DOE/NASA/0017-7
NASA CR-182189

IN-44
174572
9P.

Assessment and Comparison of 100-MW Coal Gasification Phosphoric Acid Fuel Cell Power Plants

Cheng-Yi Lu
Cleveland State University

August 1988

Prepared for
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
Lewis Research Center
Under Contract NCC 3-17

for
U.S. DEPARTMENT OF ENERGY
Fossil Energy
Office of Coal Utilization and Extraction

Printed in the United States of America

Available from
National Technical Information Service
U.S. Department of Commerce
5285 Port Royal Road
Springfield, VA 22161

NTIS price codes[1]
Printed copy: A02
Microfiche copy: A01

[1]Codes are used for pricing all publications. The code is determined by the number of pages in the publication. Information pertaining to the pricing codes can be found in the current issues of the following publications, which are generally available in most libraries: *Energy Research Abstracts (ERA); Government Reports Announcements* and Index (*GRA* and I); *Scientific and Technical Abstract Reports (STAR);* and publication, NTIS-PR-360 available from NTIS at the above address.

DOE/NASA/0017-7
NASA CR-182189

Assessment and Comparison of 100-MW Coal Gasification Phosphoric Acid Fuel Cell Power Plants

Cheng-Yi Lu
Cleveland State University
Cleveland, Ohio 44115

August 1988

Prepared for
National Aeronautics and Space Administration
Lewis Research Center
Cleveland, Ohio 44135
Under Contract NCC 3-17

for
U.S. DEPARTMENT OF ENERGY
Fossil Energy
Office of Coal Utilization and Extraction
Washington, D.C. 20545
Under Interagency Agreement DE-AI21-80ET17088

ASSESSMENT AND COMPARISON OF 100-MW COAL GASIFICATION PHOSPHORIC ACID FUEL CELL POWER

Cheng-Yi Lu
Cleveland State University
Department of Chemical Engineering
Cleveland, Ohio 44115

One of the advantages of fuel cell (FC) power plant is fuel versatility. With changes only in the fuel processor, the power plant will be able to accept a variety of fuels. This study was performed to design process diagrams, evaluate performance, and to estimate cost of 100 MW coal gasifier (CG)/phosphoric acid fuel cell (PAFC) power plant systems that would use coal, which is the largest single potential source of alternate hydrocarbon liquids and gases in the United States, as the fuel. Results of this study will identify the most promising integrated CG/PAFC design and its near-optimal operating conditions. The comparison is based on the performance and cost of electricity (COE) which is calculated under consistent financial assumptions.

System Designs

Net power output considered in this study is of 100 MW scale. This requires about 1000 TPD of coal feed which is about the size of suggested initial commercialized coal gasifiers. Three conventional CGs are integrated with a water-cooled PAFC power plant, which are Koppers-Totzek (GKT) oxygen-blown, Wellman-Galusha (W-G) air-blown, and Lurgi oxygen-blown. One "near commercial" Kohlegas Nordrhein GmbH (KGN) CG was also considered because of its capability of producing tar/oil-free gases under air-blown and pressurized operation.

Cold gas cleanup is considered in the design because of its ability to clean ammonia to 0.1 to 1.0 ppm, which PAFC can tolerate, in the fuel stream.

For the PAFC, the International Fuel Cell (IFC) water-cooled 11 MW power plant and its rated operating conditions was used as the baseline. Alternatively, the Westinghouse (W) air-cooled 1.5 MW PAFC module was also assessed and compared with water-cooled systems.

The main difference between the gas fueled and coal fueled FC system configurations lies in the usage of exhaust fuel from the FC stacks. In a gas fueled PAFC system, the spent fuel from the FCs will be burned in the fuel processor to provide heat to the endothermic reforming reaction, whereas, in a CG/PAFC system the exhaust fuel will be utilized in the bottoming cycle to generate additional power. In the bottoming cycle, energy in the FC vent gases is recovered by catalytic combustion of the mixture, raising its temperature from near FC operating temperature to about the maximum allowable firing temperature of the gas turbine. Several heat recovery steam generators (HRSGs) convert flue gases into steam for direct use in the process, and into shaft energy for driving rotary machinery or an electric generator.

Performance

Typical material and energy balances for the selected CGs published in two EPRI reports (AP-3105 and EM-3162) were used in this study.

In the IFC PAFC power plant E+8 mV V-I characteristics was assumed (Ref. 1). Modification of one operation condition was made to increase efficiency: the fuel utilization ratio of FC was adjusted to permit the maximum allowable firing temperature (2000 °F) to be reached in the bottoming cycle (Ref. 2).

Performance of the systems studied is summarized in Table 1.

SYSTEM	GKT	W-G	LURGI	KGN-IFC	KGN-W
CG	GKT	W-G	LURGI	KGN	KGN
Status	Conventional	Conventional	Conventional	Pilot	
Type	Entrained	Moving	Moving	Moving	
Coal Type	Ill. #6 Bituminous	Western Subbit.	Ill. #6 Bituminous	Western Subbit.	
Coal Input (TPD)	1065	1052	1029	856	917
Oxidant	O_2	Air	O_2	Air	
Raw Gases Produced					
T (°F)	1832	610	1078	1700	
P (psia)	15	15	315	170	
Cold-Gas Eff.(%)	67	79	80	84	
Sulfur Capture	Stretford	Stretford	Stretford	Stretford	
Tars/Oils (TPD)	neg.	43.3	neg.	neg.	
Fuel Cell	IFC	IFC	IFC	IFC	W
Gross Power Generated (MW - 100 MW Net Power Output)					
PAFC	69.9	74.4	71	57.5	59.3
GT	40.5	53.7	48.1	42.9	44.2
ST	32.9	6.6	10.1	22.5	25
Power Consumed	43.3	31.4	32.5	22.9	28.5
Efficiency (%)	30.9	36.4	32.5	44.7	41.7

TABLE 1. System Performance Summary

Economics

Cost of CGs were quoted from various EPRI reports (AP-4018, EM-3162, and AP-3109) and escalated with consistent factor of indirect field cost suggested by Fluor Engineers in their three EPRI reports (AP-4018, AP-3486, and AP-3129).

Recently published Technical Assessment Guide (1986) (P-4463-SR) was applied to provide a consistent set of economic factors, financial assumptions which were based on federal tax laws in effect on Nov. 1, 1986, and fuel price projections. Some of the plant economic and financial assumptions used in the analyses are listed in Table 2. All capital costs were expressed in 1984 dollars.

Cost Basis	1984 Constant Dollars
Plant Class	Fossil-Fueled Generation
Plant Construction Years	2
Process Contingency (%)	
concept with bench-scale data	30
pilot plant data	20
commercialized	5
Fuel Cell Stack Life (Years)	6 @ 65% Capacity
Capacity (%)	65
Accumulated Present Value Factor of Replacement Stacks for Fuel Cells	1.773
Carrying Charges (%)	10.34
Coal Price ($\$/10^6$ Btu) Projections (Delivered to East Central)	
Ill. # 6 Bituminous	1.55 w 0.8%/Yr escalation
Western Subbituminous	1.85 w 1.3%/Yr escalation

TABLE 2. Economic and Financial Assumptions

Results

Table 3 is a breakdown of the capital cost and COE estimates.

Total Plant Investment ($/kW)	GKT	W-G	LURGI	KGN-IFC	KGN-W
CG & Related	1301	745	902	790	833
Raw Gases Clean-up & Shift	206	139	380	121	129
PAFC	535	544	495	397	444
Rotary Machinery	356	310	240	300	496
BOP	225	195	216	185	233
Other Capital Charges	149	124	129	112	144
AFUDC	83	61	71	57	67
TOTAL	2853	2118	2432	1960	2346
COE (mills/kWh)					
Capital Cost	51.8	38.5	44.2	35.6	42.6
O/M Costs	34.1	25.5*	30.0	26.0	29.0
Fuel Cost	21.0	21.4	18.1	16.4	17.6
TOTAL	106.9	85.4	92.2	78.0	89.2

* Tars & Oils Credit = 4 mills/kWh

TABLE 3. Total Plant Investment and COE Estimates (Constant 1984 Dollars)

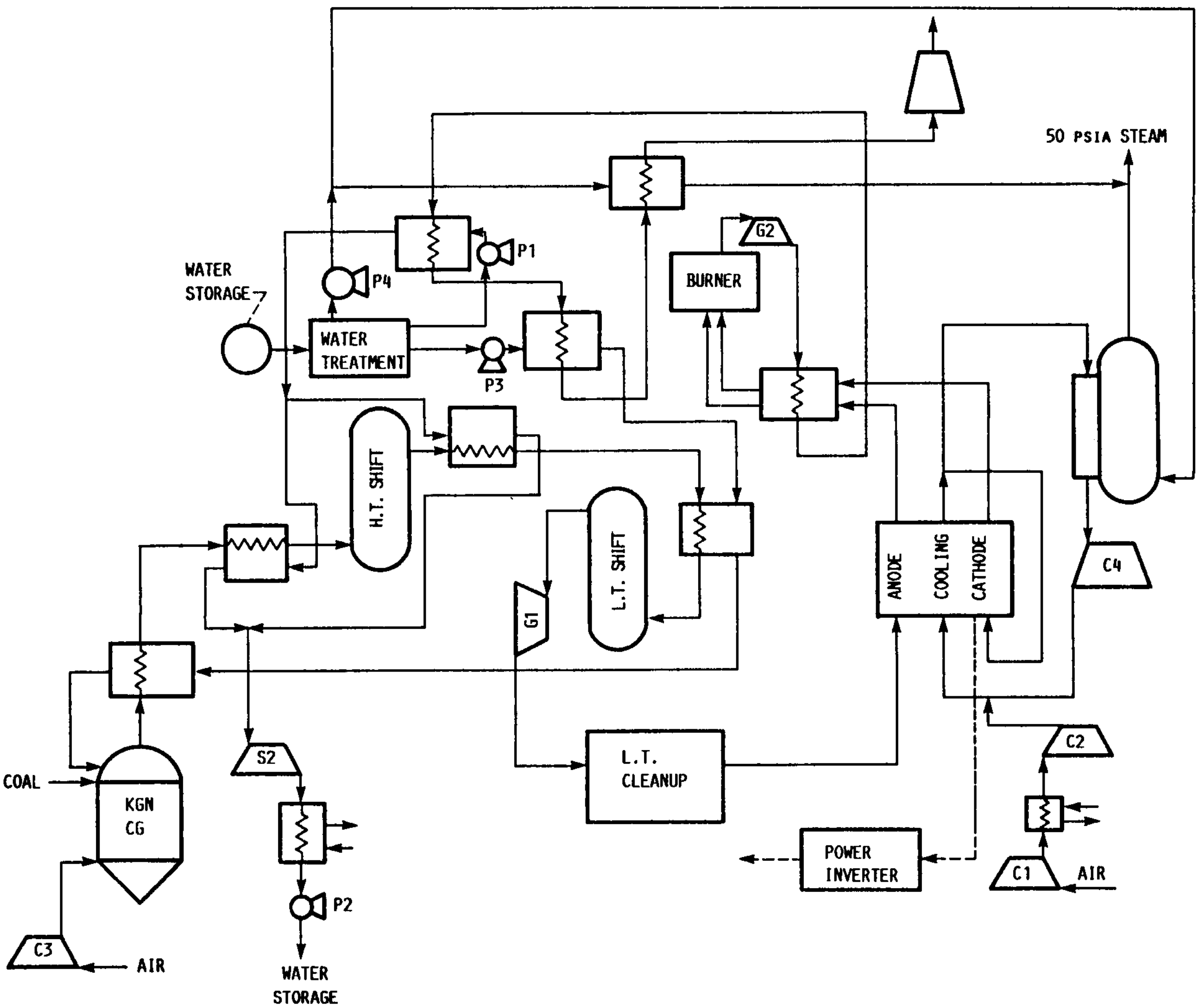
The results show that among the conventional CGs the air-blown W-G CG/PAFC system using low sulfur coal has a higher efficiency and a lower COE, both of which are mostly attributed to low power consumption and low cost for air compression relative to the oxygen plant. But the advantage of lacking oxygen plant in the air-blown CG is partially offset by the larger sized downstream components. Because of low sulfur contained in the Western subbituminous coal (0.44 wt%), the clean-up in the W-G CG/PAFC system costs much less than the other systems using high sulfur coal (4 wt%). Again this should be traded with higher delivered price of Western subbituminous coal.

Because of the higher operating temperature in the KGN CG (1700 °F), the system using KGN CG results in higher efficiency and lower COE than using lower temperature W-G CG (610 °F). A higher operating temperature (higher than 1200 °F) can produce tar/oil-free synthesis gases, and more sensible heat can be used to generate high quality steam (650 psig). In addition, a pressurized KGN CG (170 psia) will eliminate fuel gases compression if the PAFC is operated at elevated pressure (120 psia in IFC PAFC power plant). It is more power consuming and costly to compress a large amount of fuel gases rather than to compress oxidant for the CG.

Both the KGN CG integrated systems show that the FC module generates near one half of the total power and the gas and steam turbines generate the remaining half with a two to one ratio, respectively.

Air Cooled PAFC Module

Usage of the air-cooled PAFC stack in the CG/PAFC integrated system (Figure 1) was assessed and compared with the power plant using IFC's water-cooled PAFCs. The Westinghouse 7.5 MW module and its rated operating conditions was integrated with KGN CG. The areal specific cost of air-cooled stack was assumed to be the same as that of water-cooled stack. Final results show that the performance of a system with the air-cooled PAFCs is less efficient (41.7%) and more expensive (2346 $/kW) than the system with the water-cooled PAFCs (44.7% and 1960 $/kW, respectively). Main reasons for this are lower efficient PAFC power plant due to lower operating temperature and pressure, the waste heat in the PAFC stack is indirectly integrated into the bottoming cycle, extra compressor used for cooling air pressure drop makeup, and additional initial operation cost for compressing cooling air.



ALL ROTARY MACHINERY ARE SHAFT CONNECTED

FIGURE 1. - KGN/AIR-COOLED PAFC SYSTEM DIAGRAM.

Acknowledgment

This study was supported by U.S. Department of Energy, Morgantown Energy Technology Center through the NASA Lewis Research Center Phosphoric Acid Fuel Cell Project Office.

References

1. W. H. Johnson, T. G. Schiller et al, " Electric Utility Acid Fuel Cell Stack Technology Advancement, Final Report," DOE/NASA/01910-1, NASA CR-1748094, Nov. 1984.

2. C.Y. Lu, "Preliminary Design of Coal Gasification/Phosphoric Acid Fuel Cell Power Plants on an Electronic Spreadsheet", 1986 Fuel Cell Seminar Abstracts.

NASA
National Aeronautics and Space Administration

Report Documentation Page

1. Report No. NASA CR-182189 DOE/NASA/0017-7	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle Assessment and Comparison of 100-MW Coal Gasification Phosphoric Acid Fuel Cell Power Plants		5. Report Date August 1988
		6. Performing Organization Code
7. Author(s) Cheng-Yi Lu		8. Performing Organization Report No. E-4320
		10. Work Unit No. 778-17-01
9. Performing Organization Name and Address Cleveland State University Department of Chemical Engineering Cleveland, Ohio 44115		11. Contract or Grant No. NCC 3-17
		13. Type of Report and Period Covered Contractor Report Final
12. Sponsoring Agency Name and Address U.S. Department of Energy Office of Coal Utilization and Extraction Washington, D.C. 20545		14. Sponsoring Agency Code

15. Supplementary Notes

Prepared under Interagency Agreement DE-AI21-80ET17088. Project Manager, Robert Wagner, Power Systems Integration Office, NASA Lewis Research Center, Cleveland, Ohio 44135. Prepared for the 1988 Fuel Cell Seminar, sponsored by the National Fuel Cell Coordinating Group, Long Beach, California, October 23-26, 1988.

16. Abstract

One of the advantages of fuel cell (FC) power plant is fuel versatility. With changes only in the fuel processor, the power plant will be able to accept a variety of fuels. This study was performed to design process diagrams, evaluate performance, and to estimate cost of 100 MW coal gasifier (CG)/phosphoric acid fuel cell (PAFC) power plant systems that would use coal, which is the largest single potential source of alternate hydrocarbon liquids and gases in the United States, as the fuel. Results of this study will identify the most promising integrated CG/PAFC design and its near-optimal operating conditions. The comparison is based on the performance and cost of electricity (COE) which is calculated under consistent financial assumptions.

17. Key Words (Suggested by Author(s)) Coal gasifier; Phosphoric acid fuel cell; Power plant; Cost of electricity; Total plant investment	18. Distribution Statement Unclassified – Unlimited Subject Category 44 DOE Category UC-97D

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No of pages	22. Price*
Unclassified	Unclassified	7	A02

NASA FORM 1626 OCT 86

*For sale by the National Technical Information Service, Springfield, Virginia 22161