Modelling analysis of installing a low temperature economizer in an existing 600 MWe coal-based power plant

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Abstract

Efficiency in coal-fired power generation is of primary importance due to the increasing pressure to reduce specific CO_2 emissions and improve the overall plant economics. Extracting more heat from the exhaust flue gas is an interesting way to increase the plant overall efficiency. This heat is extracted through a low temperature economizer (LTE).

This paper tackles the low temperature economizer issue. Firstly, a generic systematic model for a 600 MWe coal-based supercritical power plant is introduced, including the combustion section, flue gas section, steam turbine section and feedwater preheat section. An operation case is then presented. In order to recover more heat from exhaust flue gas (> 140 °C), a detailed analysis of low temperature economizer (LTE) arrangement is carried out: 4 flow scheme with different feedwater and flue gas conjunction points are proposed and modelled. By considering the efficiency increase, installation and operation simplicity comprehensively, 2 design flowsheets have been recommended to the plant operator.

The modeling approach presented in this work shows an industrial interest for data reconciliation purposes and for understanding the source of plant operation parameters discrepancies and main efficiency losses. Moreover, it allows the evaluation of power plant retrofit options.

Keywords: low temperature economizer, process modelling

Introduction

Upon the scarcity of fossil fuel and the urgency to mitigate climate change, a lot of studies are dedicated to improve efficient energy utilization. Coal-fired power generation is still the main method to produce electricity, and is therefore a key area to increase energy conversion efficiency. Judging from the whole thermal system, one of the largest efficiency losses in a coal-fired power plant is the heat loss in flue gas, which normally takes 5% - 8% of the whole boiler efficiency. Therefore, recovering the waste heat from the exhaust flue gas is an interesting option to increase the boiler and whole plant efficiency.

Currently, 2 main ways are used to recover heat from exhaust flue gas: organic ranking cycle (ORC) and modifications on the original thermal system, such as installing LTE. Compared to the way of installing LTE, ORC systems have 2 main disadvantageous: complexity in the integration with the original thermal system and organic working fluid management issues . On the contrary, LTE can be easily placed at the downstream of flue gas section dedusting equipment and it also shows interesting performance relating to the low investment cost, high operation flexibility and coal saving possibility.

Methodology

A 600MWe supercritical power plant has been chosen for this study. Based on the plant design data, a full plant model has been established including the combustion section, flue gas section and steam cycle. The model was validated by using one set of referencing operation data at base load operating mode. Based on the model, 4 options of LTE arrangement with different feedwater and flue gas conjunction points are proposed and analyzed.

The model was implemented in Aspen Plus®, an integrated process modeling environment.

Model description

Figure 1 illustrates the flowsheet of the 600MWe coal-based power plant.

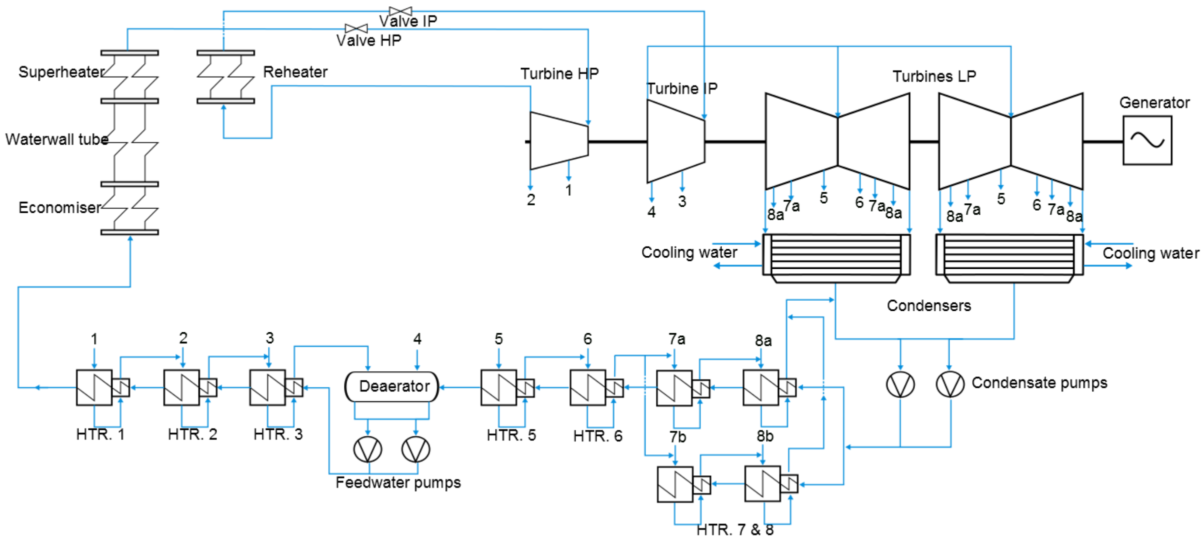

Figure 1 Flowsheet of the 600MWe coal-based power plant

In the model coal and air react at thermo-dynamical equilibrium. The two main parameters of the model are the temperature of the flue gas leaving the furnace part (≈ 1300°C) and the fraction of unburnt carbon. Heat released through coal combustion is transferred to waterwall tubes and flue gas. Resulting hot flue gases are then progressively cooled down through a series of heat exchangers, representing superheaters, reheaters, economizer and air preheater. The specifications of each of these heat exchangers are based on target design temperature of steam and flue gases. Additional desuperheating water sprays are added before the main steam superheaters. The sprayed water is extracted from the feedwater after deaerator. After being superheated, steam drives the turbine. The steam turbine is split into 10 parts in the model in order to model the 8 bleedings necessary for feedwater preheating.

Turbine isentropic and mechanical efficiencies are specified in the model. Design or measured steam pressures are imposed at the outlet of each stage of the turbine. In operation cases, the isentropic efficiencies at the design condition are applied in it. Part of the steam after IP is transferred to the boiler feed pump turbine, which drives the boiler feed pump operating. Finally, steam at the LP turbine outlet is then condensed, pumped and preheated through a series of feedwater heaters. The condensate pump after condenser is included. Pump efficiency and driver efficiency are specified in the model as Table 1 below.

Table 1 General efficiency hypothesis of equipment

Turbine brake efficiency	Turbine isentropic efficiency	Generator efficiency	Pump efficiency	Pump driver efficiency
99.6%	94% - 85%	98.5%	75%	95%

Main features of this model are presented below:

- Coal is defined by its elementary composition (C, H, O, N, S and ash), moisture content and HHV value;
- Main combustion products considered are CO_2, H_2O and SO_2, as well as inert Ar and N_2, no precise estimation of CO and NOx is generated;
- All the ash content in coal is considered as flying ash after combustion;
- Air leakage in the flue gas circuit is considered, the leakage rate is set as 6% empirically;
- Heat losses from main and reheat steam are defined in dedicated heat exchangers before the high- and intermediate-pressure turbine;
- Heat losses along the pipes connecting turbine and feedwater preheaters for bleedings are taken as the design case;

Operation case

Table 2 showed the plant main parameters in the design and operation cases. The data in operation case is taken as the raw input into the model.

Table 2 the plant main parameters in the design and operation cases

Item	Design case	Operation case
Coal (kg/s)	70.5	76
Total air inlet (kg/s)	572	595
LHV (KJ/kg)	20230	20887
HHV (KJ/kg)	23075	22449
Flue gas temp. after air preheater (°C)	117	150
Main steam mass rate (kg/h)	1808	1850
Feedwater temp. at boiler inlet (°C)	280	275
Steam cycle efficiency[1]	45%	44%
Generator active power (MW)	600	591
Main steam mass rate (kg/h)	1808	1850
Main steam pressure (bar abs)	242	242
Main steam temp. (^{o}C)	566	562
Reheat steam pressure (bar abs)	41.2	38.5
Reheat steam temp. (^{o}C)	566	561
#1 bleeding pressure (bar abs)	63	58
#2 bleeding pressure (bar abs)	44	41

[1] Cycle efficiency is defined as the ratio of total turbine brake power in relation to the total power steam extracted from boiler. The link between this different efficiencies is :

#3 bleeding pressure (bar abs)	22	22
#4 bleeding pressure (bar abs)	11	11
#5 bleeding pressure (bar abs)	4	3
#6 bleeding pressure (bar abs)	1	0.9
#7 bleeding pressure (bar abs)	0.6	0.6
#8 bleeding pressure (bar abs)	0.2	0.2
Condenser pressure / Corresponding saturation temp.	11.8 kPa 49 ^oC	9 kPa /14 kPa 44 ^oC /52 ^oC
Condenser temp. (^oC)	49/49 (saturated)	43/51 (subcooled)
Feedwater tank temp. (^oC)	181	180

LTE performance analysis

This chapter first analyzes the 4 proposed LTE configuration. The design technical specifications for the LTE is presented in the Table 3.

Table 3 Design specifications of low temperature economizer

Item	Figure
Inlet flue gas temperature (^oC)	150
Outlet flue gas temperature (^oC)	110
Water stream flow rate (t/h)	600
Inlet water temperature (^oC)	>60
Outlet water temperature (^oC)	101 (variable)
Heat loss	1%

All the 4 arrangements are proposed without effects in the air preheater proper operation (no decreasing in the temperatures of primary and secondary combustion air). Descriptions and concise flowsheet can be found in the Table 4 and Figure 2. The modeling work is conducted under the condition of no changes in the water temperature at each feedwater preheater inlet and outlet. The power plant operation is based on the based-load operation mode.

Table 4 Description of 4 proposed LTE configurations

Option	Description
I	The flue gas exiting from air-preheater at around 150^oC is used to heat a600 t/h feedwater extracted before #8 FW heater and after #7 FW heater, then the heated water is injected back to FW circuit before or after #5 FW heater.
II	Part of flue gas is extracted at the inlet of air-preheater at around 350^oC is used to heat part of the feedwater, at 600 t/h, extracted before #5 FW heater, then the water is injected back to FW circuit after #5 FW heater.
III	Part of flue gas is extracted at the inlet of air-preheater at around 350^oC is used to heat part of the feedwater, at 600 t/h, extracted before #6 FW heater, then the water is injected back to FW circuit after #6 FW heater.
IV	Part of flue gas is extracted at the inlet of air-preheater at around 350^oC is used to heat part of the feedwater, at 600 t/h, extracted before #7 FW heater, then the water is injected back to FW circuit after #7 FW heater.

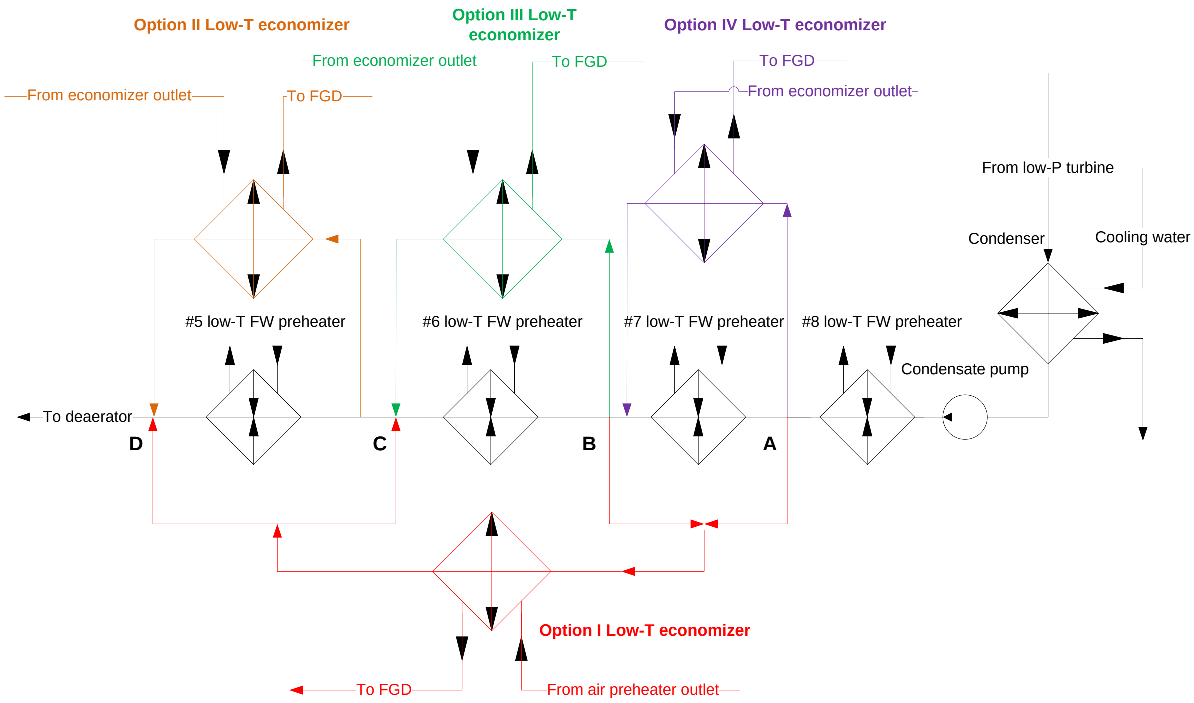

Figure 2 Flowsheet of LTE Option I, II, III & IV

In the figure 2, A, B, C and D stand for 4 piping lines. The opening and closing of these 4 piping lines are adjusted to meet the operation need. In total, 4 operation modes are possible:

Operation mode	Inlet valve		Outlet valve	
	A	B	C	D
1	OPEN	CLOSE	OPEN	CLOSE
2	OPEN	CLOSE	CLOSE	OPEN
3	CLOSE	OPEN	CLOSE	OPEN
4	CLOSE	OPEN	OPEN	CLOSE

Table 5 Descriptions of 4 operation modes of LTE option I

The modeling results show that from all different options considered, options 3 exhibits a higher power plant efficiency. In the operation mode 3, the LTE is placed in parallel with relatively higher pressure feedwater preheater (FW preheater #5 & 6), which reduces the steam bleeding at a higher pressure. The Figure 3 presents the efficiency improvement for option I for the different operation modes considered.

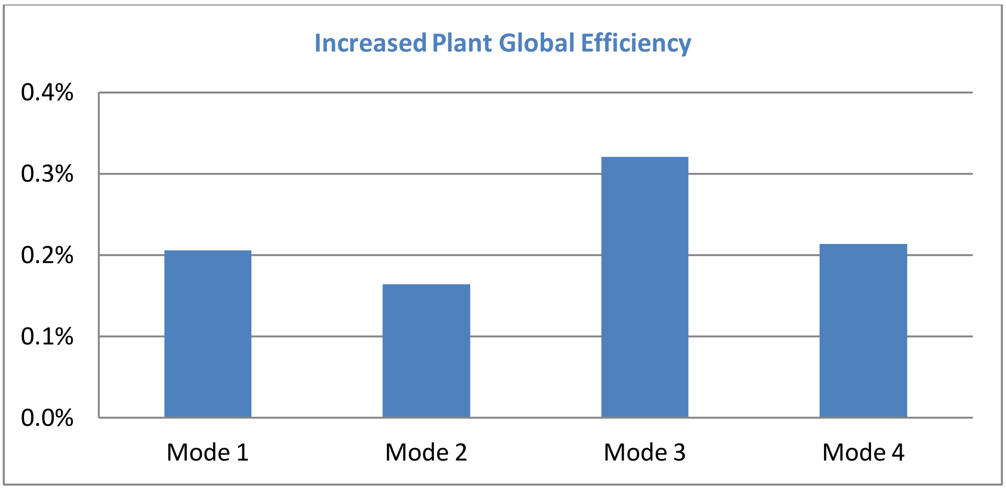

Figure 3 Plant efficiency increase (% points) in operation case with Option I LTE

The idea of options II and III aim to use the higher temperature flue gas and splitting into 2 flows.

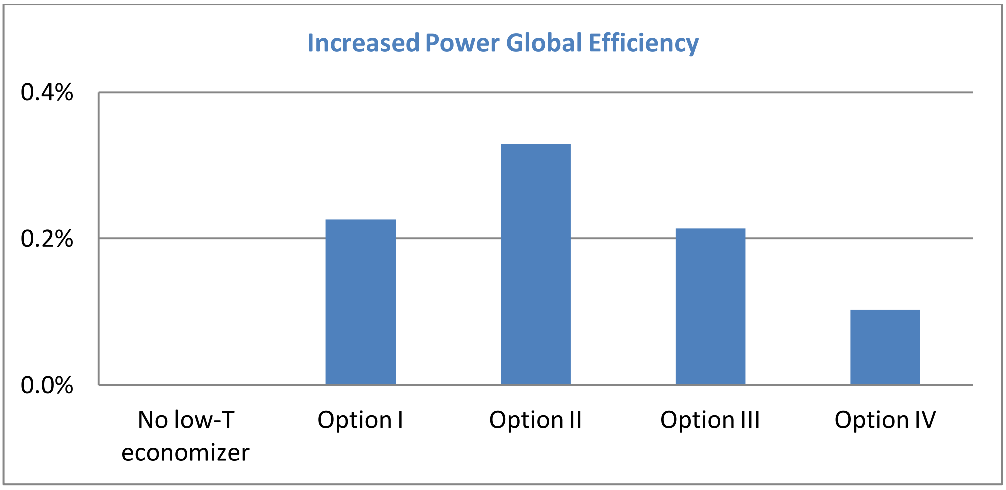

Figure 4 Power plant efficiency increase (% points) in operation case with Option I, II, III & IV[2]

The power plant efficiency improvement for each option is shown in the Figure 5. Option II makes the largest contribution to the efficiency improvement, due to that it is to reduce the steam bleeding amount at a higher pressure, which produces extra work in the steam turbine compared to the other options. Concerning the coal consumption rate, around 2 to 3.4 grams of coal per KWh are saved by installing the LTE. Concerning the boiler efficiency, it increases for about 0.9% points after installing the LTE for Option I as the Figure 5.

[2] The efficiency of Option I in the Figure 9 is the average number of the power plant efficiency in the 4 operation modes.

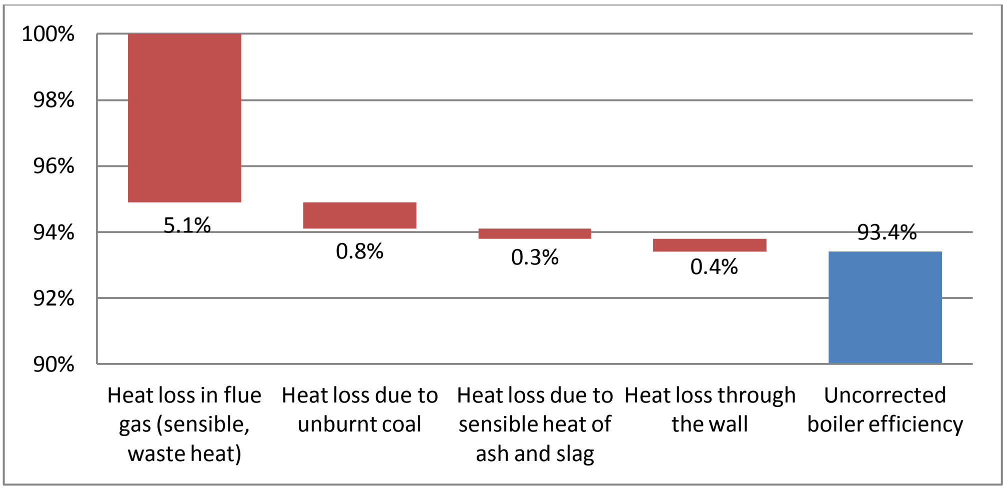

Figure 5 Boiler efficiency in operation case after adding Option I LTE

In terms of engineering issues for these cases, Options II, III and IV are more complicated than Option I. A flue gas splitter needs to be added before the air preheater in order to part of the flue gas (at around 350^{o}C) to the LTE.

Globally it is observed that LTE configurations, in which economizers are placed in parallel with a higher temperature feedwater preheater, result in higher plant efficiency, because these options reduce the required bleeding amount at a higher pressure level.

Conclusion

A complete 600 MWe plant model was established in the Aspen Plus®. The model is validated with the operating data of the power plant at 100% ECR condition. A focus is made on the study of installing LTE in order to recover more heat from the flue gas. In total, 4 flowsheets are proposed and modeled. The Option II presents the highest efficiency in the 4 flowsheets, while Option I gives a modest efficiency increase but a simpler engineering installation.

The modeling approach presented in this work shows an industrial interest for data reconciliation purposes and for understanding the source of plant operation parameters discrepancies and main efficiency losses. Moreover, it allows the evaluation of power plant retrofit options.