. Consequently, transmitting them through a pipeline would be more costly than for natural gas, and their economic value as a fuel gas to be sold to a third party would be highly site-specific. Unless there is a nearby chemical plant that could utilize the offgases based on the value of their hydrogen content, their economic value as a fuel gas will be considerably below that of natural gas. For this reason, the offgas was assumed to have no economic value in the non-integrated baseline plant, and that it would be flared at the power plant site.

Table 2

OVERALL PLANT PERFORMANCE FOR SEED INTEGRATION OPTIONS

PLANT TYPE:	Non-Integrated Baseline	Offgas to A/B	Offgas to MHD	Offgas to Fuel Cell	Partially Integrated
POWER SUMMARY, kWe					
MHD DC Power, kWe	97,008	97,008	104,420	97,008	97,008
Steam Turbine Power, kWe	174,123	181,186	178,476	168,165	168,165
Fuel Cell Net AC Power, kWe	-	-	-	15,129	-
Gross Power, kWe	271,131	278,194	282,896	280,302	265,173
Auxiliaries, kWe	(50,694)	(52,218)	(54,992)	(51,749)	(51,673)
Net Power, kWe	220,437	225,976	227,904	228,553	213,500
Net Efficiency, % Coal HHV	41.44%	42.48%	42.84%	42.96%	40.13%
Net Heat Rate, Btu/kWh (HHV)	8,236	8,034	7,967	7,944	8,504

Notes:

a. Coal feed rate held constant at 161,516 pph, 532.0 MWt (as-received Illinois No. 6 Coal)

b. Sulfur capture per present New Source Performance Standards (90 % Capture)

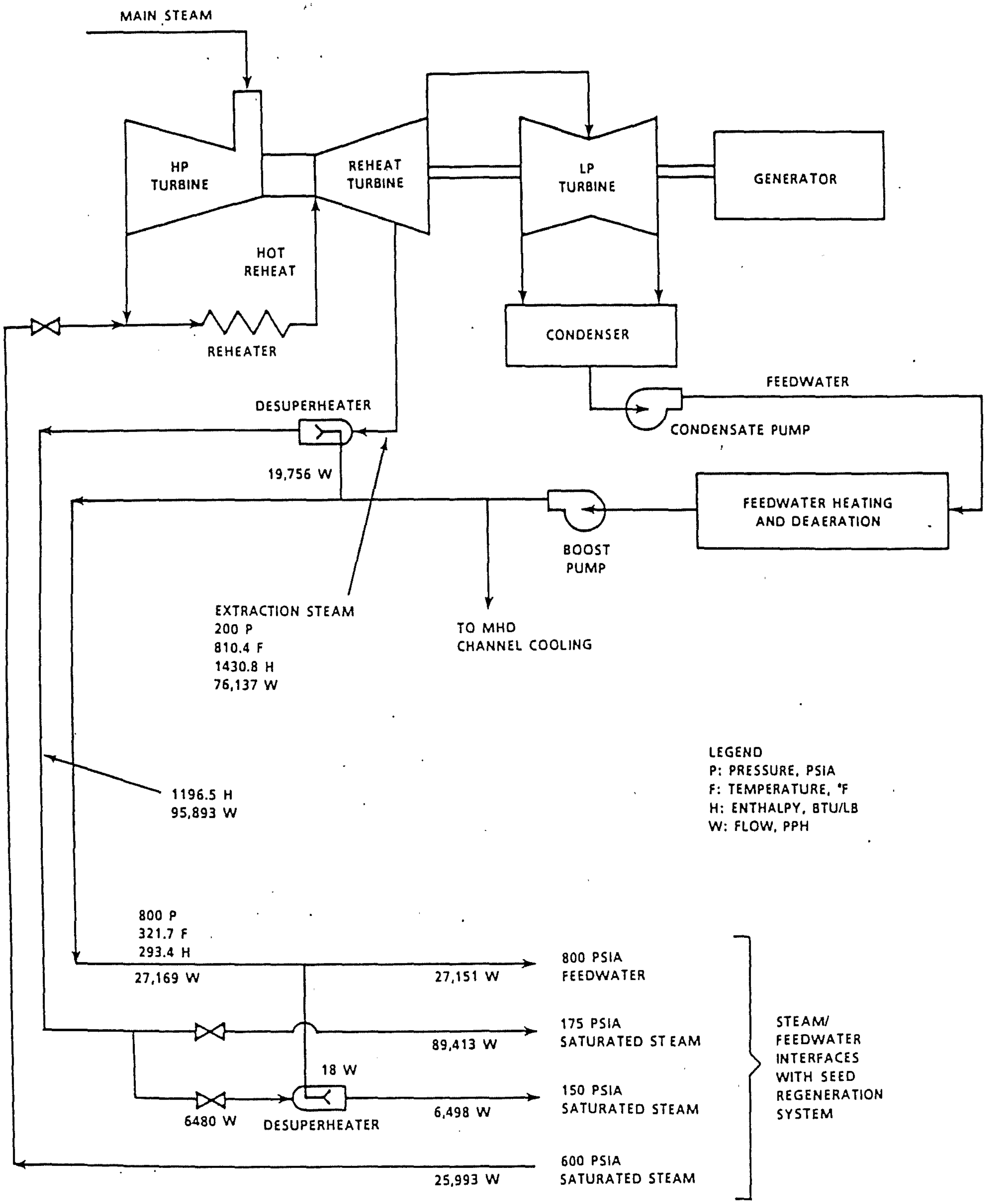
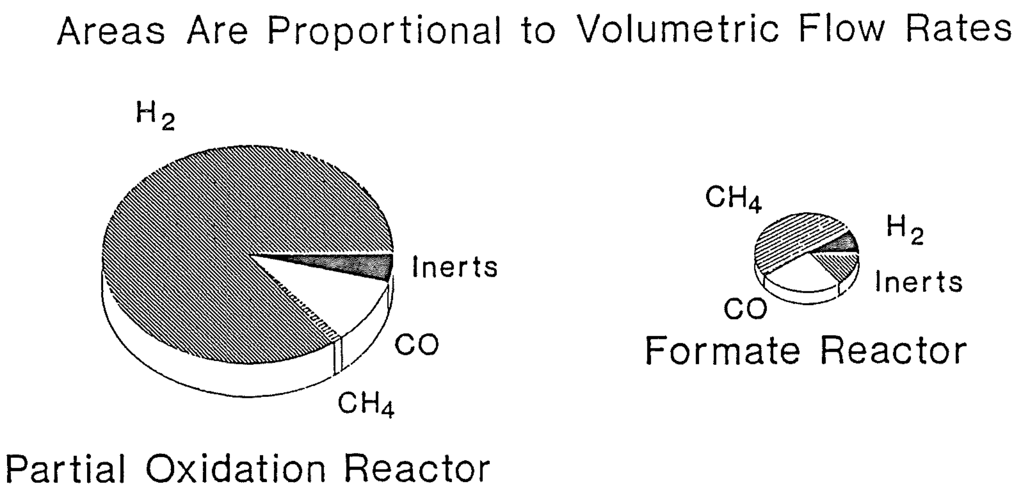


Figure 1
Steam & Feedwater Interfaces for
Seed Regeneration/Power Plant Integration



Areas Are Proportional to Volumetric Flow Rates

Partial Oxidation Reactor

Formate Reactor

Figure 2
Offgas Properties for the TRW Econoseed Process

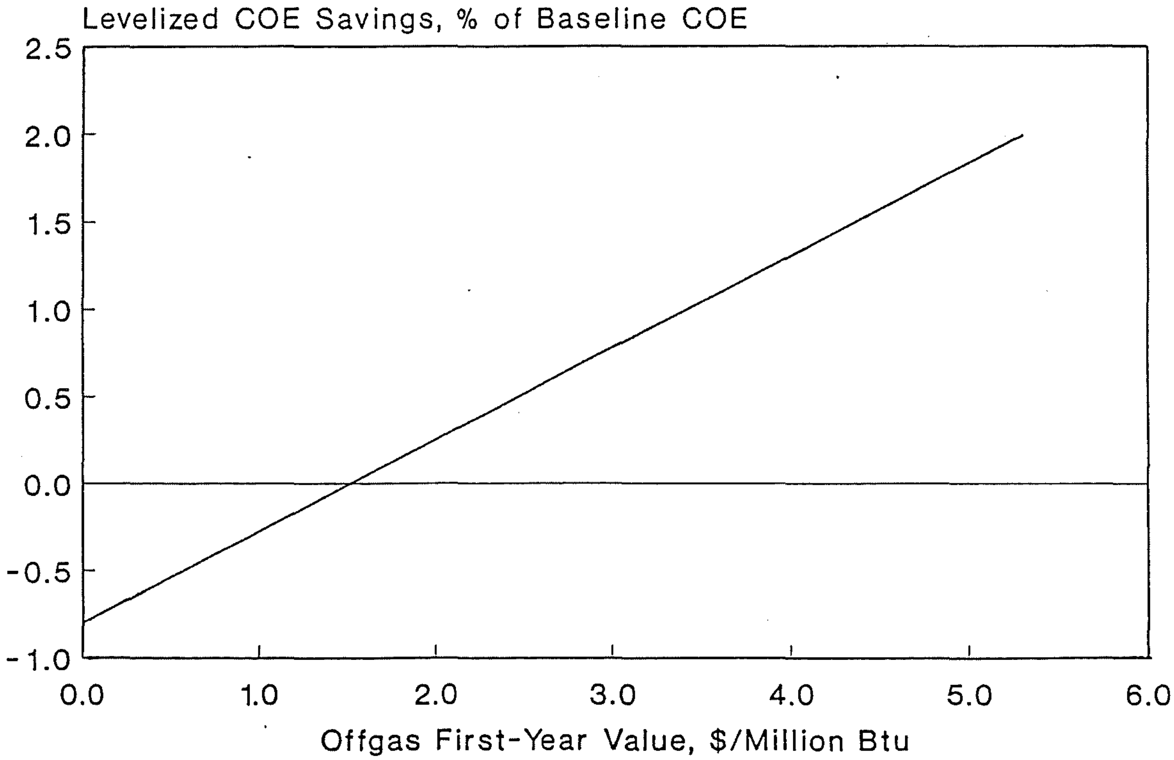


Figure 3
Sensitivity of COE Savings to Offgas Value

In the fully integrated configurations, the offgases were assumed to be burned in:

- the afterburner section of the heat and seed recovery (HRSR) system, or
- the MHD combustor, or
- a phosphoric acid fuel cell (PAFC) system; the high hydrogen content of the offgases makes it an attractive fuel for a fuel cell.

In addition, a partially-integrated configuration was examined, where steam, feedwater, and oxygen are supplied by the power plant, but the offgases are assumed to be sold to a third party for use as a fuel, or as a chemical feedstock based on the hydrogen content.

PERFORMANCE COMPARISON

Conceptual designs of the baseline plant and the four integration options were developed, and performance was determined for each configuration. Coal feed, and hence the seed production rate, were held constant, so the MHD topping cycle parameters and output were also constant for each case except the one case where the combustible offgases are burned in the MHD combustor. The performance of the bottoming cycle and balance-of-plant systems were determined for each case.

Table 2 shows the overall performance for the baseline plant and for each of the integration options. Full integration results in an increase in net plant output; the loss in power resulting from having the MHD plant supply oxygen and steam to the Econoseed system is more than offset by the increase in output resulting from burning the offgases in the MHD plant or in a fuel cell. The partially integrated plant shows a loss in net power, since the offgases for this plant are sold rather than consumed in the power plant. The thermal efficiencies listed in this table are based on the coal feed to the MHD combustor; the feedstock natural gas consumed by the Econoseed system and the offgases flared, exported, or consumed by the power plant are not included in the denominator of the efficiency calculation.

During the early phases of this study, there was concern that burning of offgases in the MHD combustor might degrade topping cycle performance due to the large amount of hydrogen in the offgases. Hydrogen in the MHD combustor fuel will increase the number of hydroxyl (OH) radicals in the plasma, and the OH radicals will in turn capture free electrons and reduce plasma conductivity. As the study progressed, the analysis showed that burning the offgases in the MHD combustor had no adverse effect on performance. Table 3 compares some of the MHD channel parameters for this integration option with the baseline plant. Although the offgas to MHD combustor plant has lower conductivity throughout the channel, its enthalpy extraction ratio and isentropic efficiency match those of the baseline plant. The primary adverse effect noted for this option is that the channel and magnet length must be about 7 percent longer in order to expand the plasma to the same diffuser exit temperature, which, as shown below, would increase the capital cost of those two components.

ECONOMIC COMPARISON

Capital costs and operating costs were determined for each of these plant configurations, and these costs were compared with those of the baseline plant. These costs include all the costs associated with the Econoseed plant in addition to coal pile to busbar costs for the power plant.

Capital Costs

Table 4 provides a breakdown of the capital cost differences resulting from integration of the seed regeneration process.

Table 3

EFFECT OF OFFGASES ON MHD TOPPING CYCLE CHARACTERISTICS

Configuration	Baseline	Offgases to MHD Combustor
MHD Combustor Thermal Inputs, MWt (HHV)		
Coal Thermal Input	532.0	532.0
Offgas Thermal Input	0.0	37.5
Total MHD Thermal Input, MWt	532.0	569.5
Combustor Inlet Total Pressure, atm	4.88	4.96
Seed, % Potassium	1.352	1.288
Combustor Exit Flow, kg/sec	130.18	136.63
Combustor Exit Total Temperature, K	2,708	2,716
MHD Combustor Oxidant Flow, kg/sec	108.75	114.85
Channel Inlet Conditions		
Static Temperature, K	2,559	2,567
Static Pressure, atm	2.95	3.00
Conductivity, mho/m	6.17	5.83
Channel Exit Conditions		
Static Temperature, K	2,176	2,175
Static Pressure, atm	0.77	0.77
Conductivity, mho/m	1.95	1.78
Channel Length, m	12.2	13.0
Inlet Area, m^2	0.359	0.373
Exit Area, m^2	1.551	1.641
Channel Cooling Duty, MWt	23.5	26.0
Maximum Ex, V/m	2,500	2,500
Maximum Ey, V/m	3,857	3,898
Maximum Jy, A/cm^2	0.591	0.565
Maximum Hall Parameter	3.61	3.55
DC Power Output, MWe	97.01	104.45
Enthalpy Extraction Ratio, %	18.5	18.6
Channel Isentropic Efficiency, %	74.0	74.1

Notes:

Channels designed for diffuser exit temperature of 2200 K (3500 °F)

Channel Inlet Mach number = 0.95; channel exit Mach number = 0.80.

Seed feed rate set for 90 % sulfur capture.

It is important to recognize that at the conceptual level of these evaluations, that absolute costs are quite uncertain. However, a consistent approach was used in generating the costs for each case, so the relative costs and differences between cases are a good indication of the trends that would occur through process integration.

Each of the full and partial integration options considered resulted in an increase in total plant cost (TPC) on a dollar basis. The largest TPC increase was 5.27 percent for the option that burns the offgas in a fuel cell; the fuel cell system accounts for almost all of that cost increase. With offgas to the MHD combustor, the TPC increased by 2.86 percent, with most of that increase being in the MHD generator and magnet, the oxidant supply system, the HRSR, and accessory electrical equipment. For off-gas to MHD afterburner integration, the TPC increase was 2.86 percent, with

Table 4

MHD SEED INTEGRATION CAPITAL COST SUMMARY

Title	Fully Integrated Configurations Off-Gas To A/B	 Off-Gas To MHD	 Off-Gas To PAFC	Partially Integrated Plants Off-Gas @ Zero Value	 Off-Gas @ $5.31/10^6 Btu
Net Plant Output, MWe	226.0	227.9	228.6	213.5	213.5
Net Output Difference, % of Baseline	2.5	3.4	3.7	-3.1	-3.1
Total Plant Cost Differences, % Of Baseline TPC					
311-STRUCTURES & IMPROVEMENTS	0	0	0	0	0
312-BOILER PLANT					
HRSR Steam Generator	0.664	0.471	0	0	0
Other Boiler Plant Equip.	0.143	0.104	0	0	0
314-TURBOGENERATOR UNITS	0.289	0.119	-0.178	-0.178	-0.178
315-ACCESSORY ELECTRICAL EQUIP.	0.145	0.407	0.092	0.092	.092
316-MISC.POWER PLANT EQUIP.	0	0	0	0	0
317-MHD TOPPING CYCLE EQUIPMENT					
Combustor System	0	0.282	0	0	0
Generator & Magnet Systems	0	0.756	0	0	0
Oxidant Supply & ASU	0.272	0.531	0.272	0.272	0.272
Seed Regeneration System	0	0	0	0	0
Other Topping Cycle Equip.	0	0.195	0	0	0
340-OTHER GENERATION(PAFC)	0	0	5.085	0	0
Total TPC Difference					
% of Baseline TPC	1.515%	2.864%	5.271%	0.186%	0.186%
% of Baseline $/kW	-0.97%	-0.51%	1.53%	3.44%	3.44%

Notes:

The Net MWe % values are based on the Baseline Plant value of 220.44 MWe.

The indicated changes are expressed in terms of percent change relative to the Non-Integrated Baseline Plant TPC.

the largest cost component increase occuring in the HRSR, reflecting the greater quantity of steam produced there as a result of burning the offgas in the HRSR. At the TPC level, there was little difference between the partially integrated configuration and the baseline plant.

Although the TPC increased for each of the cases studied, the net plant output also increased for each of the fully integrated configurations, mitigating the effect of the TPC increment. On a unit cost ($/kW) basis, offgas to afterburner integration provides the lowest plant cost (TPC), with a unit cost savings of 1.0 percent relative to the baseline. The offgas to MHD combustor integration option shows a TPC unit cost savings of 0.5 percent relative to the baseline. The offgas to PAFC and partially integrated configurations show unit cost penalties of 1.5 and 3.4 percent relative to the baseline, respectively. The partially integrated configuration shows the largest increase in TPC unit cost because it had a loss in net output of 6.9 MWe (3.1 percent) relative to the baseline in addition to a 0.2 percent increase in TPC on an absolute basis.

Cost of Electricity

Table 5 shows changes in the levelized cost of electricity (COE) that were calculated for each of the plant configurations. These COE increments are levelized over 30 years using December 1989 dollars, and are expressed as a percentage of the baseline plant levelized COE. The costs of natural gas and lime consumed by the Econoseed system are accounted for as "Consumables" in this table, and the credits received for 600 psi steam and offgases (in the partially integrated plant) are accounted for as "Byproduct Credits".

The configurations where the offgas was burned in the afterburner and in the MHD combustor showed the best improvements in COE; either of them would provide a reduction in COE of 3.8 percent. The offgas to PAFC option showed a smaller savings in COE, with its COE being 1.7 percent lower than that of the baseline plant. Although this configuration had the highest net output and highest efficiency, the capital and O&M costs associated with adding a fuel cell system to the plant resulted in poorer economic performance than the other two fully integrated options.

The partially-integrated configuration, where the offgases are exported to a third party, was evaluated at two different values for the offgas. In the first case, the offgases were assumed to have neither an economic value nor a penalty; in the second case, it was assumed that the offgases could be sold on the basis of their hydrogen content rather than on their heating value. The hydrogen was evaluated at its market value, which is about 7.51 $/million Btu of the hydrogen higher heating value, while the remainder of the offgases were assumed to have no economic value.

Figure 3 shows the sensitivity of COE savings to the offgas sales price for the partially integrated configuration. Partial integration shows poorer economics than a non-integrated configuration for any offgas value less than 1.50 $/million Btu, and, for any realistic credit for the offgas, can not match the 3.8 percent COE savings achievable from integrating the offgases to the MHD afterburner or to the MHD combustor. Thus, partial integration has no merit relative to the most favorable integration options.

Table 5

MHD SEED INTEGRATION ECONOMICS SUMMARY

	Fully Integrated Configurations			Partially Integrated Plants	
Title	Off-Gas To A/B	Off-Gas To MHD	Off-Gas To PAFC	Off-Gas @ Zero Value	Off-Gas @ $5.31/10^6 Btu
Net Plant Output, MWe	226.0	227.9	228.6	213.5	213.5
Net Output Difference, % of Baseline	2.5	3.4	3.7	-3.1	-3.1
Total Plant Cost Difference, % of Baseline TPC					
TPC Difference, $ basis	1.5	2.9	5.3	0.2	0.2
TPC Difference, $/kW basis	-1.0	-0.5	1.5	3.4	3.4
COE & COE Component Differences, % of Baseline Levelized COE					
Fixed Charges (Based on TPC)	-0.6	-0.4	0.8	1.9	1.9
O&M Cost	-0.3	-0.3	0.7	0.6	0.6
Consumables	-3.2	-3.3	-3.3	-2.9	-2.9
Byproduct Credits	0.7	0.7	0.7	0.7	-2.1
Fuel Cost	-0.4	-0.5	-0.6	0.5	0.5
Total Levelized COE Difference	-3.8	-3.8	-1.7	0.8	-2.0

Notes:

The Net MWe % values are based on the Baseline Plant value of 220.44 MWe.

All TPC cost difference values are based on the corresponding Baseline Plant values.

All COE and COE component values are based on the percent change relative to the Baseline Plant total COE on a 30 year levelized, 65% plant capacity factor basis and first-year fuel costs of $1.68/million Btu for coal and $2.25/million Btu for natural gas.

DESIGN AND INTEGRATION ISSUES

Oxygen Supply

The Econoseed system was assumed to utilize the same ASU as the MHD power plant. Several studies[3,4,5] on MHD power plants have selected low-purity (70 percent oxygen content by volume) ASUs as the most economical source of oxygen for enrichment.

The Econoseed process study[1] was based on the utilization of 95 percent purity oxygen for the partial oxidation reactor. Having the same air separation unit (ASU) supply oxidant to both the MHD plant and the Econoseed plant would be desirable, as this would reduce plant complexity and plant capital cost. Since the MHD power plant consumes over ten times the oxidant that the Econoseed consumes, the ASU should be selected to meet the needs of the power plant. Consequently, the effect of supplying a partial oxidation reactor with 70 percent oxidant on the rest of the Econoseed process should be investigated.

Alternate Sources of CO

The seed regeneration plant configuration studied was based on the use of a partial oxidation reactor to produce carbon monoxide (CO) for the Econoseed process. Other sources of CO have been suggested, such as a coal gasifier, or the bleeding of gas from the first stage of a two-stage MHD combustor. In order to establish the limit on savings that could be realized from an alternative supply of CO, the economics of the baseline plant were re-evaluated based on the assumption that CO was provided at no cost as a byproduct of some other process. This allows elimination of the capital charges for the partial oxidation reactor and its associated equipment, and also eliminates the charges for natural gas consumption.

The change in TPC on a unit cost basis for this hypothetical case is a savings of 1.1 percent of the baseline plant cost, while the COE is reduced by 3.9 percent. The largest component in the COE savings is the elimination of natural gas cost; this amounts to a COE reduction of 2.3 percent. The COE savings from reduced fixed charges for capital cost are 0.8 percent; the remaining 0.8 percent COE reduction is due to the elimination of. oxygen costs for the partial oxidation reactor and reduced Operation and Maintenance costs.

The 3.9 percent savings in COE from utilizing a zero-cost source of CO can not be added to the 3.8 percent savings achievable from process integration, since much of the COE savings from integration is due to the utilization of the partial oxidation reactor offgas and 600 psi steam, which are byproducts of CO production.

The use of a coal gasifier as a source of CO might be cost-effective if the seed regeneration process were to be sized to serve 2000 MWe or more of high sulfur coal-burning MHD power plants. The economics of a larger capacity, coal gasification-based Econoseed system have not yet been evaluated.

Using the MHD combustor as a source of CO has the advantage of eliminating the need for a separate coal gasifier. The capacities of the MHD combustor and its coal and oxidant supply systems would need to be incremented by a small amount, about 6 percent on coal feed, and 3 percent on the oxidant supply system, to make up for the gas bleed. One disadvantage of this configuration would be the need for a gas cooling, particulate removal, and sulfur removal system sized for a small gas flow rate. Another disadvantage is that unless there is an alternate source of CO, this configuration would not allow the seed regeneration system to operate when the MHD combustor is shut down.

Reliability

Sufficient excess capacity must be provided in the seed reprocessing unit so that an inventory of seed can be built up to assure continued operation of the MHD plant for all but the most severe temporary failures, trips, or other unscheduled shutdowns or curtailments of production of the seed regeneration facility. The reliability of the Econoseed plant should be quantified so that a reasonable analysis may be performed on the optimum amount of excess capacity or redundant equipment in the Econoseed plant.

Unscheduled outages of the MHD plant would adversely affect the economics of seed regeneration if it is necessary to operate the Econoseed plant to replenish the seed inventory. Operation of the Econoseed system is possible even when the MHD plant is totally shut down. Steam can be supplied from a package boiler that services the MHD plant during start-up, while oxygen can be supplied from the liquid oxygen storage tank that is provided with the ASU.

ASPEN PROCESS SIMULATION

An ASPEN simulation of the Econoseed system was developed to aid future analysis of possible changes to the seed regeneration process. ASPEN simulation sub-models have been developed for the following three units:

- Carbon monoxide generation
- Calcium and potassium formate reactors, and
- Product washing and evaporation

The ASPEN model is based on an empirical approach for describing the extent to which the major reactions occur. The model could be upgraded to use the electrolyte flash equilibrium calculations that are built in to the ASPEN code, but the empirical approach was followed because of the greater availability of experimental data.

The model presently has the flexibility to simulate several of the design variations that might occur in the seed regeneration system. Variations from the basic design developed by TRW that have been simulated with the model include the effect of using 70 percent rather than 95 percent purity oxygen for the partial oxidation reactor, the regeneration of spent seed from a low sulfur coal, and the effect of bypassing seed around the potassium formate reactor to decrease the formate/sulfate ratio in the product.

ACKNOWLEDGEMENT

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REFERENCES

1. TRW. MHD Seed Recovery and Regeneration. Final Report. Contract No. DE-AC22-87-PC79672. October 14, 1988.
2. Boulay, R.B., Hyre, M.R, and Buchanan, T.L., Seed Regeneration Options for Commercial MHD/Steam Power Plants, G/C Report No. 2834, April 6, 1990.
3. Gilbert/Commonwealth, Inc., and NASA, Magnetohydrodynamics Engineering Test Facility (ETF). NASA CR-165452, 1981.
4. MHD Development Corporation, Conceptual Design of a Coal-Fired MHD Retrofit, Volume II, Technical Discussion, 1989.
5. Westinghouse Electric Corporation, Advanced Energy Systems, Conceptual Design of a Coal-Fired MHD Retrofit Plant, Draft Final Report, March 1989.