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Performance Improvement of Integrated Coal Gasification Combined Cycle by a New Approach in Exergy Analysis

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Abstract−A new approach to exergy analysis is proposed for examing the consumption of energy as the minimum driving force and of exergy consumption that is avoidable, and for the development of a method to predict the alternatives in system improvement by exploring possible reduction in the avoidable exergy consumption. Also suggested in this study is a dimensionless parameter γ_{AVO}, which is the ratio of avoidable exergy consumption over total fuel energy input to the system. Detailed analyses, including the calculation of exergy consumption, exergy loss and avoidable exergy consumption, were conducted for each component in the syngas cooling system in the Integrated coal Gasification Combined Cycle (IGCC) plant, to prove the effective application of the proposed method. The analysis showed that the rank of avoidable exergy consumption was different from that of total energy consumption, and hence it confirmed that an energy analysis by conventional methods misled the focus of improvement in system design. The methodology developed in this study offers a new approach for system designers to analyze and to improve the performance of a complex energy system such as an IGCC plant.

Key words : Energy, Exergy, Aspen Plus, Avoidable Exergy Consumption, Integrated Coal Gasification Combined Cycle

INTRODUCTION

In the past, exergy analyses have focused primarily on distinguishing the causes of exergy loss, estimating energy loss based on the first law of thermodynamics, comparing the magnitudes of such losses, or on calculating exergy consumption in each piece of equipment or equipment group in the system, i.e., loss allocation, etc. [Woudstra et al., 1995; Lobachyov et al., 1995; Lozza et al., 1996; Tawfik et al., 1993; Tsatsaronis et al., 1992]. However, it was not possible to clarify whether exergy consumption was inherent or avoidable under techno-economic constraints, and it was difficult to decide whether any further efforts should be made for improvement simply because the magnitude in loss was significant. In the energy system, exergy consumption occurs as an essential driving force for the operation of each process. Therefore, it is important to identify the minimum exergy consumption as an inherent process driving force with actual technical and economic conditions taken into consideration and the avoidable exergy consumption which may serve as a basis for establishing the priority in equipment groups which need improvements in the design.

The objective of the present study was to develop new methods for eliminating the conventional limitations in exergy analysis, to suggest a series of methods to separate the total exergy consumption into the minimum exergy consumption as a process driving force for the unit and the avoidable exergy consumption, and to analyze the feasibility in the performance improvement options in unit processes and in the entire system.

Also, a dimensionless parameter, γ_{AVO} of avoidable exergy consumption, which could be used as an index indicating the feasibility for the improvement of the system efficiency, was proposed; and a method for energy calculation in Aspen Plus was developed as an auxiliary tool for effectively fulfilling the analyses. The methods proposed have been successfully applied to the IGCC system.

AVOIDABLE EXERGY CONSUMPTION

1. Avoidable Exergy Consumption, E_{AVO}

The E_{AVO} may be estimated by [Feng et al., 1996]

$$E_{AVO}=E_{CON}-E_{MIN} \tag{1}$$

E_{CON} is the total exergy consumption, and the practical minimum exergy consumption E_{MIN} is the minimum exergy loss that is unavoidable, technically and economically as well. If the total energy consumption in a process is less than the minimum energy loss, the operation of the process is technically not possible or economically unreasonable. The value of minimum exergy loss depends on the technical progress and economical environment. When the minimum exergy consumption is determined, the avoidable exergy consumption can be found immediately. Hence, the minimum exergy consumption of the major equipment or the process should be estimated. For some equipment or processes the minimum exergy consumption, E_{MIN}, can be estimated as follows if the technical level of this equipment is known:

(a) Evaporator (gas cooler and Heat Recovery Steam Generator, HRSG)

$$E_{MIN}=QT_0\,(1/T_{max,\,stm}-1/T_{max}) \tag{2}$$

where Q is the amount of heat transfer, $T_{max,\,stm}$ is the maximum mean temperature of the cooling medium, and T_{max} is the maximum mean temperature of the gas.

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(b) Heat exchanger [Szargut et al., 1988]

$$E_{MIN}=QT_0\,(T_{HM}-T_{CM})/(T_{HM}T_{CM})+RT(n_H \ln[P_H/(P_H-\Delta P_H)] + n_C \ln[P_C/(P_C-\Delta P_C)]) \quad (3)$$

where Q is the heat load of a heat exchanger, T_{HM} and T_{CM} are the mean temperatures of high and low temperature flows, n is the flow rate, P and ΔP are the pressure and the pressure drop, respectively. The subscripts H and C refer to high and low, respectively.

(c) Gas turbine and steam turbine

$$E_{MIN}=T_0\,\Delta S_{min} \quad (4)$$

where ΔS_{min} is the entropy produced and calculated at the maximum turbine efficiency.

(d) compressor

$$E_{MIN}=T_0\,\Delta S_{MIN} \quad (5)$$

where ΔS_{MIN} is the minimum entropy produced and corresponds to the maximum compressor isentropic efficiency under realistic conditions.

2. Avoidable Exergy Consumption Dimensionless Ratio, γ_{AVO}

In this study, an avoidable exergy consumption dimensionless ratio γ_{AVO} is proposed and then applied along with the existing exergy consumption dimensionless ratio γ.

$$\gamma_{AVO}=(E_{AVO}/E_{fuel})\times 100 \quad (6)$$

$$\gamma=(E_{CON}/E_{fuel})\times 100 \quad (7)$$

where E_{AVO}, E_{fuel} and E_{CON} are avoidable exergy consumption, the total supplied fuel exergy in the system and the total exergy consumption, respectively. The term γ_{AVO} is a dimensionless ratio that compares fuel exergy in the system with the total exergy loss less the minimum exergy loss which is unavoidable because of the inherent and realistic restrictions, a ratio of the avoidable exergy loss to the total fuel exergy in the system. This is a very useful concept for the performance improvement of the energy system since it enables one to find real and exact avoidable sites in the system under realistic conditions taken into consideration. For the energy system for power production, the calculated γ_{AVO} value enables one to find out immediately the absolute value of the composite plant efficiency for potential improvement, a potential improvement of the efficiency of the system from 40% to 42% with a γ_{AVO} value of 2%.

ASPEN PLUS EXERGY ANALYSIS METHOD (APEAM)

Many researchers have calculated exergy in Aspen Plus [Rosen, 1986; Rosen, 1885; De Ruyck et al., 1997]. In this study, a method for the calculation of exergy, APEAM was developed in a new version of Aspen Plus. In APEAM, the enthalpy and the entropy of each stream and the reference environment are calculated by using the Aspen Plus property-set. The chemical potentials of the reference environment as well as that of the dead state are also calculated. The chemical exergy of the mixed flow is calculated by In-

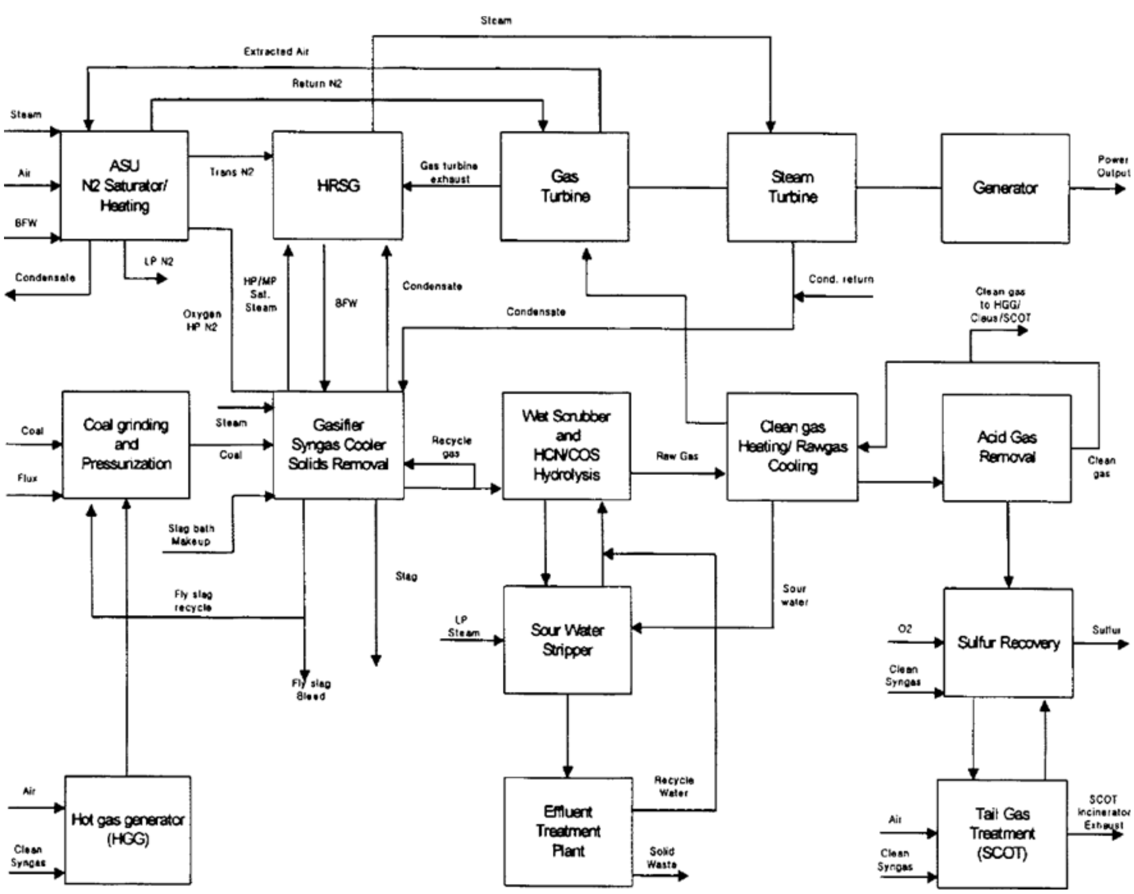

Fig. 1. Simplified IGCC process flow diagram [Bechtel, 1995].

Line Fortran. This method is constructed in such a way that its modification can be rather simply made by the user as the environmental model is changed. The exergy associated with the transfer of heat and work and physical, chemical and total exergy values are calculated for each stream of materials flow.

ANALYSIS OF IGCC SYSTEM

1. The IGCC System

A process flow diagram of the IGCC system considered is shown in Fig. 1. The coal gasification system is composed of syngas quencher, syngas cooling system, HCN/COS hydrolysis process, low temperature syngas cooling process, and acid gas removal (ASU) is of medium-pressure type. About 20% of the air is extracted from the compressor of a gas turbine, while the remaining is handled by a separate auxiliary air compressor. The oxygen and a portion of nitrogen product in the air separation process are supplied to the gasifier. The remaining nitrogen is moisturized in a saturator by using feed water taken in from a steam turbine. The combined cycle is composed of GE MS7001FA gas turbine, steam turbine, heat recovery steam generator (HRSG), condenser etc. [Bechtel, 1995].

2. ASPEN PLUS Modeling

Using Aspen Plus, unit process models were developed and tested, and then a system model was constructed [Kim et al., 1996]. The model for the gasification process was divided into gasifier, syngas quenching, gas cooling, dust removal, and slag removal parts. The temperature was adjusted by using recirculated cooling gas while the syngas leaving the gasifier at about 1,450 °C was quenched. The gas was cooled to about 250 °C in a gas cooler composed of heater, splitter, and heat exchanger models, and evaporated steam was supplied to the gasifier and HRSG. The conversion of COS into H_2S in the HCN/COS hydrolysis process was about 95%, while a separator model was used for acid gas separation. In the gas turbine model, the amount of cooling air and the effect of cooling air on turbine efficiency were calculated [Johnson, 1989; Stone, 1985]. A stoichiometric reactor model (RSTOIC) was used for a burner. The expander was composed of power production and cooling air mixing parts. In the HRSG model a temperature of 8.3 °C at low pressure was applied as a pinch temperature for each evaporator and the approach temperatures were 11.3 °C at medium pressure and 8.3 °C at low pressure, respectively. The air separation process model is constructed to enable the control of oxygen flux, the amount of air extracted from the gas turbine air compressor, and the flux of external air input. The power consumed was calculated by using a compressor model. In a complex system such as an IGCC plant, the performance of the plant may differ greatly according to the configuration of each unit process. In this study, models were constructed to have steam integration and air integration separately, and a proper value was calculated by using the design specification and In-Line Fortran of Aspen Plus [Kim et al., 1996].

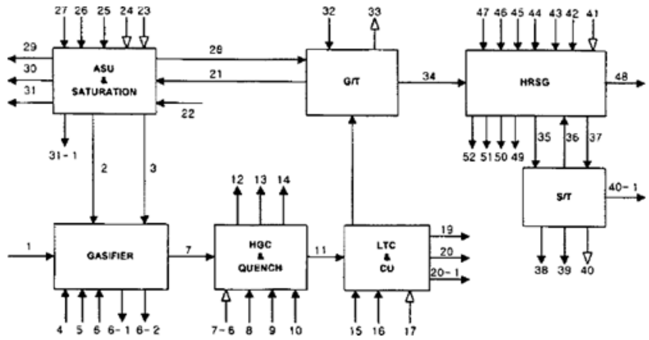

Fig. 2. Shell gasification-GE IGCC system for APEAM calculations.

3. Exergy Analysis of IGCC System

The exergy calculation was performed according to the APEAM using the data appearing in a previous study [Kim et al., 1997]. Shown in Fig. 2 is the process flow diagram of the IGCC system and the results of the calculation are given in Table 1 and Fig. 3.

In the gas turbine, 23.677% (158.208 MW) of the total fuel exergy supplied was consumed. The loss was primarily due to reactions in a combustor, the friction losses in compressor and expander, the heat loss in burner, and mixed loss at the time of cooling of turbine, etc. The loss in the gas turbine was the minimum exergy consumption, E_{MIN}, indicating that there was no room for improvement under the present technical and economic conditions. Among the total fuel exergy supplied, the loss in the gasification system was 9.835% (65.839 MW). The loss due to the irreversibility of coal gasification, and the loss of unburned carbon contained in slag was 4.595 MW. Such exergy consumption may be improved partially by preheating of coal and oxidant supplied to the gasifier, minimum use of oxidant, higher pressure water supply at water walls, etc. The exergy consumption of the low temperature cooling and cleaning system was 5.514% (36.842 MW) and the loss of sulfur discharged was about 4 MW. The heat exchange network of low

Table 1. Exergy in/out, consumption, loss, efficiency and dimensionless number (exergies in MW)

	E_{IN}	E_{OUT}	E_{CON}	E_{LOSS}	ε (%)	γ (%)
Gas turbine	538.062	379.854	158.208		70.597	23.677
Gasification	685.825	615.391	65.839	4.595	89.730	9.853
LTC & Cleanup	559.388	518.546	36.842	4.000	92.699	5.514
HRSG	466.783	420.233	27.140	19.410	90.027	4.062
HGC & Quenching	674.611	645.211	29.383		95.642	4.397
Steam turbine	327.915	303.885	19.660	4.370	92.672	2.942
ASU & Saturation	144.155	127.502	15.003	1.650	88.448	2.245
Total system	668.200*	282.100	352.075	34.025	42.218	52.690

*E_{fuel}

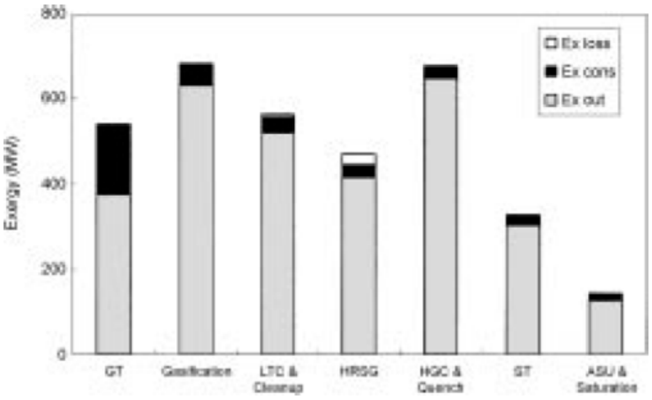

Fig. 3. Exergy distribution of subsystems.

temperature cleaning process can be optimized by a proper pinch temperature, and a method of using low-pressure or medium pressure water supply for cleaned gas heating instead of high-pressure is to be enforced. In HRSG, 4.062% (27.140 MW) of the total supply fuel exergy was consumed; mostly the loss was due to heat transfer and pressure drop. The exhaust gas loss to stack was about 19.41 MW. In order to reduce such loss, it is necessary to design an economizer of low approach temperature. By optimum integration of HRSG and the process, it is possible to minimize the loss by properly calculating the heat necessary for the process, deriving the portions that can be supplied by HRSG, and selecting and integrating the flow, which has the smallest specific exergy. Of the total fuel exergy supplied, the high-temperature gas cooling produces an exergy loss in the high temperature gas cooling of 4.397% (29.383 MW). The mixing loss in the quenching process was found to be 7.441 MW.

ANALYSIS OF AVOIDABLE EXERGY CONSUMPTION

For the analysis for avoidable exergy consumption, the syngas cooling system was selected and the minimum exergy consumption E_{MIN} for process driving, the avoidable exergy consumption, E_{AVO}, and the dimensionless ratio, γ_{AVO}, were calculated as shown in Table 3. Fig. 4 shows a diagram of the syngas cooling system and the stream number. The physical and chemical exergy values of each stream are presented in Table 2.

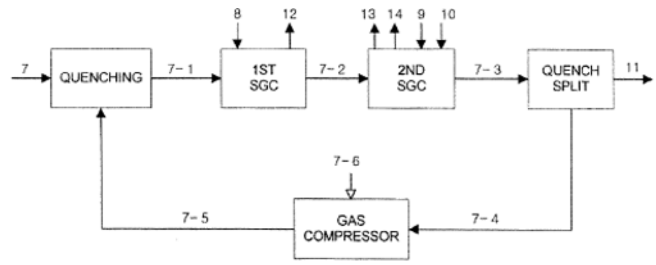

Fig. 4. Flow diagram of the gas cooling system for APEAM.

(a) Quencher

A quencher was used for quenching down the syngas to about 900 °C for the purpose of preventing flying slag included in hot corrosive gas (1,450 °C) produced in a gasifier attached to a syngas cooler. The calculated total exergy consumption was 7.441 MW. It was expected that the loss could be reduced if a temperature could be found of which the material of the syngas cooler was tolerant and the entire molten slag in the gas was solidified. The maximum temperature of the convection heat exchanger taken was 1,100 °C [Lummus, 1993]. By the selection of a material that could withstand this temperature, the loss could be lowered significantly since the amount of loss for the syngas quenched at low temperature was reduced and the reduced portion of loss was E_{AVO}. Since the exergy consumption at a quenching temperature of 1,100 °C was the minimum exergy consumption, E_{MIN}, the avoidable exergy, E_{AVO} could be estimated.

The amount of the minimum energy consumption was calculated by APEAM, and was found to be 4.265 MW.

(b) First syngas cooler (SGC)

High-pressure steam was produced as the gas was cooled down from 900 °C to 300 °C in a first syngas cooler. In order to improve the thermodynamic efficiency of the equipment, the temperature of the steam was kept as high as possible. Reducing the temperature

Table 2. Exergies in each stream of gas cooling system (exergies in MW)

Stream number	E_{PH}	E_{CH}	E_{TOT}	Stream
7	91.230	518.733	609.961	Raw gas from the gasifier
7-1	105.222	988.242	1093.460	Raw gas to 1st syngas cooler
7-2	52.970	988.242	1041.210	Raw gas to 2nd syngas cooler
7-3	44.652	988.242	1032.890	Raw gas to splitter
7-4	21.214	469.530	490.744	Raw gas to gas compressor
7-5	21.411	469.530	490.940	Raw gas to quencher
7-6	0.234	0.000	0.234	Power input to gas compressor
11	23.574	518.713	542.150	Raw gas to down process
8	23.859	0.000	23.589	Feedwater to 1st syngas cooler
9	4.485	0.000	4.485	Feedwater to 2nd syngas cooler
10	0.000	0.000	0.000	Feedwater to 2nd syngas cooler
12	57.757	0.000	57.757	Steam production from syngas cooler
13	0.000	0.000	0.000	Hot water from 2nd syngas cooler
14	9.227	0.000	9.227	Hot water from 2nd syngas cooler

Table 3. Analysis results of the gas cooling system (exergies in MW)

	E_{IN}	E_{OUT}	E_{CON}	E_{MIN}	E_{AVO}	γ (%)	γ_{AVO} (%)
Quenching	1100.901	1093.460	7.441	4.265	3.176	1.114	0.475
1^{ST} SGC	1143.430	1125.104	18.326	16.001	2.325	2.743	0.348
2^{ND} SGC	1056.344	1052.766	3.578	0.567	3.011	0.535	0.451
Compressor	490.978	490.940	0.038	0.011	0.027	0.006	0.004
Split	1033.654	1033.654	0.000	0.000	0.000	0.000	0.000
Sub Total	-	-	29.383	20.844	8.539	4.397	1.278

difference between the two fluids enables lowering of exergy consumption due to lowering the driving force. E_{MIN} in the first syngas cooler was calculated by employing Eq. (2), and a value of 16.001 MW was obtained. The $T_{max, stm}$ of the present study was 328 °C, which was the temperature of saturated steam at 127 kg/cm^2, the maximum main steam pressure in a combined cycle, which was adopted in a gas cooler.

(c) Second syngas cooler

The second syngas cooler is a heat exchanger which heats feed water while cooling the gas from 360 °C to 235 °C. The pinch temperature of the second syngas cooler of this study was about 18 °C. As in the recent trend of designing heat exchangers, as close to 13 °C in pinch temperature as possible, the minimum pinch temperature in this study was 13 °C for the calculation of E_{MIN}. E_{MIN} obtained from Eq. (3) with the properties of Aspen Plus was 0.567 MW.

(d) Recirculation gas compressor for quenching

The pressure of a recirculated quenching gas was raised by a gas compressor at the exit of the separator. At 0.516 kg/cm^2 the isentropic efficiency of a compressor used in the present process was 72%. E_{MIN} of a compressor was calculated according to Eq. (5). For the compressor of 90% efficiency corresponding to the minimum entropy production, E_{MIN} estimated was 0.011 MW.

These results are shown in Table 3 and Fig. 5. As shown in Table 3, the exergy consumption of the syngas cooling system is 29.383 MW, of which the inherent loss, estimated by taking into consideration practical technical and economic conditions at present, i.e., the minimum loss for the process driving, E_{MIN} of the system, was 20.844 MW. Hence, E_{AVO} was 8.539 MW, and γ_{AVO}, which indicates the maximum possibility for the improvement of the efficiency of the entire IGCC system due to the contribution in the syngas cooling system was 1.278%

PERFORMANCE IMPROVEMENT

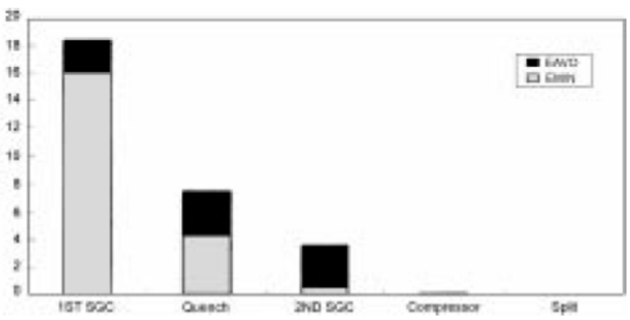

Fig. 5. Comparison of minimum and avoidable losses in the gas cooling system.

Analysis has been performed in the possible reduction of avoidable exergy consumption for performance improvement. The alternatives or variables in the examination for performance improvement of the syngas cooling system include: 1) increasing the quenching temperature from 900 °C to 1,100 °C; 2) lowering the pinch temperature of the second syngas cooler from 18 °C to 13 °C; 3) raising the efficiency of a gas compressor from 72% to 90%; and 4) increasing the main stream pressure from 103 kg/cm^2 to 127 kg/cm^2. Models with the four alternatives above were developed and simulations were performed. And the exergy consumption E_{CON}, avoidable exergy E_{AVO} and its deviation from the base case, ΔE_{AVO} and also the dimensionless ratio and its deviation from the base case $\Delta\gamma_{AVO}$ were calculated and discussed.

1. The Increase in the Quenching Temperature

The results of calculations for the increase of the quenching temperature from 900 °C to 1,100 °C are shown in Table 4. The avoidable exergy consumption of 3.176 MW was improved by reducing the flow rate of quench gas, and the improved value of the avoidable dimensionless ratio $\Delta\gamma_{AVO}$ was 0.475%. Increase in the quenching temperature brought an additional exergy consumption of 2.706 MW in the first syngas cooler. However as the exergy value of the steam produced was increased along with the increase in loss, a portion of this exergy consumption was reduced in a steam cycle and steam turbine. Exergy consumption of 1.43 MW was reduced by lowering of gas flux in the second syngas cooler, and in the compressor, the loss was reduced by about 0.018 MW due to lowering of gas flow for quenching. From all these values, it was shown that the amount of avoidable exergy was lowered by 1.908 MW due to an increase in the quenching temperature in the entire syngas cooling system.

The effects of the increase in the quenching temperature to 1,100 °C to the entire system compared to the base case are shown in Table 5. Change in the quenching temperature increased the exergy efficiency by 0.449% and power output by 3 MW. It was also shown

Table 4. Analysis results of the gas cooling system (the effect of quench temperature increase) (exergies in MW)

	E_{CON}	E_{MIN}	E_{AVO}	γ_{AVO} (%)	ΔE_{AVO}	$\Delta\gamma_{AVO}$
Quenching	4.265	4.265	0.000	0.000	3.176	0.475
1^{ST} SGC	21.032	16.001	5.031	0.762	−2.706	−0.405
2^{ND} SGC	2.148	0.567	1.581	0.239	1.430	0.214
Compressor	0.020	0.011	0.0189	0.003	0.008	0.001
Split	0.000	0.000	0.000	0.000	0.000	0.000
Sub Total	27.465	20.844	6.631	1.004	1.908	0.285

Table 5. The effect of quench temperature increase to total system (exergies in MW)

	Base case	Results	Differences
E_{fuel}	668.200	668.200	0.000
E_{power}	282.100	285.100	3.000
E_{CON}	352.075	349.075	−3.000
γ	52.690	52.241	−0.449 ($\Delta\gamma_{AVO}$)
ε	42.218	42.667	0.449

Table 6. Analysis results of the gas cooling system (the effects of lower pinch temperature) (exergies in MW)

	E_{CON}	E_{MIN}	E_{AVO}	γ_{AVO} (%)	ΔE_{AVO}	$\Delta\gamma_{AVO}$ (%)
Quenching	7.506	4.265	3.241	0.485	−0.065	−0.010
1ST SGC	17.637	16.001	1.636	0.245	0.689	0.103
2ND SGC	3.355	0.567	2.788	0.417	0.223	0.033
Compressor	0.034	0.011	0.023	0.003	0.004	0.001
Split	0.000	0.000	0.000	0.000	0.000	0.000
Sub Total	28.532	20.844	7.688	1.150	0.847	0.126

that the output increase was identical with the reduction in exergy consumption, and the efficiency was increased by an equal amount in the deviation of dimensionless ratio $\Delta\gamma_{AVO}$.

2. Reduction of the Minimum Approach Temperature Difference in the Second Syngas Cooler

The calculated results of lowering the pinch temperature of second syngas cooler from the base case of 18 °C to 13 °C for the syngas cooling system are shown in Table 6. Since the temperature of the gas discharged from second syngas cooler was lower by 5 °C compared to the base case, the temperature of the gas for quenching was lower than that of the base case as well.

Therefore, the temperature difference between two fluids to be mixed at the quencher was larger by about 5 °C, and the exergy consumption was increased by 0.065 MW.

In the first syngas cooler, the amount of exergy consumption was reduced by about 1.6 MW compared to the base case due to lowering of syngas flux. In the meantime, in the second syngas cooler and the compressor, exergy consumption was reduced to 0.223 MW and 0.004 MW, respectively. It is shown that the amount of exergy consumption that is reduced due to lowering of the minimum approach temperature difference of the second syngas cooler is 0.847 MW. As a result of these improvements, the power output was increased by 1.501 MW, while the efficiency was increased by 0.157% as shown in Table 7.

Table 7. The effect of decrease in the minimum temperature difference in second gas cooler to total system (exergies in MW)

	Base case	Results	Differences
E_{fuel}	668.200	668.200	0.000
E_{power}	282.100	283.151	1.051
E_{CON}	352.075	351.024	−1.051
γ (%)	52.690	52.533	−0.157($\Delta\gamma_{AVO}$)
ε (%)	42.218	42.375	0.157

Table 8. Analysis results of the gas cooling system (the effects of increase in gas compressor efficiency) (exergies in MW)

	E_{CON}	E_{MIN}	E_{AVO}	γ_{AVO} (%)	ΔE_{AVO}	$\Delta\gamma_{AVO}$ (%)
Quenching	7.446	4.265	3.181	0.476	−0.005	−0.001
1ST SGC	18.216	16.001	2.215	0.331	0.110	0.016
2ND SGC	3.568	0.567	3.001	0.449	0.010	0.002
Compressor	0.013	0.011	0.002	0.000	0.0267	0.004
Split	0.000	0.000	0.000	0.000	0.000	0.000
Sub Total	29.263	20.844	8.399	1.256	0.142	0.021

Table 9. Analysis results for gas cooling system (the effect of increase in main stream pressure) (exergies in MW)

	E_{CON}	E_{MIN}	E_{AVO}	γ_{AVO} (%)	ΔE_{AVO}	$\Delta\gamma_{AVO}$ (%)
Quenching	7.441	4.265	3.176	0.475	0.000	0.000
1ST SGC	17.263	16.001	1.262	0.189	1.063	0.159
2ND SGC	3.578	0.567	3.011	0.451	0.000	0.000
Compressor	0.038	0.011	0.027	0.004	0.000	0.000
Split	0.000	0.000	0.000	0.000	0.000	0.000
Sub Total	28.320	20.844	7.476	1.119	1.063	0.159

3. Increase in Efficiency of a Gas Compressor for Quenching

The calculation results for the effect of increasing the efficiency of a gas compressor for quenching from 72% to 90% on the syngas cooling system are shown in Table 8. The effect of this variable on the IGCC system is found to be insignificant, and therefore, excluded from the analysis.

4. Increase in the Main Steam Pressure

The first syngas cooler is a two-phase heat exchanger; it is operated at a saturated temperature and the main point of improving performance of exergy is in the increase of the saturated temperature according to the increase in the main steam pressure. The main steam pressure of the base case is 103 kg/cm^2, and 127 kg/cm^2, which is a realistically applicable pressure to the IGCC system, is selected in this analysis. The result of calculation is shown in Table 9. It is found that there are no effects of the increase in the main steam pressure on the quencher, second syngas cooler, and compressor. Only exergy consumption in the first syngas cooler is reduced due to lowering of the minimum approach temperature difference between fluids since there is a temperature increase of about 10 °C due to increase in the steam pressure in the first syngas cooler. How the increase in the steam pressure affects the IGCC system is shown in Table 10.

CONCLUSIONS

Table 10. The effects of the main steam pressure increase to total system (exergies in MW)

	Base case	Results	Differences
E_{fuel}	668.200	668.200	0.000
E_{power}	282.100	284.114	2.014
E_{CON}	352.075	350.061	−2.014
γ (%)	52.690	52.389	−0.301 ($\Delta\gamma_{AVO}$)
ε (%)	42.218	42.519	0.301

Through an exergy analysis typically performed for a syngas cooling system, the exergy consumption for driving a process and the avoidable exergy consumption in the total exergy consumption were found to be 20.8 MW and 8.5 MW, respectively. The avoidable energy consumption dimensionless ratio γ_{AVO} of the system performance was 1.28%; hence, the potential for improving the efficiency of the IGCC plant due to the improvement of the syngas cooling system was also 1.28%. The analysis also showed that the avoidable exergy consumption was 3.18 MW in the quencher, indicating the greatest potential for performance improvement of this equipment. The exergy analysis method used previously, however, misdirected efforts for improvement since the total exergy consumption was highest (18.33 MW) in the first syngas cooler. When the designer realizes that the other equipment (quencher) has the highest potential, the system should repeatedly be modified for improvement in system performance after the entire system is redesigned because of this misled guidance. The method of avoidable exergy consumption analysis suggested in this study could successfully be employed to prevent or to reduce the efforts caused by trial and error steps in the system design.

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