

Integration of a high-pressure piperazine capture plant with a power plant: An energetic evaluation

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ABSTRACT

Post-combustion CO₂ capture can have a significant contribution to the reduction of CO₂ emissions. However, it also requires a considerable amount of energy, causing a significant decrease in the net electricity output of the power plant it is associated with. A vast array of research initiatives is currently aimed at reducing this decrease. One of the main approaches is the development of improved solvents, replacing the conventionally used 30 wt% aqueous mono-ethanolamine (MEA) solution. Recently, Rochelle et al. [1] reported on the use of aqueous piperazine (PZ) and concluded that it could be the new standard solvent for CO₂ capture. One of the discussed advantages of PZ is its thermal stability, allowing the regeneration step of the absorption process to be done at a temperature of 150 °C, instead of the 120 °C which is typically used for MEA solutions. This increased regeneration temperature, in combination with a higher CO₂ desorption pressure, is claimed to allow a better energy performance of the capture plant.

In the current work, we perform a more-detailed analyses of the energetic performance of a 1000 MW_{el} coal-fired power plant in combination with a post-combustion CO₂ capture process using 40 wt% aqueous PZ as solvent. Similar to the work by de Miguel Mercader et al. [2], the energy penalty will be evaluated by the integrated use of two types of model approaches. In this work, the capture plant is modeled in detail using Aspen Plus, while the power plant and CO₂ compression are modeled with a high-level approach using efficiency performance curves that are based on a combination of fundamental and empirical relations. For the power plant, these curves give the operational envelope of the plant and describe the plant efficiency as function of power plant load and thermal energy withdrawal characteristics.

The CO₂ capture plant is a slightly simplified version of the process mentioned by Rochelle et al. [1]. It is a conventional absorption process, with one important change: desorption is realized by a series of two heated flashes, both operating at 150 °C. To allow for the two flashes, the rich solvent pump increases the pressure of the solvent to about 15 to 20 bar. The CO₂ that is desorbed in the second low-pressure (LP) flash is first cooled to a temperature of 40 °C and compressed to the pressure at which the first high-pressure (HP) flash is operating. Subsequently, it is combined with the CO₂ that is desorbed in the HP flash and fed to a compression train.

The entire absorption process is modeled in Aspen Plus V7.3. A default template provided by the software vendor is used as basis for the simulation. The pressure of the LP flash is found by specifying the lean solvent loading. The pressure of the HP flash is varied as part of the current investigation. Upon increasing the pressure of the HP flash, its thermal duty is being replaced by the duty of the LP flash. Increasing the pressure also increases the required pump duty, and

because the amount of CO₂ released in the second flash increases as well, the duty of the LP to HP compressor increases too. The duty of the compression train, which is not included in the capture plant model but in a separate submodel, decreases if the HP flash pressure increases.

The resulting total heat duty shows a minimum of 2.65 GJ_{th}/ton CO₂ around a pressure of 15 bar. The total electric duty of the capture plant increases from 0.05 GJ_{el}/ton CO₂ at a pressure of 12 bar up to 0.09 GJ_{el}/ton CO₂ at a pressure of 17 bar. In order to calculate the combined effect of the heat and electric duties, the difference between the quality of electrical energy and heat at a temperature of 150 °C needs to be taken into account. This can be done by using the exergy contents of these streams. The exergy contents of electrical energy is identical to its energy contents. For heat at a temperature of 150 °C and an ambient temperature of 25 °C, the conversion factor becomes 0.33. The minimum of the combined thermal and electric duties is found at a pressure of 14.5 bar, where the total duty of the capture plant is 0.96 GJ_{ex}/ton CO₂.

Rochelle et al. [1] suggest a pressure of 17 bar and report a minimum value for the total heat duty of 2.6 GJ_{th}/ton CO₂. Although the found heat duties are lower than the duties typically found for standard and advanced MEA-based processes, being between 3.0 and 3.6 GJ_{th}/ton CO₂ [2], it should be kept in mind that there exists a difference between the quality of the heat that is used. Based on exergy, 2.6 GJ of heat at 150 °C is equivalent to approximately 3.5 GJ of heat at 120 °C. In practice, this difference in quality translates into a different steam quality requirement, which eventually causes a different efficiency penalty of the power plant. So, although the electric duty of the PZ process is lower than that of the MEA-based processes, because CO₂ is desorbed at higher pressures, its overall energetic performance can still be worse than that of the MEA-based processes.

This work assesses the influence of the different heat quality and quantity requirements on the efficiency of a new-build power plant for which the turbine pressures can still be designed, as well as a retrofit case for which the turbine pressures are already determined. In this way, a more-definite answer can be given on the question whether the energetic performance of the PZ process is indeed better than that of an advanced MEA-based process. The results and conclusions presented in this work are an important initial step towards the estimation of the true potential of PZ-based capture processes.

REFERENCES

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