Heat Rejection Design for Zero Liquid Discharge Shand Coal-Fired Power Station Integrated with CO_2 Capture and Storage

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Extended Abstract

This paper presents the design of a heat rejection system for the Shand Power Station that maintains the neutral liquid impact on the existing plant while adding SO_2 and CO_2 capture processes. The common concern when integrating CO_2 capture and storage (CCS) to a coal-fired power plant is the energy penalty due to the steam extraction for solvent regeneration [1]. However, another challenging issue is the additional cooling requirements especially when the plant has limited water and is operating under a Zero Liquid Discharge (ZLD) permit. ZLD management not only provides a solution to the environment challenge of eliminating wastewater but also reduces the volume of water a power plant needs to draw from other sources.

Shand Power Station is a 305 MW single unit pulverized coal-fired power plant with CO_2 emissions of over 2 million tonnes per year. This lignite-fired unit is located 12 kilometers east of the Boundary Dam Unit 3 CCS project. The International CCS Knowledge Centre is undertaking a feasibility study to explore the business case for a life extension with the addition of CO_2 capture. The existing power plant currently draws water from three sources which are surface water (Rafferty Dam), secondary treated sewage water from the city of Estevan (after passage through a constructed wetland) and a yard drainage system collecting snow melt, rain and runoff. The water is pumped to the raw water pond before sending it to the Cooling Tower (CT), where most of the heat rejection is realized by the evaporation of the water. The evaporation concentrates the contaminants in the water, requiring the blowdown of water into two streams. The first stream is sent to a softener to be clarified and softened before it is sent to the soft water pond and is recycled back to the cooling water system. The second stream of the blowdown water from the CT is sent to Vapor Compressor Evaporators (VCEs) and a demineralizer system in a water treatment plant to produce demineralized water used for boiler makeup. Excess demineralized water is sent to the soft water pond to be used in the heat rejection system. The residual from the water treatment plant is sent to the decant pond and used in a SO_2 removal process (LIFAC), to maintain the plant as ZLD.

The integration of CCS to Shand Power Station not only results in the increase in water consumption and cooling duty, but also additional water released from cooling the flue gas to the much lower temperature required for the process. Therefore, management of water usage becomes vital for this project. The integration with the CO_2 capture process increases the cooling duty to the plant by 339 MW_{th}. The additional cooling loads include flue gas cooling water cooler, wash water cooler at the top of absorber, CO_2 absorber and stripper cooler, and CO_2 compression and dehydration unit. Offloading of duty from the existing condenser of approximately 119 MW_{th} due to the steam extraction for solvent regeneration will free up heat duty from the existing cooling tower. This allows the flue gas cooling load to be serviced from the existing cooling tower and the lower heat duty frees up some makeup water allowance to be used in the new cooling system.

The design of the integrated CCS unit results in four new liquid water discharge streams being generated (i) water condensed out of the flue gas from the CCS facility quencher (ii) acidic water from Flue Gas Cooler (FGC) washing process (iii) water from the wet stage CO_2 compressor and (iv) blowdown from the heat rejection system. These streams need to be managed in such a way that there is no discharge as liquid. Fig. 1 shows a simplified diagram of optimized water usage and waste.

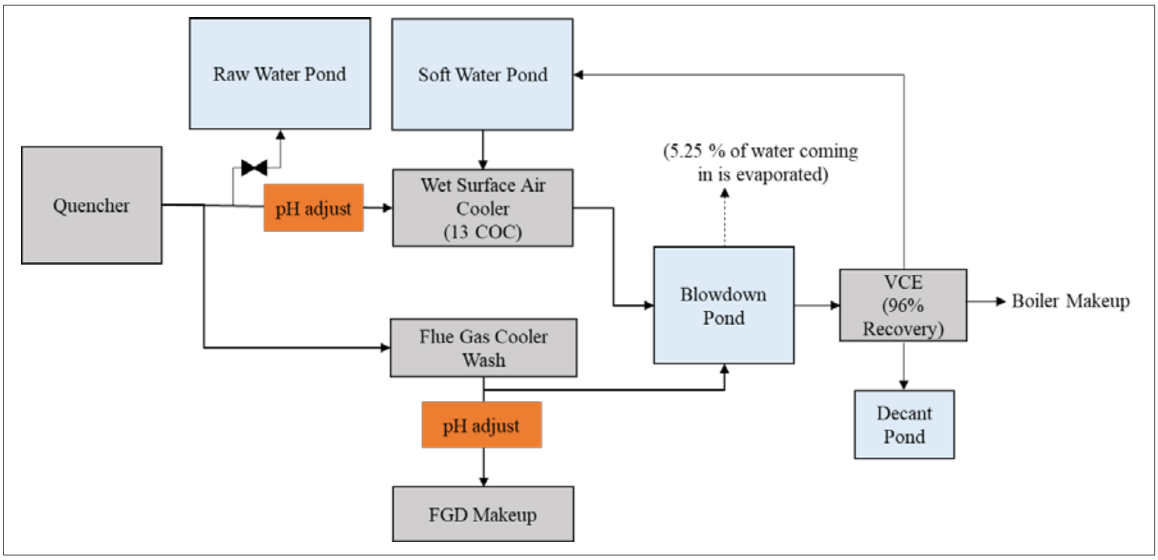

Fig. 1. Simplified diagram of optimized water usage and waste

The quenching system will generate 97.5 tonne/hr of liquid water that will be used for the FGC wash and a portion of the makeup requirements for the Wet Surface Air Cooler (WSAC). After washing the FGC, the water becomes acidic (pH ≈ 4) due to the dissolution of acidic contaminants in the flue gas. The spent wash water will be pH adjusted and used for Flue Gas Desulfurization (FGD) makeup, with un-needed surplus being sent to the blowdown pond without requiring pH adjustment. Based on water analysis, the WSAC can be operated with 13 Cycles of Concentration (COC). The WSAC blowdown will be mixed with the excess water from the FGD makeup in the blowdown pond. Some of the water in the blowdown pond is naturally evaporated while some of the water will be drawn to be treated by VCEs and the demineralizer system. The demineralized water produced from the demineralizer will be used for boiler makeup with the excess recycled back into the heat rejection system.

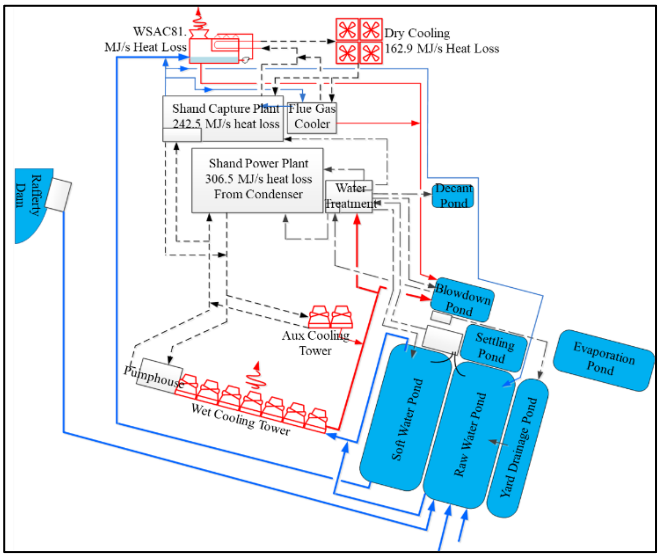

Fig. 2. Shand Power Station integrated CCS water balance

The heat rejection systems were designed and optimized by using Aspen HYSYS. Aspen EDR was used for equipment design and cost analysis. The design dry bulb and wet bulb temperatures are 18˚C and 13.7˚C respectively. These temperatures were obtained from 85th percentiles of Estevan's weather data for 15 years from 1991 to 2005. The designed heat rejection system for Shand integrated CCS is a hybrid dry and wet cooling system. Dry cooling alone cannot provide sufficiently low temperature of cooling water year-round because it is limited by dry bulb temperature. Wet cooling system alone is limited by the amount of water resources available for the process.

The design of the hybrid system was tailored for zero impact on the overall water balance of the plant and based on the best design strategy of maximizing the heat load in wet cooling which has a potential to reduce operation cost [2,3]. The water balance and flow diagram of water usage in the plant is shown in Fig. 2. The hybrid heat rejection system consists of 26 modules of dry air coolers and four modules of WSAC connected in series. The return cooling water from the CSS facility at the flow rate of 10,533 tonne/hr and the temperature of 44.5 ^{o}C will first reject heat in the dry air cooler, cooling it down to 31.5 ^{o}C. Then it is introduced to the WSAC to further reject heat to the desired cooling water temperature of 25 ^{o}C before returning to the CCS facility. The heat load on the dry air cooler and WSAC is 156.5 (66%) and 81.8 (34%) MWth respectively. The power consumption at the design condition is 3.91 MWe for the dry air cooler and 1.01 MWe for the WSAC. Both the dry air cooler and the WSAC have variable frequency drives (VFD) which allows them to adjust the relative amount of overall cooling to match ambient conditions, and allows the heat rejection to be shifted between wet and dry cooling in order to adjust the amount of cooling that is evaporative in order to maintain the water balance of the site.

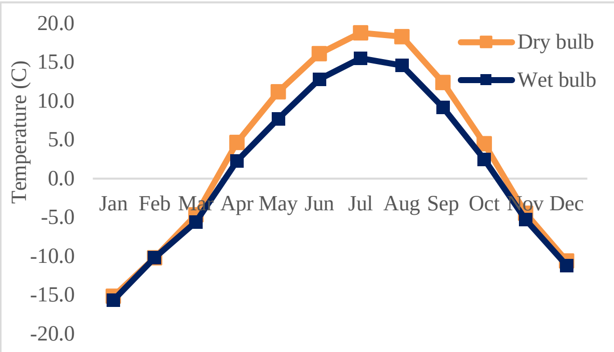

Fig. 3. Monthly average dry and wet bulb temperature

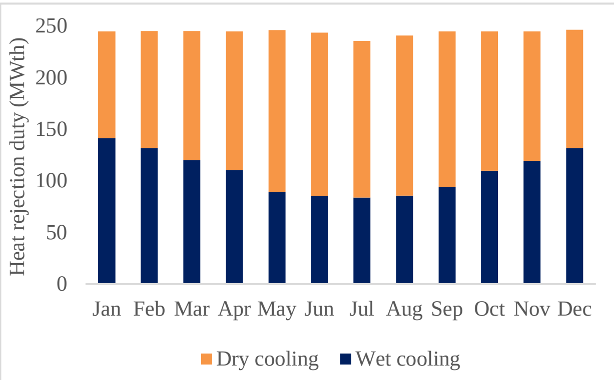

Fig. 4. Heat rejection load on wet and dry cooling

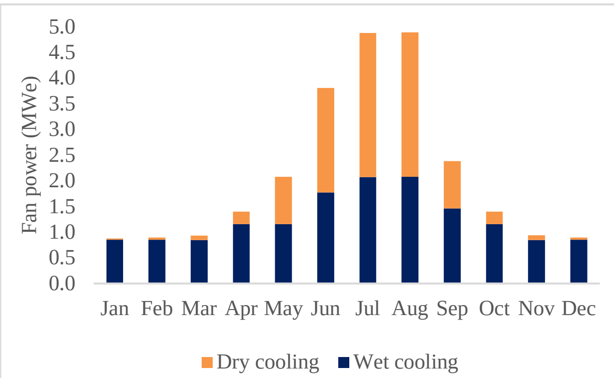

Fig. 5. Fan power consumption

Annual variations in dry bulb and wet bulb temperatures affect the heat load of the hybrid cooling system. To understand the impact of these variations, Thermoflex was used to simulate a series of cases. Initially a design model was built based on the 18 ^{o}C dry bulb temperature and 13.7 ^{o}C wet bulb temperature. The average dry bulb and wet bulb temperature of each month throughout a year from 2005 to 2012 in Estevan area (shown in Figure 3) were then evaluated using the model. Figure 4 presents the attribution of heat rejection load to the dry and wet cooling system associated with the average dry and wet bulb temperatures of each month. It is noted that a higher temperature shifts the heat rejection load towards dry cooling. Fan power consumption was also evaluated (Figure 5). Results indicated that a lower ambient temperature correlates to reduced fan power requirements. The average fan power consumption throughout a year is 2.12 MW which is only 43% of the design case (4.9 MW).

References

[1] Lucquiaud, M., & Gibbins, J. (2011). Effective retrofitting of post-combustion CO_2 capture to coal-fired power plants and insensitivity of CO_2 abatement costs to base plant efficiency. *International Journal of Greenhouse Gas Control*, *5*(3), 427-438.

[2] Barigozzi, G., Perdichizzi, A., & Ravelli, S. (2011). Wet and dry cooling systems optimization applied to a modern waste-to-energy cogeneration heat and power plant. *Applied Energy*, *88*(4), 1366-1376.

[3] Zhai, H., & Rubin, E. S. (2010). Performance and cost of wet and dry cooling systems for pulverized coal power plants with and without carbon capture and storage. *Energy Policy*, *38*(10), 5653-5660.