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Heat Exchange in CCS Feasibility Studies – A review of the impact of temperature cross

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Abstract

Carbon Capture and Storage (CCS) is a critical solution for achieving net-zero emissions, particularly for hard-to-abate industries such as cement, steel, and chemicals, as well as the decarbonization of power generation. As the global CCS industry expands, advancements in capture, transport, and storage technologies are driving cost reductions, improving feasibility, and accelerating deployment.

Feasibility studies are a key part of the techno-economic analysis of a potential CCS system prior to further engineering exploration and eventual integration into an environment for emissions mitigation. Within CCS techno-economic analysis, significant attention is devoted to the absorber and desorber within a typical amine capture facility to optimize specific reboiler duty, solvent loading, and equipment sizing, all of which have an impact on the overall system cost to capture and avoid one tonne of CO_2. Other sections of typical amine plants (Figure 1) such as the Lean-to-Rich Heat Exchanger receive relatively less attention in CCS techno-economic analysis literature but are by no means less important. On the contrary, the heat exchange that occurs within this subunit has ramifications upon the rest of the CCS plant and can alter the resultant overall costs to capture CO_2 from a post-combustion CO_2 point source.

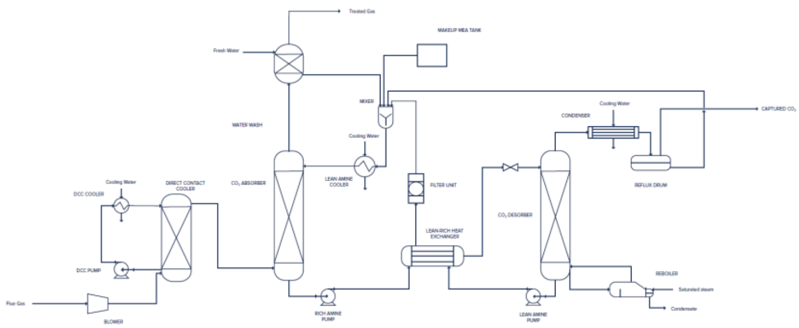

Figure 1: Process Flow Diagram of a Typical MEA Capture Plant [1]

The lean-to-rich heat exchanger transfers thermal energy between the cooler rich solvent from the absorber heading to the desorber and the hotter lean solvent from the desorber heading back to the absorber. There is an incentive for heat exchange to be maximized across this unit operation, as cooler lean solvent has better absorption characteristics in the exothermic CO_2-MEA absorption reaction, and hotter rich solvent reduces the thermal duty required by the reboiler in the desorber, indicated by a lower specific reboiler duty in the system [2].

Using a typical heat exchanger pinch limitation of 10°C across the ends of the heat exchanger [3], the boundary is met between the lean outlet and the rich inlet. This limitation, when using process modelling software, also results in the rich outlet (cold stream outlet) being hotter than the lean stream outlet (hot stream outlet). This situation is known as a "temperature cross" and is shown in Figure 1. A modelled scenario without a temperature cross is shown in Figure 2. The scenario without temperature cross results in a lower rich solvent temperature (cold stream) headed to the desorber, increasing specific reboiler duty, and a higher lean solvent temperature (hot stream) headed to the absorber, impacting absorption.

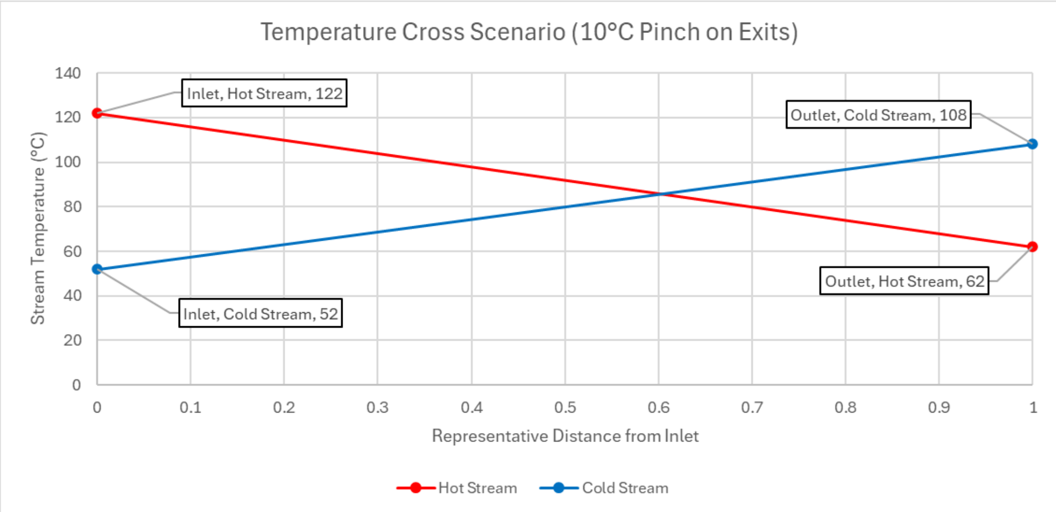

Figure 2: Temperature Cross Scenario for a Lean-to-Rich Heat Exchanger in a Typical MEA Capture Plant using 10°C Approach on the Exits of the Heat Exchanger.

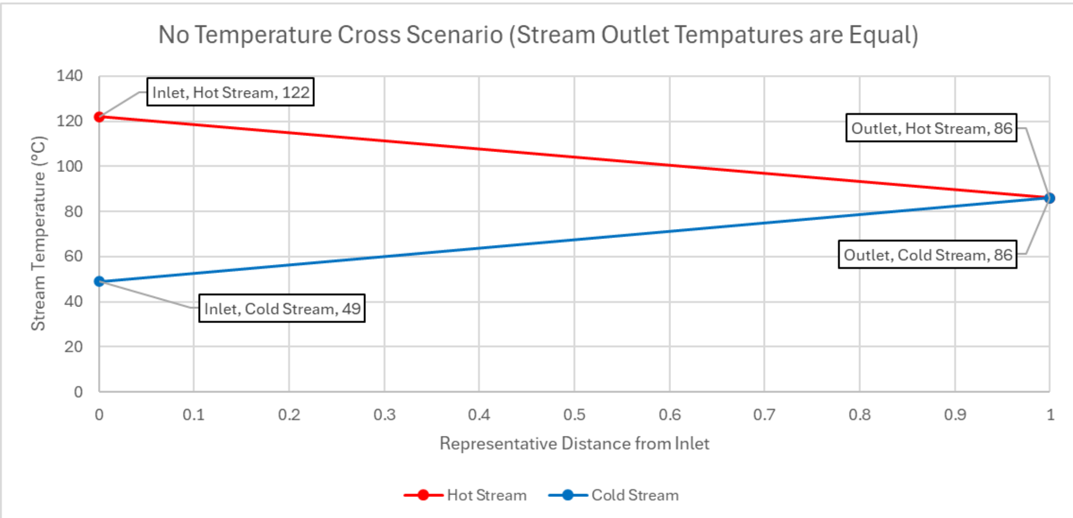

Figure 3: No Temperature Cross Scenario for a Lean-to-Rich Heat Exchanger in a Typical MEA Capture Plant Using the Condition that the Hot and Cold Outlet Temperatures Must be Equal.

Shell and tube heat exchangers are the most common type of heat exchangers used in chemical, petroleum and general process services [4]. In designing a shell and tube heat exchanger for service, the "true temperature difference" (ΔT_m) is estimated by applying a correction factor (F_t) to the logarithmic mean temperature difference (ΔT_{lm}) (Eqn. 1)[3]:

$$\Delta T_m = F_t \times \Delta T_{lm} \quad (Eqn. 1) - [3]$$

In shell and heat tube exchanger design, Ft can be manually calculated or derived from graphical interpretation [3][4]. When a temperature cross occurs, the correction factor falls rapidly, reducing the true temperature difference used in design applications. It is noted by Towler and Sinnott that "an economic [shell and tube] exchanger design cannot normally be achieved if the correction factor F_t falls below 0.75" [3]. In the model visualized in Figure 2, a typical model of the lean-to-rich heat exchanger conditions, the exchanger has a correction factor well below 0.75. Shell and tube heat exchangers have been reported in techno-economic analysis of CCS systems [2].

Recent CCS project front-end engineering design studies indicate that the lean-to-rich heat exchangers selected tend not to be shell and tube heat exchangers, and instead plate and frame type heat exchangers tend to be selected [5][6][7]. This difference between technoeconomic analysis and front-end engineering design selection may result in variations between the costs of capture at the different study levels.

This presentation will explore the impacts of temperature cross within an MEA plant on the lean-to-rich heat exchanger, comparing shell and tube heat exchangers with various shell-passes and plate & frame heat exchanger types. This presentation will then further discuss the impacts on the cost of the lean-to-rich heat exchanger subunit and review the system impact on the overall costs of capture.

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Keywords: Process Configuration, Heat Exchange; Process Modelling; Temperature Cross; Techno-Economic Analysis