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Advanced integrated gasification combined cycle (A-IGCC) by exergy recuperation—technical challenges for future generations

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Abstract

With limited coal resources worldwide, a new technology has been developed in the use of low grade coal to break through the current technical limitation in the IGCC system and achieve higher plant efficiency. This study attempts exergy-recuperation within the combined cycle on an HYSYS process simulation, the so-called Advanced IGCC (A-IGCC), in which the system is designed to increase cold gas efficiency and save the exergy of the fuel throughout the system by using gas turbine exhaust as an external heat source to encourage an autothermal reaction. Three types of syngas compositions were investigated, depending on the gasifier conditions with exergy recuperation. Plant efficiency was significantly higher in the presence of exergy recuperation in the system. This was attributed to efficient exergy saving in the system as opposed to a conventional IGCC, which has significant exergy loss in the combustion and gasification processes. Improved plant performance generated from a low temperature gasifier was obtained with the A-IGCC model, although the model requires further developments in technology, such as gasification at a lower gas temperature, a powerful heat exchanger, gas purification at high temperature, etc., for actual implementation.

Keywords: IGCC, Exergy, Sub-bituminous coal

1. Introduction

Coal gasification is a technology that can achieve high thermal efficiency with low carbon emissions by producing hydrogen (H_2) dominant fuel gas. In light of the intense interest in global warming, the coal industry has experienced pressure to find technologies to lower carbon dioxide (CO_2) emissions whilst improving energy efficiency. One solution is to increase the overall thermal efficiency to compensate for the loss in heat value through gas cleaning processes.

Coal presently accounts for 27.0% of the world's total primary energy fuel supply, second only to oil (33.2%), and provides 41% of the world's electricity generation [1]. Whereas the current demand for coal is expected to continue at roughly the same level over the next two decades, coal contributes the largest share of CO2 emissions from fuel burning (42.9%) [1]. Lignite and sub-bituminous coal make up about $\frac{1}{2}$ of all coal reserves, but their use is restricted under currently available technologies. It is therefore important to develop a technology that can utilize these low grade coals as a future energy source to com-

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pensate for the decreasing supply of good-quality bituminous coal. The Japan Coal Energy Center (JCOAL) has been working on a coal gasification project sponsored by the New Energy and Industrial Technology Development Organization (NEDO) in Japan since 2007, with the aim being to develop a method of efficient electric power generation that can utilize wet and uncrushable coals [2].

This study investigates the effect of exergy recuperation on an integrated coal gasification combined cycle (IGCC). The importance of thermodynamic evaluation of thermal power plants has been shown as an effective approach to optimize plant performance [3–5]. The A-IGCC (Advanced IGCC) proposed in this study is IGCC with exergy recuperation, in which the heat required for the endothermic reaction in the coal gasifier is supplied from gas turbine exhaust [6]. This promotes autothermal gasification supported by additional steam with reduced exergy loss instead of gasification by partial oxidation alone. Thermal energy in the exhaust is converted to chemical energy.

In the current entrained flow coal gasification system, the coal is gasified in the high temperature field formed by partial combustion and the coal ash is fused and drained. It is difficult to increase system efficiency in this case because the effective chemical energy of coal decreases and heat recovery from melting ash is not easy. The gasifier used in this study is a triple-bed combined circulating fluidized bed, which is described in detail elsewhere [7, 8]. It would facilitate the gasification of coal at relatively low temperatures at which heat recuperation from the gas turbine exhaust could be realized.

Accordingly, this study investigates the gasification of coal at low temperatures (700–900°C), and the heat required for the gasification is supplied from the exhaust heat of a high temperature gas turbine (1,700°C class); hence steam is used as a gasifying agent instead of oxygen. The A-IGCC system seeks to achieve higher net thermal efficiency than the basic IGCC through the recuperation of heat and reduction of oxygen production energy.

IGCC and the Integrated gasification fuel cell cycle (IGFC) are expected to be commercially available by 2020, but having need of more efficient electric power production in the future, new technology should be developed to improve the system efficiency of coal based power plants including IGFC. Milestones of thermal efficiency for A-IGCC and A-IGFC where A-IGCC and Advanced IGFC (A-IGFC) will achieve 57% and 65%, respectively, by 2030 are shown in Fig. 1. In order to achieve these goals, all the resources from coal would have to be converted to H_2, i.e. clean energy, to produce power [6].

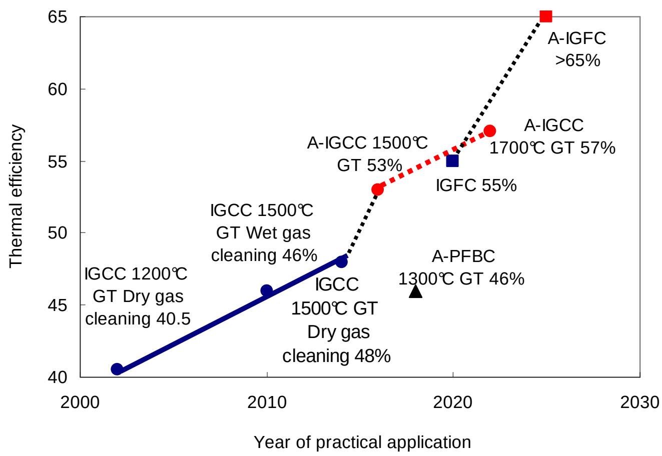

Figure 1: Performance projection of future coal based power plants [6]

The purpose of this study is to improve the thermal efficiency of the coal-fired combined power generation system, with consideration given to the use of sub-bituminous coals. The study attempts to encourage steam reforming to the extent possible and to minimize partial oxidization in the gasifier by providing additional heat from gas turbine exhaust. Identification of the technological development required is necessary to assess the feasibility of the A-IGCC system in the future.

2. Theory

2.1. Recuperation of Energy

The concept of "exergy" provides a useful way to find the source of a reduction in thermal efficiency. In another words, it allows us to harness the potential of heat recuperation in order to increase thermal efficiency. Exergy, E, is an available or useful energy and may be thought of as a measure of the quality of energy, which is given by:

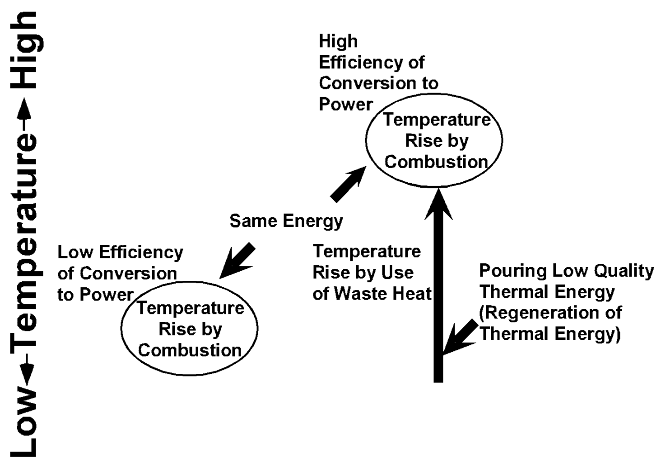

Figure 2: Effective energy conversion by recuperating exergy [10]

$$E = H - H_0 - T_0(S - S_0) \quad (1)$$

where: H–enthalpy, H_0–enthalpy at T_0 (25°C), S–entropy and S_0–entropy at T_0 (25°C) [9]. Exergy rate, ε, refers to the ratio between the exergy and the energy [9], given by:

$$\varepsilon = 1 - T_0 \frac{(S - S_0)}{(H - H_0)} \quad (2)$$

If the exergy rate of supplied energy is 100%, then this energy can potentially be converted to another form of energy without any loss. The exergy rate of thermal energy is lower than that of other forms of energy, such as chemical, electrical or kinetic energy, and it decreases with temperature. Therefore energy conversion from chemical energy to thermal energy results in losing exergy especially at low temperature. For example, heating fresh air with the waste heat of the exhaust gas means energy conversion from thermal energy to thermal energy in almost the same temperature range. Exergy loss in this case is smaller than the energy conversion from chemical energy to thermal energy at low temperature. Materials therefore should be preheated by the waste heat with low exergy rate. If the energy is converted from chemical energy to thermal energy after heat regeneration, high thermal efficiency can be obtained (Fig. 2) [10]. Subsequently, heat regeneration using waste heat (exhaust gas) efficiently converts chemical energy to kinetic energy. Heating at a lower temperature by combustion consequently decreases exergy, whereas heating by waste heat instead of the fuel increases thermal efficiency by keeping more exergy.

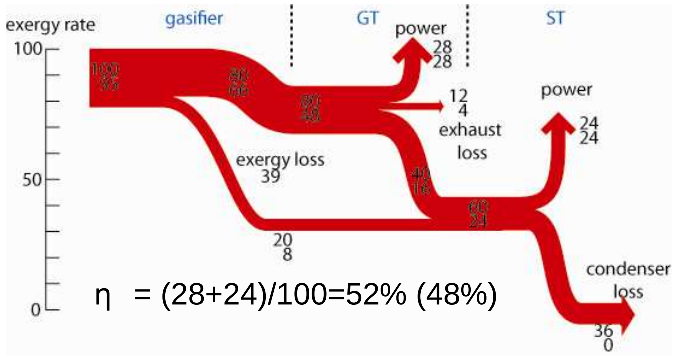

Figure 3: Theoretical energy/exergy flow of a conventional cascading IGCC system [6]. The net efficiency in brackets takes oxygen generation power into consideration.

Chemical exergy recuperation is a more profitable option. For example, endothermic reactions such as steam reforming requires heat that can be supplied from the exhaust gas if the temperature of the supply is higher than the reaction temperature, thereby autothermal gasification by steam reforming can decrease exergy loss more than gasification by partial oxidation. A theoretical energy flow in percentage figures of a conventional cascading IGCC shows energy and exergy losses within the system (Fig. 3) [6]. The thickness of the energy band corresponds to its enthalpy, and the position corresponds to the quality of the energy, i.e. exergy rate. The figures underneath the energy values denote the exergy of the corresponding process streams which can be calculated as the sum of physical exergy and chemical exergy [6, 11]. The physical exergy is the available work content of the stream relative to the restricted state in thermodynamic equilibrium as a reference condition. The chemical exergy is the available work content obtainable as the system passes from the reference state to the state where it is in complete chemical equilibrium with the environment [11]. The chemical exergy can be calculated by the exergy of the individual components and their molar fractions [9, 12].

The cold gas efficiency is 80% where the remaining 20% is recovered as steam to be used in the downstream steam turbine. Low cold gas efficiency (80%) results in poor power generation with a 12% exhaust heat loss. The system also requires 4%

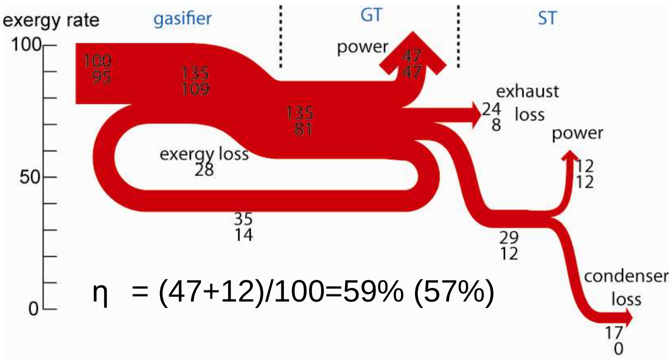

Figure 4: Theoretical energy/exergy flow of the Advanced IGCC system with exergy recuperation [6]. The net efficiency in brackets takes oxygen generation power into consideration.

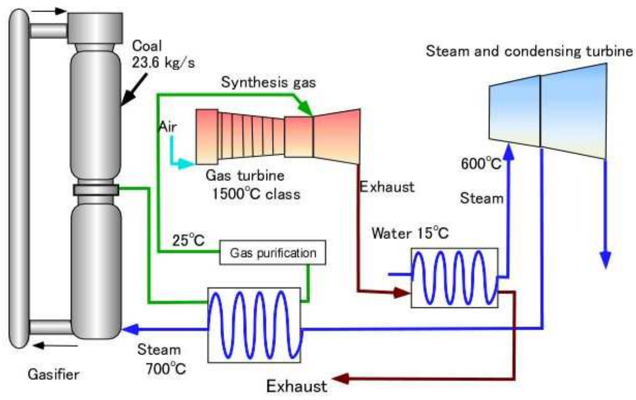

Figure 5: IGCC system model

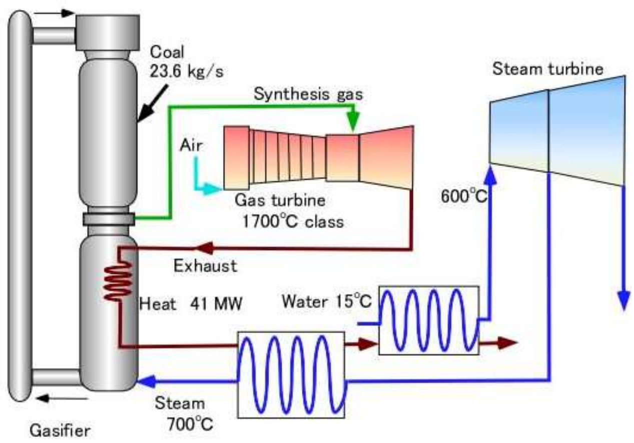

Figure 6: A-IGCC system model

power to generate oxygen, alongside which net efficiency drops to 48%. In contrast (Fig. 4), exergy recuperation in A-IGCC system allows high cold gas efficiency (135%) and exergy rate which enables the gas turbine to generate greater electric power. The power required to generate oxygen can be lowered because the main reaction in the gasifier is steam reforming. Although the steam turbine output is halved (12%) and, compared to IGCC, the net efficiency is higher (57%) including the power to generate oxygen (2%). The A-IGCC energy flow diagram shows better energy conversion without energy loss at heat transfer. In this case the gas turbine exhaust gas supplies endothermic heat from steam reforming, i.e. energy and exergy transferred to hydrogen via an endothermic reaction. This process is equivalent to recuperating exergy from thermal energy to chemical energy.

2.2. IGCC models

Table 1 shows a comparison between the conventional IGCC and A-IGCC for integration, gasification, gasifier and thermal efficiency. Coal is first pyrolyzed and the chars obtained are steam reformed to produce H_2, CO and CO_2. The gasification method emphasized partial oxidization for IGCC and steam reforming for A-IGCC.

The gasifier used in IGCC was a conventional entrained flow, whereas a triple-bed circulating fluidized bed (TBCFB) gasifier was used for A-IGCC. The entrained flow bed coal gasifier operates at a furnace temperature of over 1,000°C. TBCFB is designed to accommodate the gasifying condition at lower temperatures (700–1,000°C), as discussed elsewhere [7, 8].

Sub-bituminous coal contains more volatile and inherent moisture rather than inherent carbons, the gasification of the coal requires a much longer time for pyrolysis and steam reforming than that of bituminous coal. In addition, it is essential to have a gasifier temperature of less than 1,000°C in order to supply the heat from the exhaust gas. In this study, the temperatures of the partial combustor and steam gasifier were 950°C and 800°C. Steam at 700°C is supplied to the gasifier, which encourages steam reforming via an endothermic reaction. The remaining hot solid particles, such as chars and sands separated from the syngas, are then returned to the pyrolysis of the gasifier as a heating medium.

The system flow diagrams of IGCC and A-IGCC are shown in Fig. 5 and Fig. 6 respectively. In IGCC,

Table 1: System comparison between conventional IGCC and A-IGCC

	Conventional IGCC	Conventional IGCC
Integration	Cascade utilization	Exergy recuperation
Gasification	Partial oxidation High temperature (1,100–1,500°C)	Steam reforming Low temperature (700–1,000°C)
Gasifier	Entrained flow bed	Triple bed CFB
Efficiency	46–48%	53–57%

the syngas from the gasifier is cooled to generate steam via a heat exchanger and fed to the gas purification unit. The gas turbine is 1,500°C class, which is commercially available at present. A heat recovery steam generator (HRSG) recovers the exhaust heat of the gas turbine to produce high pressure 600°C steam which is sent to the steam/condensing turbines. A-IGCC on the contrary assumes gas cleaning performed without cooling the gas, or a relatively high temperature to save the heat value of the gas. A 1,700°C class gas turbine was used to maximize the power output, supplying enough heat (41 MW) to the gasifier to encourage more steam gasification. The exhaust gas, after providing the heat to the gasifier, was further heat-exchanged to generate 700°C steam for the gasifier and 600°C steam for the steam turbine.

The adiabatic efficiencies of the turbines and the other operating conditions are summarized in Table 2, which was referred by a previous study [13]. The values are configured to achieve 43% (HHV) of the net efficiency of the 1,500°C class base IGCC within a feasible level of current power generation systems. A previous study had pointed out that the 1,500°C class gas turbine is not powerful enough to generate extra exhaust to heat supply (41 MW) to the gasifier [13]. Therefore a 1,700°C class gas turbine was applied to the A-IGCC system. The auxiliary consumption was assumed to be 5% (HHV). The other turbine operating conditions were the same for both models. The minimum temperature difference, ΔT_p, in a heat recovery steam generator (HRSG) where hot exhaust from the gas turbine was fed to generate steam was set at 30°C. The flow rate of the water in HRSG was limited to have the pinch point temperature higher than ΔT_p and also to keep the exhaust gas from HRSG dry.

The rate of supplied coal at 200°C was fixed at 23.63 kg/s, i.e. 667 MW (HHV). The required oxygen production power was presumed to be 0.36 kWh/Nm^3, i.e. 0.8064 MJ/kg$_{O_2}$ [13]. The coal-gasified syngas is composed of carbon monoxide (CO), CO_2, H_2, Methane (CH_4), Ethylene (C_2H_4), Ethane (C_2H_6), Propene (C_3H_6), Hydrogen cyanide (HCN), Nitrogen (N_2) and Water (H_2O) (Table 3). Two syngas compositions were investigated for A-IGCC. One case (indicated as A-IGCC in Table 3) assumed that there was only a fraction of CO_2 generated in the partial oxidation process, and the other case (indicated as A-IGCC' in Table 3) assumed that CO_2 was partially generated in the gasifier.

A process simulator, HYSYS®Plant (Aspen technology Inc.) was used to model the systems, except the gasification process whose results were adapted from previously reported studies [13]. Kabadi Danner was selected as a thermodynamic method to predict the thermodynamic properties of the component mixture because H_2O solubility in the system was important.

3. Results

Table 4 summarized the simulation results of the three study cases; IGCC, A-IGCC and AIGCC'. Net thermal efficiency and gross thermal efficiency are expressed by:

$$\eta_n = \eta_g - \frac{(W_{O_2} + W_a)}{Coal\,input} \tag{3}$$

where: η_n–net thermal efficiency, η_g–gross thermal efficiency, W_{O_2}–O_2 production power and W_a is auxiliary consumption.

As auxiliary consumption was set at 5% for all models, the net thermal efficiency of IGCC, A-IGCC and A-IGCC was 43.0%, 51.0% and 50.8% respectively. The thermal efficiency of the IGCC system

Table 2: Basic assumptions for the plant model simulation

	IGCC	A-IGCC
Air compressor adiabatic efficiency	80%	
Gas turbine adiabatic efficiency	85%	
Gas turbine temperature/pressure	1,500°C /2.0 MPa	1,700°C /2.3 MPa
Oxygen production power	0.8064 MJ/kg$_{O_2}$	
Steam turbine adiabatic efficiency	88%	
Steam turbine inlet temperature/pressure	600°C / 20 MPa	
Steam turbine outlet pressure	3.0 MPa	
Condensing turbine adiabatic efficiency	86%	
ΔT_p in HRSG	30°C	
Steam supplied to the gasifier at 700°C	16.44 kg/s	

was the lowest of the three systems by 8%. There was a very small difference in plant performance and efficiency between A-IGCC and A-IGCC’. The gas turbine output increased by nearly 50 MW (7% in the heat value of the coal) for the A-IGCC and A-IGCC’ models. The output of the steam turbine increased by 1.7 MW (A-IGCC) and 2.4 MW (A-IGCC’). Similarly, the output of the condensing turbine increased by 4.3 MW (A-IGCC) and 5.7 MW (A-IGCC’). The gasifier of the IGCC model needs 10.6 kg of oxygen, which corresponds to 8.5 MW based on the assumption mentioned earlier (0.8064 MJ/kg$_{O_2}$). This is a negative contribution to the thermal efficiency of 1.3% (HHV). However, the figure was reduced to 6.4 MW (A-IGCC) and 6.6 MW (A-IGCC’), which was attributed to the suppressed progression of partial oxidization.

Fig. 7 and Fig. 8 show the performance and the process flow diagram of IGCC and A-IGCC. A-IGCC also represents A-IGCC’ as the figures in the process are comparable. In IGCC, the syngas is cooled to 25°C before being fed to the combustor. The temperature of the exhaust gas was 782°C, which generated 108.2 kg/s of 600°C steam for the steam turbine. The temperature of the exhaust gas increased by about 20°C by using a 1,700°C class gas turbine for A-IGCC and A-IGCC’, which was at first used to feed the heat to the gasifier followed by the generation of 113.3 kg/s (115.0 kg/s for A-IGCC’) of steam in HRSG. After providing 41 MW of heat to the gasifier, the temperature of the exhaust gas dropped to 801°C, but the amount of steam generated by the remaining exhaust increased in the A-IGCC and A-IGCC’ system.

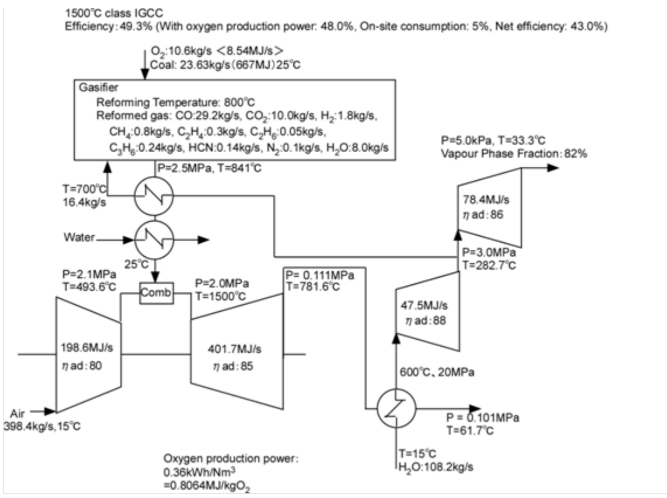

Figure 7: Performance and process flow diagram of IGCC model

The energy and the exergy flow of the IGCC and A-IGCC models are illustrated in the same fashion (Fig. 9 and 10) described in the early section. The energy exchange between the gas turbine and the air compressor is not shown, to make the diagrams more concise. The energy values including output electric powers throughout the process were normalized by the heat value of the coal. For example, the gas turbine output energy for IGCC was 203 MW which was then approximately expressed as a percentage of the total heat value (667 MW), i.e. 30.

In the studied IGCC model, some of the energy from the gasifier and the steam turbine were recycled to the gasifier, but not as much as they were in

Table 3: Elemental analysis and gasifier conditions of the studied sub-bituminous coal and syngas

Coal elements				Value
Carbon	wt %			69.4
Hydrogen	wt %			4.9
Total Sulfur	wt %			0.1
Combustible Sulfur	wt %			0.04
Noncombustible Sulfur	wt %			0.06
Nitrogen	wt %			0.9
Oxygen	wt %			24.7
Higher Heating Value	MJ/kg			28.2
Specific Heat	kJ/kg/K			1.8
Material supply to the gasifier		IGCC	A-IGCC	A-IGCC'
Coal	kg/s	23.63	23.63	23.63
Temperature	°C	200	200	200
Heating	MW(HHV)	667	667	667
value	MW(LHV)	643	643	643
O_2	kg/s	10.6	7.9	8.22
Temperature	°C	700	700	700
H_2O	kg/s	16.6	16.6	16.6
Temperature	°C	700	700	700
Heat supply from GT	MJ/s	-	41	31
Syngas molar fraction		IGCC	A-IGCC	A-IGCC'
CO		0.388	0.399	0.336
CO_2		0.084	0.074	0.137
H_2		0.334	0.385	0.443
CH_4		0.019	0.019	0.019
C_2H_4		0.004	0.004	0.004
C_2H_6		0.001	0.001	0.000
C_3H_6		0.002	0.002	0.002
HCN		0.002	0.002	0.002
N_2		0.002	0.002	0.002
H_2O		0.162	0.113	0.055
Total mass flow	kg/s	50.66	47.99	48.29
Temperature	°C	841	831	825

Table 4: Summary of simulation results

System case	IGCC	A-IGCC	A-IGCC'
Gross thermal efficiency (%)	49.3	57.0	56.8
Efficiency with O_2 production power deducted (%)	48.0	56.0	55.8
Auxiliary consumption (%)	5.0	5.0	5.0
Net thermal efficiency (%)	43.0	51.0	50.8
Oxygen production power (MW)	8.5	6.4	6.6
Gas turbine output (MW)	401.6	455.1	447.5
Air compression power (MW)	198.5	207.5	203.4
Net gas turbine output (MW)	203.1	247.6	244.1
Steam turbine output (MW)	48.0	49.7	50.4
Condensing turbine output (MW)	78.4	82.7	84.1
Gas turbine exhaust temp.(°C)/pres.(MPa)	782/0.11	903/0.12	904/0.12
Water flow rate to HRSG (kg/s)	108.2	113.3	115.0

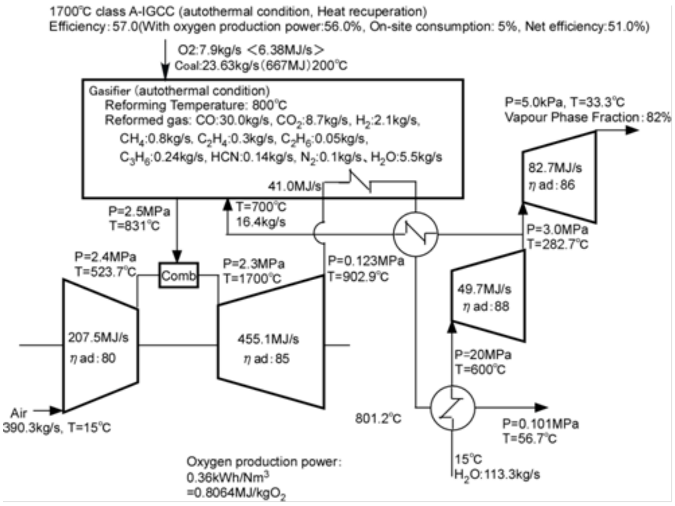

Figure 8: Performance and process flow diagram of the A-IGCC model

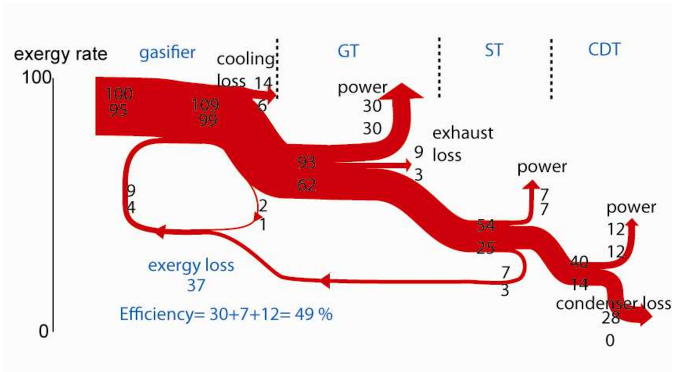

Figure 9: Energy/Exergy flow of the IGCC model

the A-IGCC model. The model therefore includes a small amount of exergy recuperation because the heat of the syngas was used to superheat the steam from the steam turbine for feeding back to the gasifier. However, the reformed gas still had unused thermal energy and is shown as a cooling loss in Fig. 9.

The cold gas efficiency was 109%, which was higher than the theoretical cascading IGCC described earlier, because it contained the recycled heat from the exhaust. The thermal losses found in this model were: cooling loss (14), exhaust loss (9) and condenser loss (28). The exergy loss due to the combustion process was 37. In the A-IGCC model, the energy and exergy recuperation was greater (15/7 in total) resulting in higher cold gas efficiency (115%). Saving the energy and the exergy of the gas led to higher power generation, as shown in Fig. 10. However, the exhaust loss increased by 30% compared to the IGCC model. The exergy loss arising from the combustion was reduced to 25.

4. Discussion

Coal gasification theoretically relies on two fundamental reactions, one of which is partial oxidization at a high temperature, given by:

$$C + 0.5\,O_2 \rightarrow CO - 111\,\frac{\text{kJ}}{\text{mol}} \tag{4}$$

where C represents carbon containing organic compounds. This exothermic reaction used in the

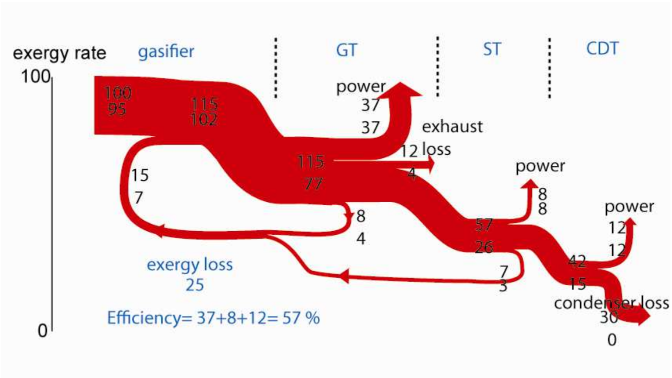

Figure 10: Energy/Exergy flow of the A-IGCC model

conventional IGCC system at over 1,000°C requires an input of 28% of the heating value of the fuel to convert C to CO, i.e. cold gas efficiency is 72%. The heat produced from partial oxidation can be supplied for further coal gasification, however this results in a reduction in cold gas efficiency. Preferably, one would maximize the gasification output by reacting carbon with steam, in the following reaction:

$$C + H_2O \rightarrow CO + H_2 + 131\,\frac{\mathrm{kJ}}{\mathrm{mol}} \qquad (5)$$

Steam gasification, which is the other fundamental reaction, can be done at relatively low temperatures (700–1,000°C) but requires a large amount of heat input. In the IGCC system, the combination of the main two reactions governs the gasification of the coal, and the surplus heat was recovered as steam to be sent to the gas purification unit. However, the exergy rate of steam is much lower than that of the coal resulting in the exergy loss. In a sense, steam recovery at this point is not very efficient. Although the ideal gasification style is to use steam reforming, it was not possible to do so under the current A-IGCC operating conditions. Instead, the A-IGCC system proposed in this study aimed to gasify the coal under the autothermal condition, which is the combination of steam reforming and partial oxidation given by:

$$\mathrm{C} + 0.458\,H_2\mathrm{O} + 0.271\,O_2 \rightarrow \mathrm{CO} + 0.458\,\mathrm{H_2} + 0\,\frac{\mathrm{kJ}}{\mathrm{mol}} \qquad (6)$$

This allowed conservation of the heating value of the fuel (higher cold gas efficiency) and reduced oxygen supply to the gasifier.

The A-IGCC' model which investigated the effect of increased CO_2 generated in the gasifier, considered the following reactions:

$$\mathrm{C} + \mathrm{O_2} \rightarrow CO_2 \qquad (7)$$
$$\mathrm{CO} + \mathrm{H_2O} \leftrightarrow CO_2 + \mathrm{H_2}$$

The model was designed for a condition where the reversible water gas shift reaction could reach equilibrium slightly towards the production side, allowing 85% more CO_2 and 15% more H_2, but less H_2O and CO in the syngas compared to the conditions used for the A-IGCC model. This did not have a significant impact on thermal efficiency: there was a slight reduction of 0.2%. However, it may make a difference if a CO_2 capture is included before the syngas combustion process, because the energy consumption for a shift reactor, which converts CO to CO_2, would be reduced by having less CO present in the syngas.

Energy/exergy flow diagrams of the IGCC and A-IGCC systems showed the comprehensive changes and distributions of exergy/energy rate throughout the cycle. The main contribution to the increased thermal efficiency in the A-IGCC model is the increase in energy/exergy in the gasifier. Cold gas efficiency increased by 9%, which was attributed to large energy/exergy recuperation in A-IGCC. The recycled heat and supplemented steam assisted the autothermal reaction in the gasifier. Their exergy rates are less than 0.5, which means that they have only a small amount of useful energies as they are alone. But in the A-IGCC model they can be converted to chemical energy via an endothermic reaction in the gasifier to generate H_2. It has a lower exergy rate (0.83) compared to the other hydrocarbons in coal. The generation of H_2 is therefore endothermic and cold gas efficiency exceeds 100%. H_2 can be then combusted to produce a large amount of electric power. As a downside of the autothermal reaction, there was more steam present in the gas turbine exhaust in the A-IGCC model which was counted as a thermal loss. But this can be compensated by all the other improvements in the system. If additional steam reforming was achieved by providing enough heat and the steam to the gasifier, cold gas efficiency would increase further resulting in an increase in system efficiency.

There are several technical requirements to be addressed for the future implementation of the A-IGCC model.

1. Syngas cleaning at a relatively high temperature.
2. 1,700°C class gas turbine
3. Powerful heat exchanger to supply the exhaust gas to the gasifier.
4. High density circulating fluidized bed gasifier

The gas cleaning process is one of the more important processes in coal power generation systems. Although not included in this study, pure hydrogen generation combined with acid gas removal would be a key gas purification process in the future for the purpose of achieving environmentally friendly power generation. Preferably the syngas cleaning should be performed at a relatively high temperature to reduce energy loss via the cleaning process. The clean syngas undergoes a combustion process in a 1,700°C class gas turbine, which is powerful enough to supply great heat to the gasifier. Finally, it is necessary to lower the gasification temperature as much as possible in order to effectively recycle the gas turbine exhaust to the gasifier. As mentioned earlier, this is under investigation as an associate project [7, 8]. These conditions would provide the basis of the A-IGCC model and deliver a potentially more effective use of sub-bituminous coal in the future.

5. Summary/Conclusions

The performance analysis of the IGCC and A-IGCC plant systems using the figures of exergy rate demonstrated that high thermal efficiency was obtained from A-IGCC with heat (exergy) recuperation. It showed the importance of recycling the gas turbine exhaust as endothermic reaction heat in the gasifier, achieving high cold gas efficiency. The change in syngas compositions, e.g. CO_2 and H_2, did not show a significant effect on plant efficiency. The study addressed the issue that the A-IGCC system requires several technologies to be developed, including a powerful heat exchanger, which would be a subject of future studies.

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Nomenclature

ΔT_p Minimum temperature difference in HRSG

η Thermal efficiency

H Entalphy

$HRSG$ Heat Recovery Steam Generator

S Entropy

T Temperature