Shand Coal-Fired Power Plant Integrating a Post Combustion CO_2 Capture Process

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Extended Abstract

The costs of the energy penalty are major concerns for power producing companies considering carbon capture and storage (CCS) technologies for mitigation of CO_2 emissions. The main objectives of this work involved evaluating the thermodynamic performances of retrofitting SaskPower's Shand Power Station, a coal fire power plant with a gross capacity of 305 MW, with CCS technology. Two primary topics were investigated: (i) Identifying the advantages of de-superheating by using indirect attemperation while reaping the benefits of recovering heat from the reboiler condensate, and (ii) Contrasting the benefits between additional stages to the intermediate pressure (IP) turbine paired with reduced crossover pressure and from the utilization of a back-pressure turbine.

GateCycle^{TM}, a commercially available heat and mass balance software, was used to model this work. Model integrity is established by conducting a process validation with Hitachi's Heat & Material Balance. The generation output and main steam flow obtained from GateCycle at Maximum Design Flow (MDF) and different percent turn downs was compared to Hitachi's Heat & Material Balance. The Average Absolute Deviation (AAD) of generation output and main steam flow were found to be 0.0437% and 0.0003% respectively. This allowed the optimization procedures to proceed with great confidence.

In a fully integrated coal-fired power plant – CCS project, the extracted steam must be de-superheated before being used for the amine regeneration process. This avoids the formation of hot spots which can contribute to degradation of solvent [1,2]. Steam is de-superheated to a temperature slightly higher than the saturation point. This can be accomplished by direct or indirect methods. The effects of four different process configurations of de-superheating and condensate return location on the plant thermal efficiency were studied (Table 1). A conventional configuration which uses direct attemperator is shown in Figure 1 while Figure 2 illustrates the use of an indirect attemperator paired with reboiler condensate heat recovery.

GateCycle^{TM} results of different de-superheating and reboiler condensate heat recovery methods are summarized in Table 1. The use of an indirect de-superheater paired with reboiler condensate heat recovery increases gross output from 266.1 MW to 271.5 MW - a 5% improvement. However, this configuration can require costly feed heating train modifications and additional equipment such as heat exchangers and control systems.

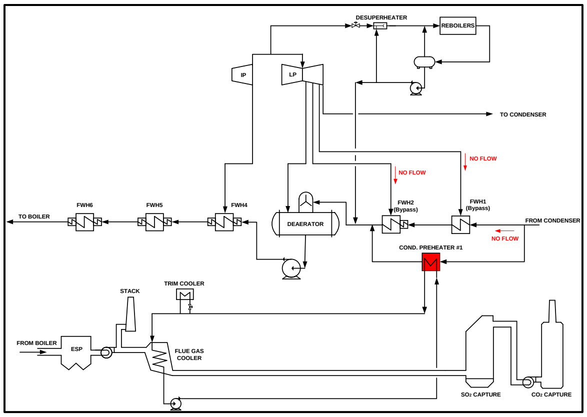

Fig. 1. Conventional integration process by direct attemperator

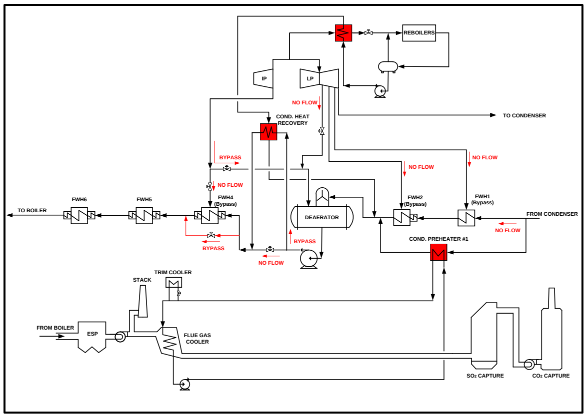

Fig. 2. Indirect attemperator with reboiler condensate heat recovery

Table 1. Summary of attemperation

Case	1	2	3	4
Attemperation	Direct	Direct	Indirect	Indirect
Reboiler condensate heat recovery	No	Yes	No	Yes
Deaerator steam	LP	LP	IP	IP
Gross output (MW)	266.1	267	267.2	271.5

Changes in gross generation with using subcooling temperatures at the reboiler outlet were investigated based on the conventional de-superheater configuration. Results are shown in Figure 3. A lower reboiler condensate outlet temperature resulted in higher gross generation output. This can be attributed to higher capacity for condensate preheating with waste heat. The effects of sub-cooling reboiler outlet temperature and condensate preheater and trim cooler duty are shown in Figure 4. It is important to note that the subcooling process not only reduced the volume of extracted steam but also maximized the heat recovery from flue gas obtained through condensate preheating by minimizing the trim cooler duty.

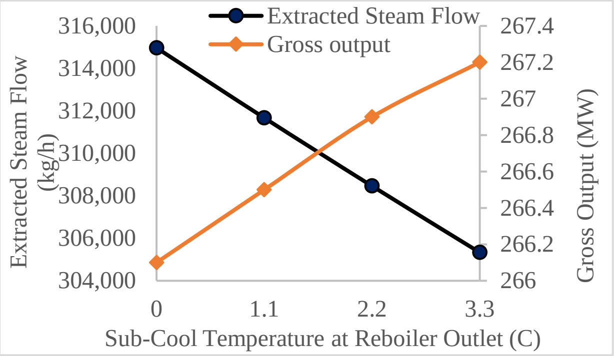

Fig. 3. Effect of subcooling on gross output and extracted steam flow

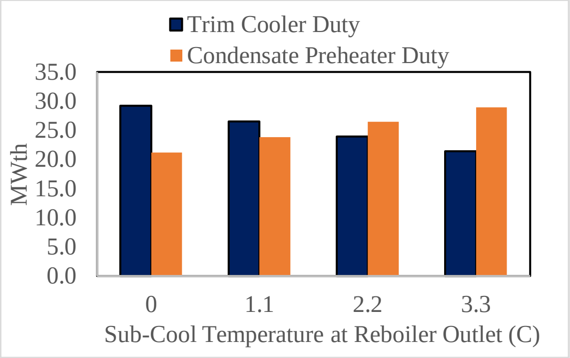

Fig. 4. Effect of subcooling on condensate preheater and trim cooler duty

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 helps to minimize the loss in power generation [3]. Extracting process steam from the crossover between intermedia pressure and low pressure turbines (IP-LP crossover) results in reduced pressure in the crossover but also causes increased stresses and reduced efficiency in the last stages of the IP turbine. A valve can be installed in the IP-LP crossover to maintain pressure at the exhaust of the IP turbine, but throttling of the crossover steam flow through this valve results in losses. If the process steam is extracted from the turbine at a pressure higher than what is required by the capture process, a back-pressure turbine can be used to reduce the pressure of the steam while also generating additional power in the process. Simplified diagrams of the steam cycle with addition of IP stages and utilization of a back-pressure turbine are illustrated in Figures 5 and 6 respectively.

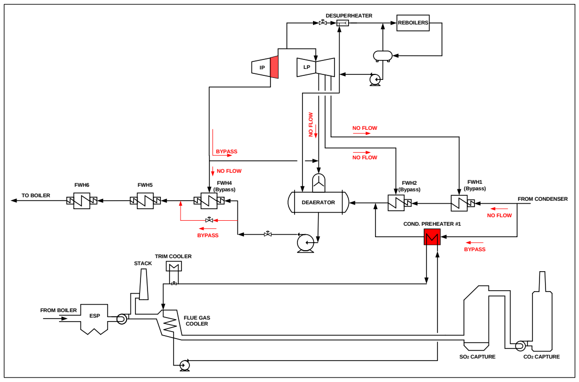

Fig. 5. Shand integrated CCS with additional IP stages

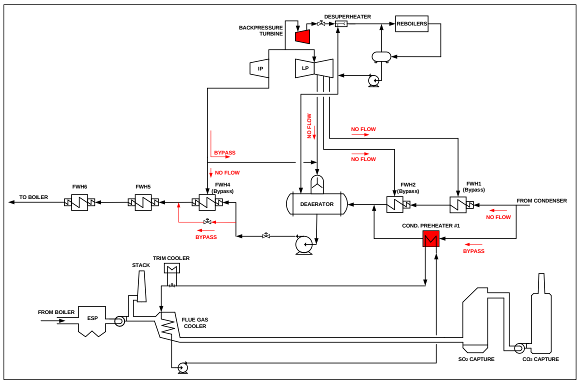

Fig. 6. Shand integrated CCS equipped with back-pressure turbine

The addition of a back-pressure turbine increases gross power output by 6.2 MW (Figure 7). Increasing IP stages from four to six increases gross output by 13.6 MW. Moreover, a steam path upgrade allows for the recovery of efficiency losses from turbine degradation and the application of new turbine technology. The existing steam path can be modified by replacing one or more of the turbine blade stages and inner casings, without changes to the outer casing or connecting piping. Such changes can allow for the addition of extra IP stages equating to improved efficiency and allowing the pressure at the crossover to be optimized for the capture process. Although a back-pressure turbine adds the possibility of increased efficiency, its installation can be very costly. Modifications to the turbine and the steam path can reproduce the efficiency increase offered by a back-pressure turbine. Furthermore, the added advantage of keeping the outer casing and associated equipment makes this option competitive or even be less expensive than the option to add a back-pressure turbine. It should be noted that although increasing the IP stages from four to six seems promising, it might also cause the pressure at the crossover to drop too low, thereby reducing the capture efficiency of the carbon capture process at reduced power plant loads. Further investigation is required.

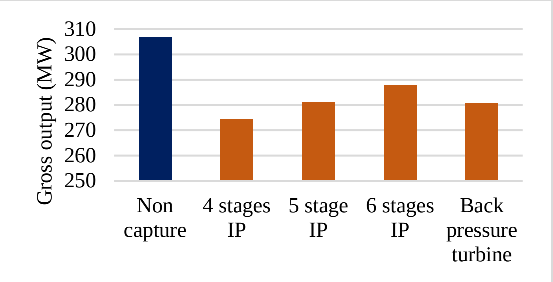

Fig. 7. Comparing gross output for different steam cycle modifications

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