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Heat Integration Analysis and Optimization for a Post Combustion CO_2 Capture Retrofit Study of SaskPower's Shand Power Station

Background

- Post-combustion CO_2 capture processes require thermal energy (from steam) for amine regeneration.
- In coal-fired power stations, steam can be extracted from within the steam cycle – resulting in a power production penalty.
- ***Heat integration is the study of minimizing energy consumption while maximizing heat recovery; required for successful CCS retrofits.***
- SaskPower's Shand Power Station (305 MW unit) was the subject of a CSS retrofit feasibility study.
- Heat integration analysis using Shand's current heat balance was conducted using Gate Cycle™
- Following configurations were investigated:
  - Steam extractions to the deaerator (DEA)
  - Extractions to the reboiler
  - Utilization of a flue gas cooler (FGC) working in conjunction with a condensate pre-heater (CPH) train
  - Optimization of steam extraction to the reboiler
  - A novel configuration of the condensate preheating train integrated within the LP feed heating

Modifications to the Steam Cycle for CCS Integration

Ideally, process steam for a post combustion capture process should be extracted from the steam cycle at the lowest pressure adequate for solvent regeneration. This occurs at the intermediate pressure to low pressure crossover but also results in reduced crossover pressure and increases stresses and reduces efficiency in the last stages of the IP turbine. Cases exploring the benefits of additional stages in the IP turbine with reduced crossover pressure versus the benefits from utilizing a back-pressure turbine were explored.

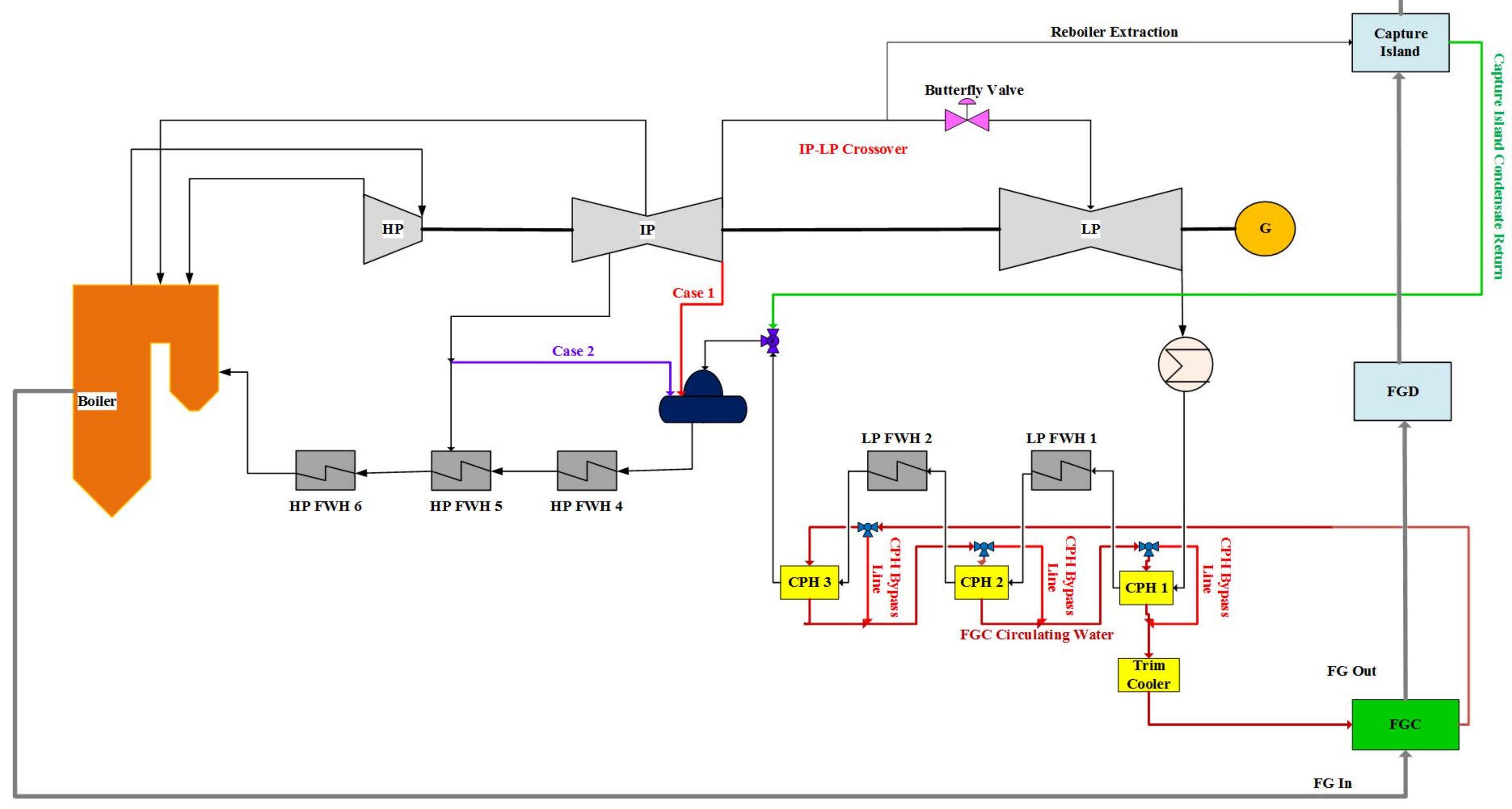

Figure 1. Steam Cycle Configurations for Reboiler and DEA Extractions

Modelling the Steam Extractions

Butterfly Valve Insertion

A butterfly valve was inserted in the IP-LP crossover. Changing the pressure at the back end of the IP turbine changes the pressure ratios within the last stages of the IP turbine, subsequently leading to changes in the volumetric flow rate (impacting turbine efficiency and stresses). In the intended design of Shand's steam cycle, the butterfly valve remains fully open at full load. At reduced loads, however, the butterfly valve functions to control supply steam at a high enough pressure to continue capture operations by throttling the flow of steam.

Extraction to the Reboiler

The extraction to the reboiler was taken from the IP-LP crossover as it provides the lowest cost of steam for the process. The FGC and CPH where consistently run in conjunction with steam extraction to the reboiler to reflect the actual changes imposed on the steam cycle with CCS online. The pressure of the DEA was increased by changing its steam source from the original positioning at the LP turbine (base case), to the IP exhaust (case 1), and finally to the extraction line from the IP to FWH5 (case 2). Each case was evaluated at 100% and 75% loads.

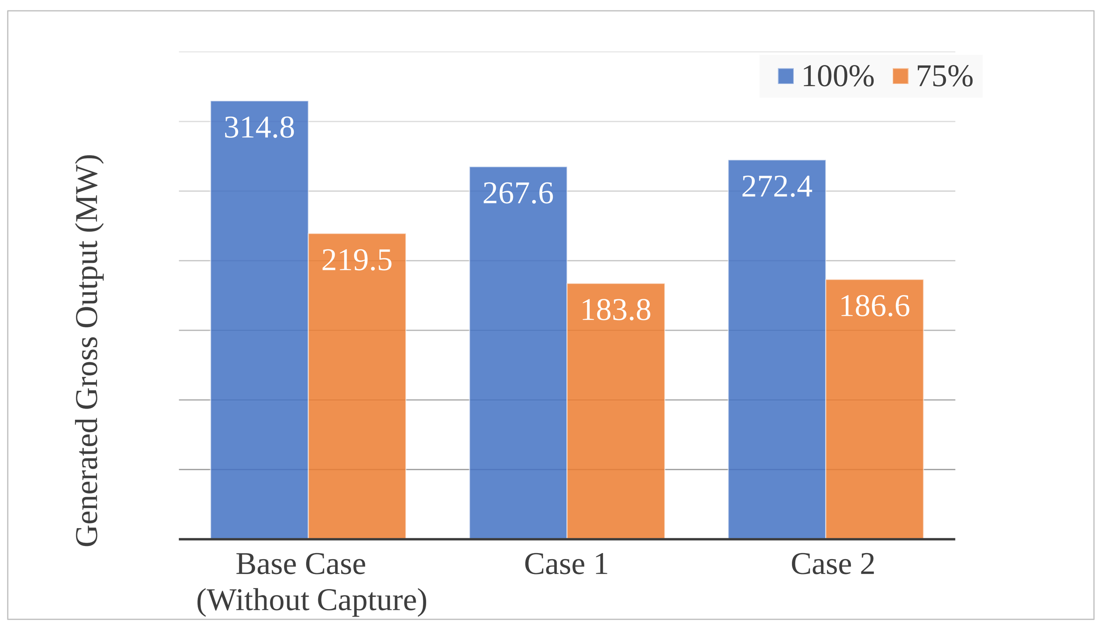

Figure 2. Comparing gross output between the base case, case 1 and case 2

Extraction to the DEA

The extraction to the DEA from a higher-pressure steam source serves to increase the operating pressure of the DEA (Figure 3). This increase in pressure is required to increase the temperature at the DEA. These changes to the DEA facilitate a greater extent of condensate preheating, better utilization of "waste" flue gas heat, and an overall decrease in the output penalty to the plant

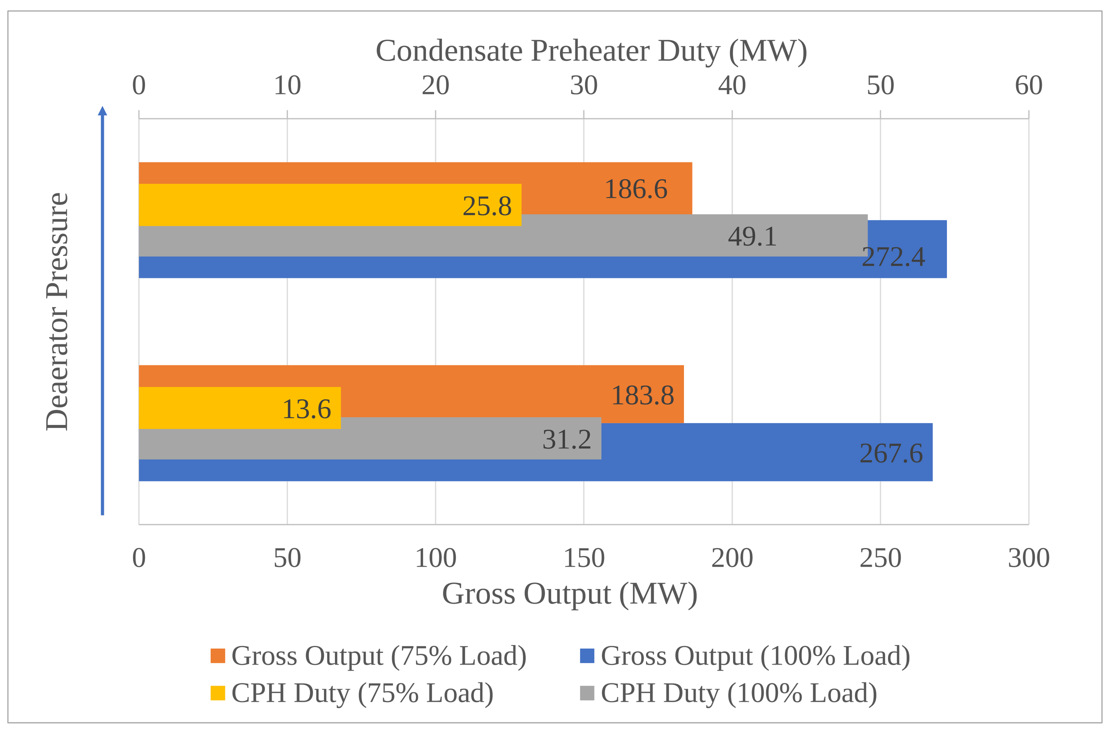

Figure 3. Effects on the Steam Cycle with Increasing Deaerator Pressure

Modelling the Flue Gas Cooler and Condensate Preheaters

Flue gas temperatures dictate the extent of condensate preheating available. The histogram depicted in Figure 4 summarized the range of available flue gas temperatures and the frequency of their occurrence at 100% and 75% load respectively. Based on this data the design FG temperature for the inlet of the FGC was set at 175ºC for the 100% load case and 155ºC for the 75% load case. A lower limit of 150ºC and a higher limit of 195ºC were also selected and subsequently used in optimizing the condensate preheating loop and trim cooler. It is also important to note that Shand is operated as a base load unit and has a capacity factor of 85%. This implies that Shand runs at 100% load most of the time; the data resulting from the full load investigated should be the basis of optimization.

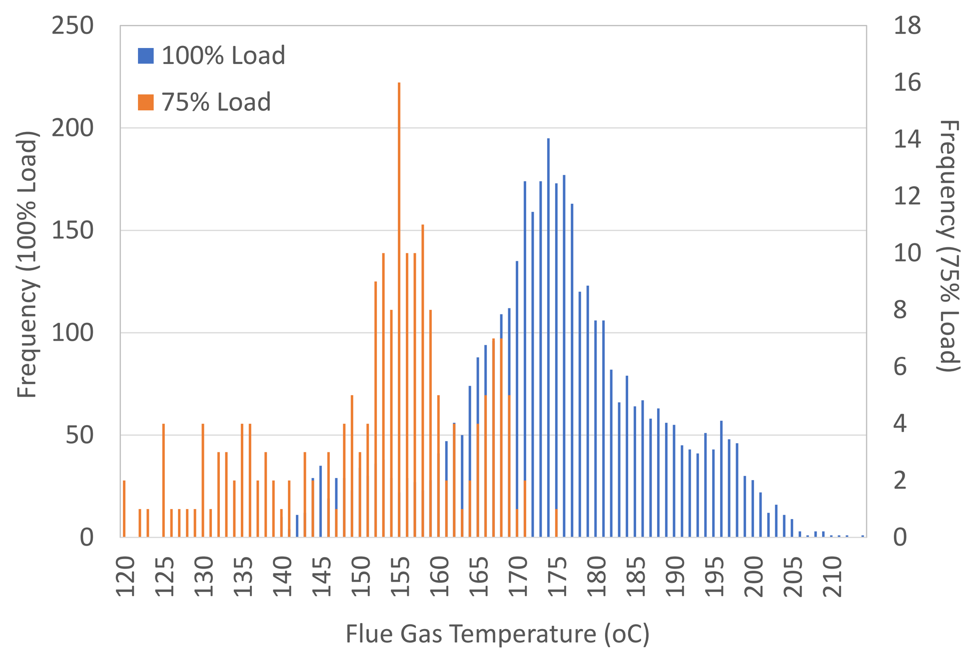

Figure 4. Histogram summarizing flue gas stack temperatures at 100% and 75% Loads

The log mean temperature difference (LMTD) and performance of the FGC and CPH within temperature ranges was calculated. The FG outlet temperatures were evaluated. Resulting heat duties of the FGC and CPH were also extracted from the model. The FG temperatures of 175ºC and 100% load and 150ºC at 75% load were finalized as the design case values. The corresponding condensate preheating duty available was determined to be 47.24 MW and 31.6 MW at 100% load and 75% load respectively.

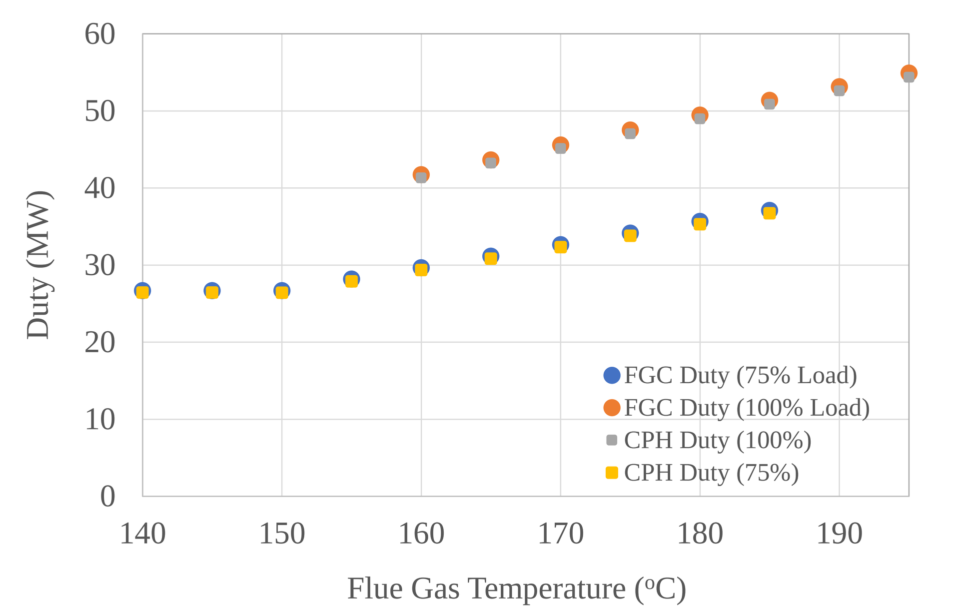

Figure 5. Summary of FGC and CPH duty with varying flue gas temperatures at 100% and 75% loads

Minimizing the Energy Penalty by Optimizing the Condensate Preheating Loop Configuration

CPH 1, 2 and 3 were sized using design case FG temperatures at 100% load. Modelling was completed iteratively by indicating a suitable "Cold Side Outlet Temperature" which would allow a duty of 5% to remain on LP FWH's 1 and 2. The trim cooler was sized by increasing the FG temperature to 195ºC. The surface areas of CPHs 1, 2 and 3 (now optimized) were kept constant while sizing of the trim cooler was adjusted to meet the requirement of a "Cold Side Outlet Temperature" of 44.5ºC. The temperature of the FG was then lowered to 150ºC. The model was run with and without the trim cooler in service at this temperature. As indicated in Figure 6. At higher FG temperatures more of the heat duty extracted by the FGC is disposed of through the trim cooler.

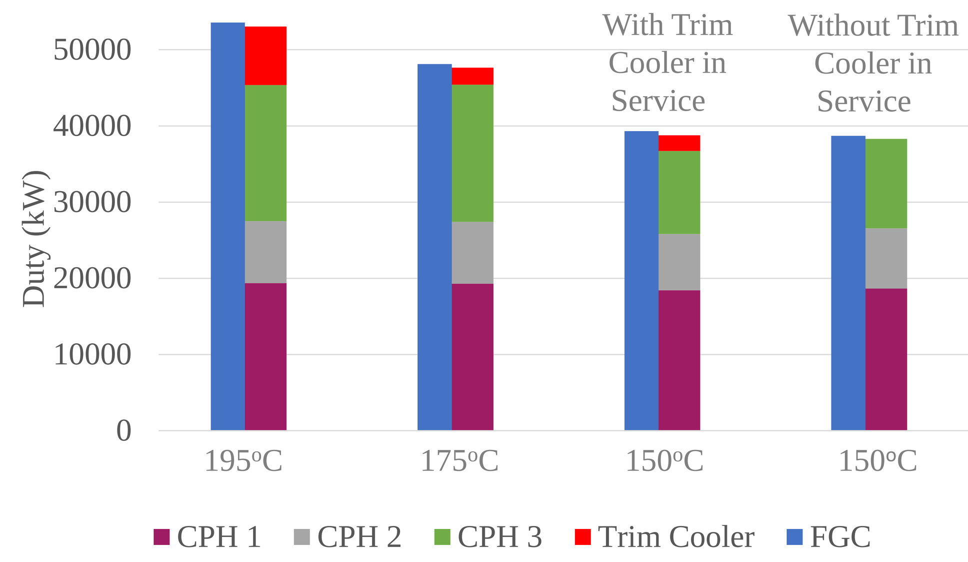

Figure 6. Summary of FGC and CPH loop duties at varying FG temperatures

At FG temperatures lower than the design case, condensate preheating availability is decreased. In this case the DEA draws additional steam to make up for this lack in condensate heating resulting in a larger temperature rise across the DEA. This comes at a cost to the power plant's gross output. Keeping the trim cooler in service at reduced FG temperatures is detrimental to power plant performance.

Comparing Enthalpy Profiles of the Feed Heating Trains With and Without CCS

Any modifications to the feed heating train must ensure that the enthalpy of the boiler feed water is maintained to conserve cycle performance and overall efficiency of the power plant. A decrease in boiler feed water enthalpy requires more work from the boiler and additional fuel input. This reduces the efficiency of the steam cycle and increases the heat rate of the power plant – an undesirable scenario. The duty comparisons for each component in the feed heating train is summarized in Figure 7.

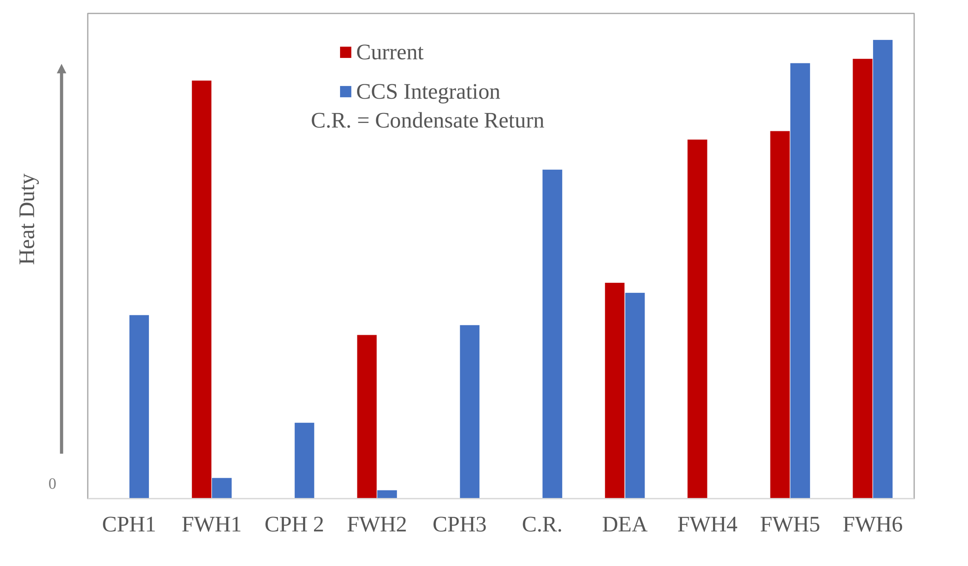

Figure 7. Comparing the associated duty for each component in the feed heating train between the current and CCS integrated cases

References

[1] Sanders, W.P. Turbine Steam Path Volume IIIa Mechanical Design and Manufacture. Tulsa: PennWell Corporation, 2004. Print.
[2] Soundararajan, R., Anantharaman, R., Gundersen, T. (2014). Design of Steam Cycles for Oxy-Combustion Coal based Power Plants with emphasis on Heat Integration. Energy Procedia, 51, 119-126.
[3] Gouedard, C., Picq, D., Launay, F., Carette, P.L. (2012). Amine degradation in CO_2 capture. I. A review. International Journal of Greenhouse Gas Control, 10, 244–270.
[4] Rinker, E.B., Ashour, S.S.,and Sandall, O.C., (1996). Kinetics and Modelling of Carbon Dioxide Absorption into Aqueous Solutions of Diethamolamine. Industrial and Engineering Chemistry Research, 35(4), 1107-1114.
[5] Garlapalli, R.K., Spencer, M.W., Alma, K. Trembly, J.P. (2018). Integration of heat recovery unit in coal fired power plants to reduce cost of carbon dioxide capture. Applied Energy, 229, 900-909.
[6] Lucquiaud, M., Gibbins, J. (2011). Steam cycle options for the retrofit of coal and gas power plants with post combustion capture. Energy Procedia, 4, 1812-1819.
[7] Oh, S., Yun, S. Kim, J. (2018). Process integration an design for maximizing energy efficiency of coal-fired power plant integrated with amine-based CO_2 capture process. Applied Energy, 216, 311-322.
[8] U.S. Department of Energy. (2012). Deaerator in Industrial Steam Systems. Energy Efficiency & Renewable Energy: Advanced Manufacturing Office.
[9] Brück, M. (2009). Cooling flue gas to maximize power plant efficiency. Power Engineering International, September.

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