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A Study on Repowering of Domestic Aged Coal-fired Power Plant

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Abstract

Recently, the public opinion is growing that the main cause of greenhouse gas, fine dust and nitrogen oxide, sulfuric acid emission is coal-fired power plant, and now the decommission or conversion to other clean fuel is being demanded. However, it is a huge national loss to decommission coal-fired power plant with remaining life, and also simple fuel converting to natural gas will lead to drastic rise on power generating cost. Therefore, this study aims to provide the analysis result about the reduction effect of CO_2, environment emission, and to influence to power plant performance and facilities when repowering with adding gas turbine is applied to domestic aged coal-fired power plant.

Keywords: Coal, Repowering, CO_2 Reduction

I. INTRODUCTION

Coal-fired power plant has played a significant role as a cheap and stable power source since the starting stage of electric power industry. However, there is global opinion that the coal-fired power plant is the major cause of greenhouse gas, fine dust and nitrogen oxide, sulfuric acid emission, and now is in demand of decommission and conversion to other clean energy source.

Meanwhile, at the 21st session of the Conference of Parties to the UN Framework Convention on Climate Change (COP21) [1], Korean government decided to reduce 37% of greenhouse gas until 2030, and announced the policy to decommission 10 aged coal power plants over 30-year operation in order to achieve CO_2 reduction (64.5 million ton) based on the 1st Climate Change Response Master Plan (2016) [2].

However, it is a huge economic loss to close existing coal-fired power plants constructed with enormous expense and it is not reasonable for energy security aspect. Thus, converting coal-fired power plant fuel to natural gas is also in consideration, but using expensive natural gas on existing Rankine cycle power generation system is not economical, and cannot avoid rise in generation cost.

Therefore, this study aims to draw an optimal repowering method which could reduce coal consumption, CO_2 and environment emission while improving power plant performance and power output for domestic aged coal-fired power plants.

II. REPOWERING TECHNOLOGY SUMMARY

A. Background of consideration

Recently, the public opinion about coal-fired power plant regarding fine dust and air pollution emission is worsening in Korea, and as the government is set to reduce 37% of green gas emission until 2030 based on COP21 agreement, the government plans to decommission aged power plant over 30-year operation.

Major coal-fired power plants built before the 1990 are listed in Table 1, and as the 20 unit 500MW standard coal-fired power plants constructed since 1993 are operated over 20 years, fundamental measures are required.

Table 1. Examples of coal-fired power plants over 30-year operation

Note	S-power plant Unit 1, 2	B-power plant Unit 1, 2	H-power plant Unit 1, 2
Year of completion	1983	1983	1973
Generating power	560×2	500×2	250×2
Fuel	Bituminous coal	Bituminous coal	Sub-bituminous coal

However, it is a huge economic loss for nation to decommission coal-fired power plants which are in operation with no physical problem.

Meanwhile, simple fuel conversion (coal→gas) or fuel mixing (coal+gas) method is proposed as counter measures, but using expensive natural gas on existing Rankine cycle power generation system is not economical.

Also, in order to mix or convert gas fuel to the current power plant, it is required to remodel for boiler facility (fuel supply system, burner system, heating surface, and fans) and operational parameter. And, in accordance with difference of coal and gas properties, the change in combustion, heat transfer characteristics and reduced efficiency of a boiler (H_2O of hydrogen in gas, potential heat absorption and loss due to increase of flue gas temperature) are inevitable.

Therefore, in order to overcome problems following remodeling of a coal-fired power plant to a dual coal-gas power plant and economic limits due to restriction of Rankine cycle, there is a need to apply repowering technique composing combined cycle by combining a gas turbine to the current power plant boiler system as in Fig. 1.

B. Repowering methods

Although implementing the repowering consumes large investment cost, it enables groundbreaking power uprating and performance improvement. The types of repowering are classified as CT based Full Repowering, Hot wind box Repowering, Feed water Repowering and Parallel Repowering [3].

Table 2 is a summary of general repowering application

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Table 2. Types of repowering techniques and characteristics [1]

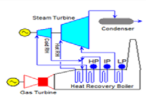
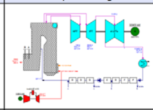
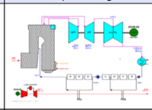
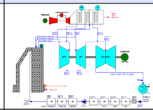
Note	CT based Full Repowering	Hot wind box Repowering	Feedwater Repowering	Parallel Repowering
Method				
	-Adding GT and HRSG -Reusing Steam turbine -Boiler demolition	- Adding GT, Eco Expanding - wind box remodeling - Remove Fan and GAH	-Adding GT -Adding gas/water heater	-Adding GT and HRSG -Adding piping -Reusing Boiler & turbine
Pros	- High output increase and efficiency increase - Less technical risk	- Low investment cost - Less site area required	- Low investment cost - Less site area required	- Recycle entire existing facility
Cons	-Requires large investment -Need to review grid influence -Requires extra site	- Complicated operation control	- Insufficient efficient, generating power improvement	-Difficult to compose logic -Unbalanced at partial load

Table 3. S-coal-fired power plant standard

Note	Item	Unit	Standard
Boiler	Type	-	Drum Type, Tangential firing
	Evaporation	T/h	1797 at BMCR
	Main stream pressure	kg/cm^2	177.9
	Main stream temperature	°C	541
	Reheat steam pressure	kg/cm^2	37.8
	Reheat steam temperature	°C	541
Turbine	Type	-	Single Reheat, Condensing, 17Stages (6/5/6×4)
	Rated power	MW	560
	Main stream pressure	kg/cm^2	169.8
	Main stream temperature	°C	538
	Reheat steam temperature	°C	538
	Extraction stage	-	7
	Condenser vacuum	mmHg	722

method. In accordance with project purpose, it is possible to get additional efficiency upgrade, generating power output enhancement by applying additional engineering variables and investment.

When implementing repowering, the power output enhancement and efficiency upgrading affect differently in accordance with various variables such as application technique (Full, Hot Wind Box, Feed water, Hybrid repowering), GT model and its capacity ratio, GT accessory equipment condition, HRSG type selection (single, double, triple pressure, duct burner condition, etc.) and steam turbine operation mode.

Each repowering method has optimal design technique. Therefore, considering proper investment cost, there is a need to select proper design to obtain maximum result (generating power, efficiency, reliability, etc.)

As for the evaluation for repowering result, the repowering efficiency and the gas turbine leverage are used. Repowering Efficiency is the ratio of increased net power output to increased fuel consumption. Gas Turbine Leverage is the ratio of increased plant total net power output to GT power output [4].

$$\eta_{Repowering} = \frac{\text{Power out after repowering-Power output of original plant}}{\text{Fuel input after repowering-Original Fuel input}}$$

$$\text{Gas turbine Leverage} = \frac{\text{Power output after repowering-Power output of original plant}}{\text{GT power output}}$$

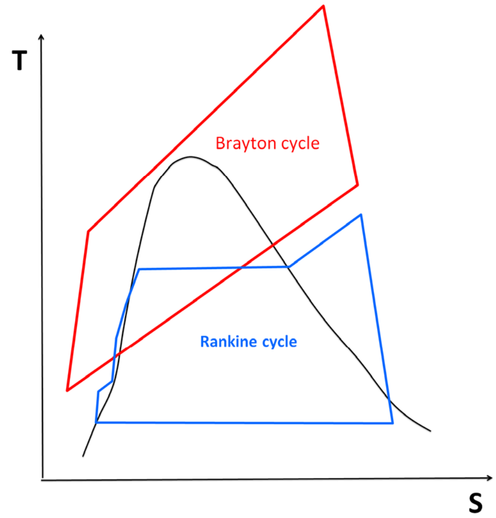


Fig. 1. Brayton-Rankine combined cycle.

III. SIMULATION AND RESULTS

A. Power plant subjected to review and repowering method

The Power plant subjected to consider repowering S-coal fired power plant with 560 MWe gross generating power level, and the major facility standards are in Table 3.

The ultimate purpose of repowering of the above S-coal fired power plant unit 1 and 2 is response to decommission of aged power plant policy, reduction of environment emission, and efficiency improvement such as power uprating. Therefore, referring to Table 2, when considering the minimization of site constraints of existing facility, collateral condition such as licensing, power transmission capacity and investment cost, it seems that hot wind-box repowering is appropriate.

Hot wind-box repowering combines a gas turbine with 30~55% range of the current steam turbine generator which uses gas turbine exhaust gas as combustion gas of a boiler. It does not combust natural gas at the combustion system of the current boiler. But first, the natural a gas is combusted in gas turbine to compose Brayton cycle and to obtain separate electrical output. Then, the exhaust gas from a gas turbine which is in high temperature and contains 11~12% oxygen, is utilized as heat source and combustion air of Rankine cycle of power plant to compose steam cycle, and to obtain another separate electrical output. At this point, the current boiler supplies fuel according to the amount of oxygen contained in gas turbine exhaust gas.

Then the high temperature combustion gas emitted from the boiler is used as heat source of feed water heating.

B. Simulation Method

The commercial process simulation program, Thermoflow, was utilized to develop a numerical model for the boiler and turbine system of S-coal-fired power plant. Then calculation result from the numerical model and the power plant real performance data were compared to conduct verification and model tuning. The properties of coal composition and heating value which are applied in the modeling, are listed in Table 4.

Fig. 2 is the result of process modeling of current S-generation system.

Fig. 3 is the simulation result of S-coal fired power plant repowering by converting baseline model to off-design mode, and

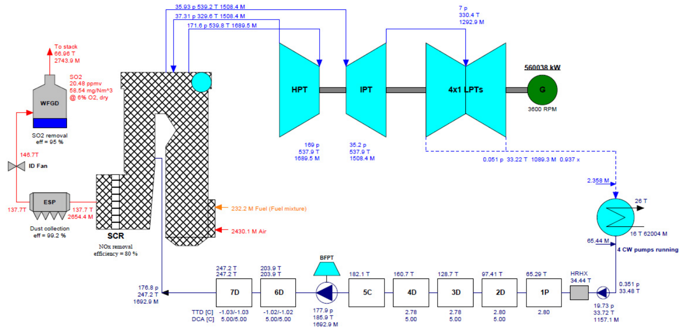


Fig. 2. S-coal-fired generation system simulation model.

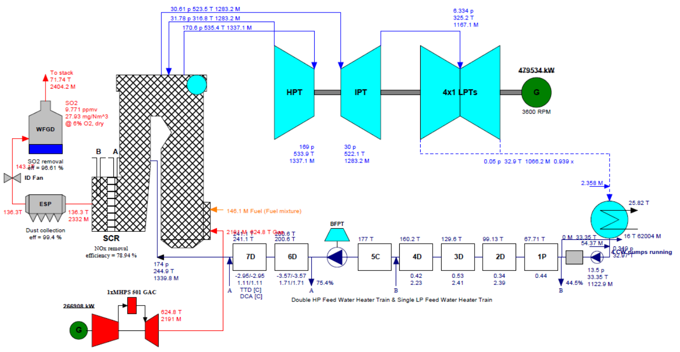


Fig. 3. S-coal-fired generation system repowering simulation model.

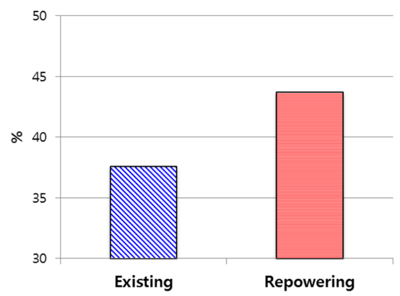


Fig. 4. Plant gross efficiency change before and after repowering.

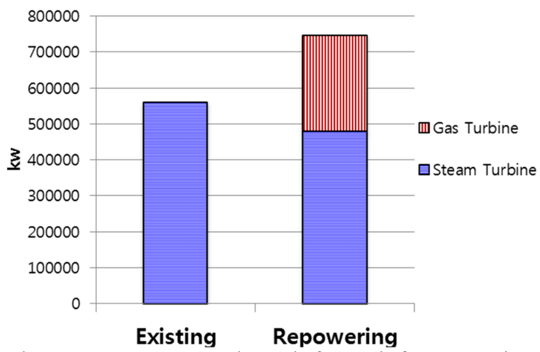


Fig. 5. Plant gross power output change before and after repowering.

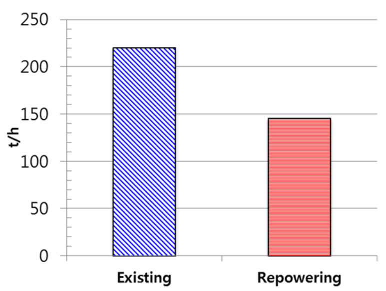


Fig. 6. Coal flow change before and after repowering

Table 4. The properties of design coal for used in performance data sheet

Description		Value
Heating Values (kJ/kg)	LHV	21820
	HHV	23116
Proximate Analysis (weight %)	Moisture	20.88
	Ash	3.22
	Volatile Matter	31.8
	Fixed Carbon	44.10
Ultimate Analysis (weight %)	Moisture	20.88
	Ash	3.22
	Carbon	58.28
	Hydrogen	3.60
	Nitrogen	1.11
	Chlorine	0.03
	Sulfur	0.26
	Oxygen	12.62

Table 5. Fuel input and generated power before and after repowering

Note	Fuel Input (kW_{th})			Generated Power (kW_e)		
	Current	Repowering	Variation	Current	Repowering	Variation
Steam cycle	1,491,276	937,945	-553,331	560,000	479,535	-80,465
GT cycle	-	769,947	769,947	-	266,908	266908
Total	1,491,276	1,707,893	216,616	560,000	746,443	226,443

adding the gas turbine and boiler exhaust gas recovery system.

C. Simulation Results

1) Plant performance and power generation

Table 5 shows the comparison of fuel input and generated power before and after the repowering. The repowering efficiency is 86.1% (186,443/216,616) and gas turbine leverage is evaluated as 85%.

Plant efficiency is expected to increase by 6.2%p from 37.5% to 43.7% after repowering and the plant gross generated power is expected to increase by 33.3% from current 560MW to 746MW after repowering.

2) Coal consumption rate

As for the coal flow, it is expected to change from current 232.2 t/h to 146 t/h after repowering as shown in Fig. 6. It is calculated as 49% of the current level when correcting the output increase, and the following CO_2 reduction effect is about 30%.

3) Environmental emission reduction

Fig. 7 and Fig. 8 are the result of dust concentration at inlet of electric precipitator and sulfur oxides concentration at inlet of desulfurization unit before and after the repowering.

It is expected that the reduction level of about 57% compared to current emission concentration is possible. Meanwhile, as for the nitrogenous oxide, which varies in accordance with applied operation parameter, additional research is required, but the reduction tendency is expected to be similar.

4) The effect of repowering on operation and facility

When applying repowering method combining a gas turbine to the current boiler, it leads to many changes to boiler combustion characteristics and heat mass balance. Thus, the influence on power plant operation and facility was examined. The heating surface arrangement of S-power plant boiler is shown in Fig. 9.

When applying repowering, as described in Fig. 10, the heat absorption rate of evaporator composing boiler's radiative heat transfer zone tends to decrease.

Such phenomenon is caused by reduced radiative heat

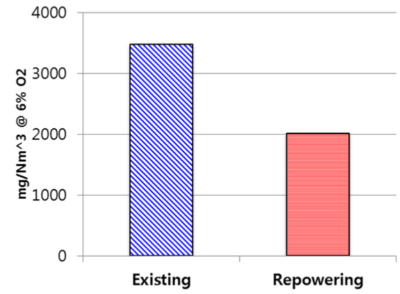


Fig. 7. Change in dust concentration around the inlet of electric precipitator before and after repowering.

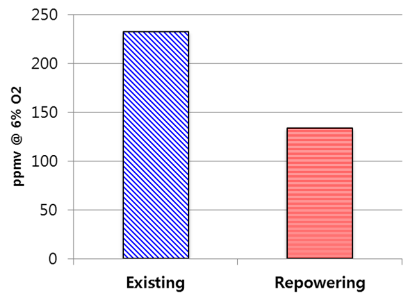


Fig. 8. Change in SOx concentration of desulfurization unit inlet before and after the repowering.

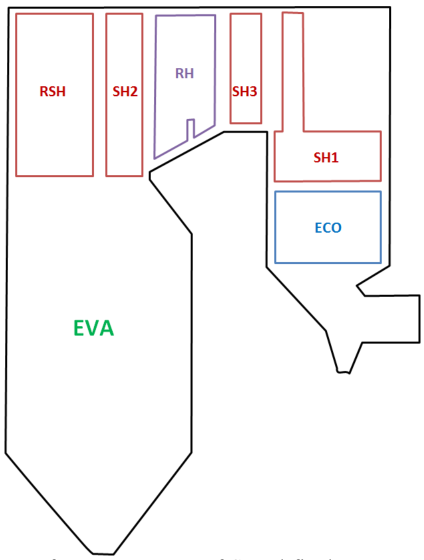


Fig. 9. Heating surface arrangement of S-coal-fired power generating system boiler.

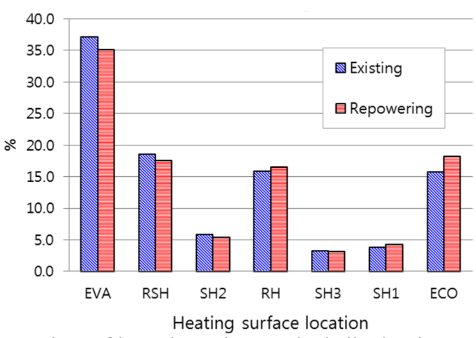


Fig. 10. Comparison of heat absorption rate by boiler heating surfaces before and after repowering.

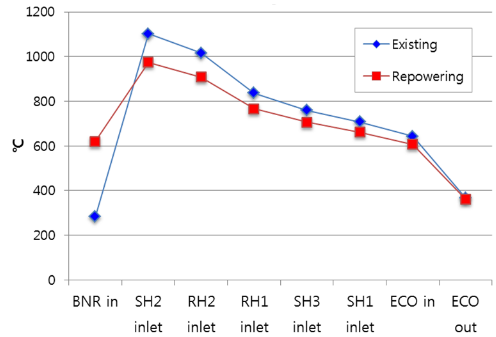


Fig. 11. Comparison of gas temperature of boiler heating surface before and after repowering.

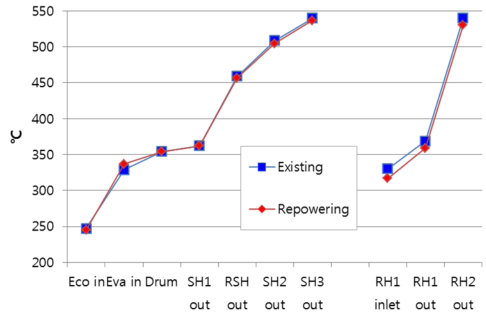


Fig. 12. Comparison of steam temperature by location of boiler heating surface before and after repowering

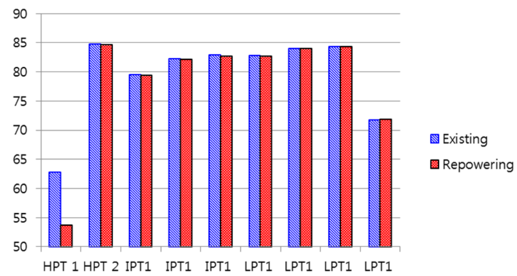


Fig. 13. Change in internal efficiency by turbine sections before and after repowering

transfer and reduced gas temperature inside of furnace in accordance with decreased concentration of ash content inside the furnace due to decrease of coal supply. Meanwhile, the heat absorption rate of heating surface of boiler back pass, the convective heat transfer zone tends to increase. Therefore, in order to mitigate such phenomenon, there is a need to adjust the boiler burner tilting angle to lower, and use the burner on lower boiler to combust.

Fig. 11 indicates result of gas temperature comparison by major heating surface location of the boiler before and after repowering. As the combustion gas supplied to the boiler during repowering increases compared to existing condition, the boiler furnace gas temperature is expected to be lower than the current condition. Therefore, it seems that there is no problem with overheating and boiler tube life problem regarding the repowering.

Fig. 12 is the result of water and steam temperature comparison by location of major boiler heating surface before and after repowering. The outlet temperature of economizer located at the convective heat transfer zone of boiler back pass showed slight increase but it seems that the current entire design condition can be maintained.

As for the steam turbine, when the supplied steam flow changes, the throttle loss and velocity ratio in control valve varies [5]. Therefore, as in Fig. 13, HP turbine section 1 internal efficiency shows slight decrease while the rest of stages maintain almost the same as the current design condition.

Fig. 14 is the result of temperature of major inlet and outlet of feed water heating system using boiler flue gas. It still has some margin compared to acid dew point of exhaust gas of general type of coal. Meanwhile, it requires preparation for fouling and dust accumulation.

IV. CONCLUSION

Considering the technical aspect, site area constraints, power transmission capacity margin and investment cost, the hot wind-box repowering method seems appropriate for domestic aged coal-fired power plants.

The expected results of hot wind-box repowering applied to S-coal-fired power plant are as follows.

▪ The plant efficiency will be increased approximately by 6.2%p from 37.5% to 43.7% after repowering. And the plant gross power will be increased approximately 33.3% from 560 MW to 746 MW after repowering. At this point, the repowering efficiency is 86.1% and gas turbine leverage is evaluated as 85%.

▪ Coal flow is calculated as 49% of the current level when correcting the output increase, and the CO_2 reduction effect is about 30%.

▪ Dust and sulfur oxides emission concentration is calculated as about 57% of the current.

The effect on power plant facilities and considerations regarding the hot wind-box repowering application to S-coal-fired power plant are as follows.

▪ In accordance with the variation of combustion characteristics, the heat absorption rate of boiler radiative heat transfer zone is reduced and heating surface of boiler back pass, the convective heat transfer zone tends to increase.

▪ There is a need to adjust the boiler burner tilting angle to lower, and use the burner on lower boiler to combust.

▪ It seems that there is no problem with overheating and boiler tube life problem regarding the repowering.

▪ There is a need to prepare for fouling and dust accumulation of flue gas-feed water heater.

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