Process Simulation and Techno-Economic Analysis of a Post-Combustion Capture Unit Using a Blend of AMP/PZ as Solvent: Application to a Biomass-Fired CHP Plant

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AMP/PZ blend: a promising solvent for amine-based carbon capture?

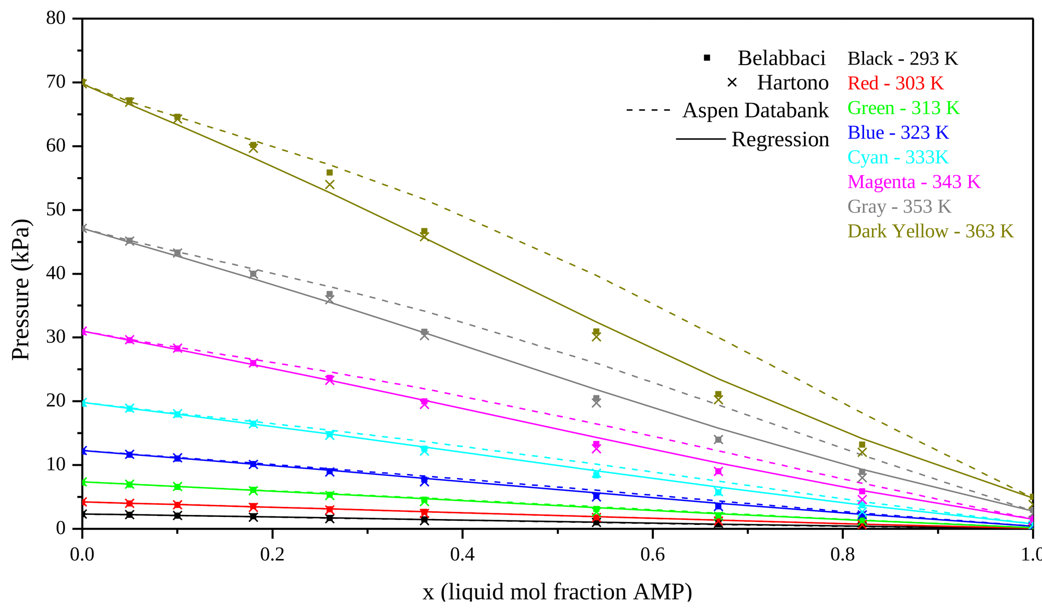
Identifying novel solvents is an important research topic in the field of solvent-based CO_2 capture. The present study compares the performance of conventional monoethanolamine (MEA) against a specific amine blend that emerges as a promising alternative: the aqueous solution of 27 wt% 2-amino-2-methyl-1-propanol (AMP) promoted with 13 wt% piperazine (PZ). It is known to lower the process energy requirements, which impede the relevance of the technology.

Using an updated thermodynamic model, a process simulation model is developed for the AMP/PZ blend. The target capture rate is set at 90%. The model is then adapted to an existing biomass-fired combined heat and power (CHP) plant. A techno-economic analysis is conducted to compare the performance of the two competing solvents.

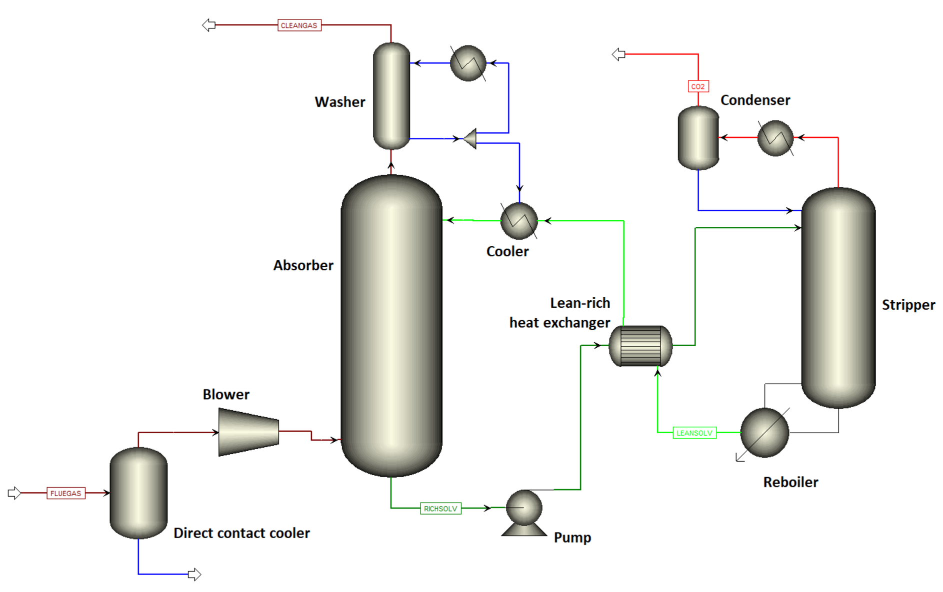
Case study: Sart Tilman CHP plant (up to 7 MW_{th} to supply the district heating network, and up to 2.4 MW_{el})

Modeling approach

- Experimental vapor-liquid equilibrium (VLE) data sets are used to regress the binary interaction parameters of the AMP/PZ/H_2O system.
- With the addition of reaction kinetics from literature, an updated thermodynamic model is obtained.
- Based on the updated model, an Aspen Plus process simulation model of an AMP/PZ-based CO_2 capture unit is assembled.
- Pilot plant results are reproduced to validate the model. The predicted capture rate only deviates by an average absolute relative deviation (AARD) of 2.22%.
- The newly-validated process simulation model and its existing MEA-based counterpart are then adapted to the selected case study.



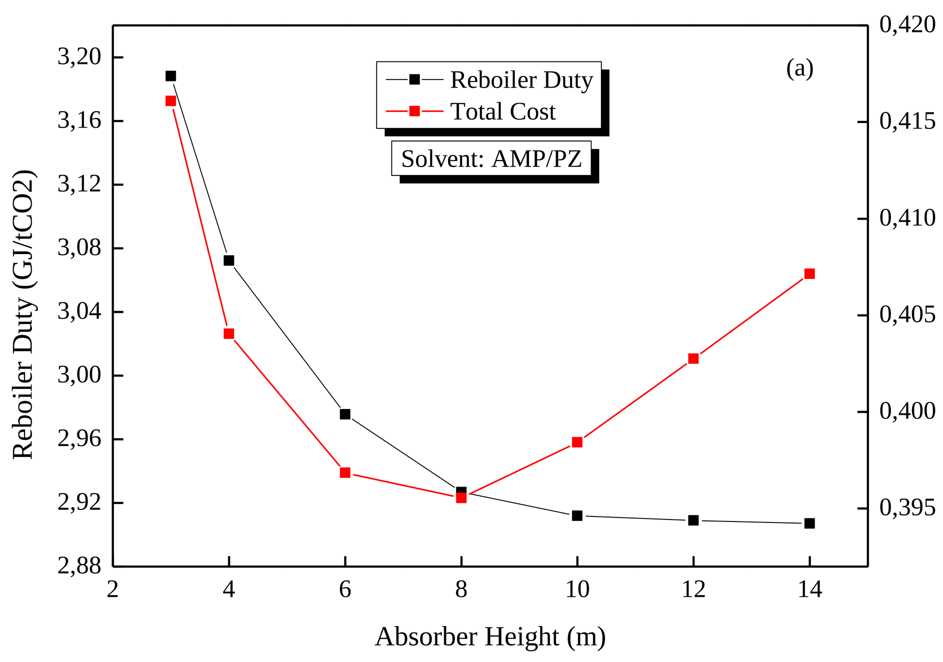
Regressed P-x curves used to update the AMP/PZ thermodynamic model



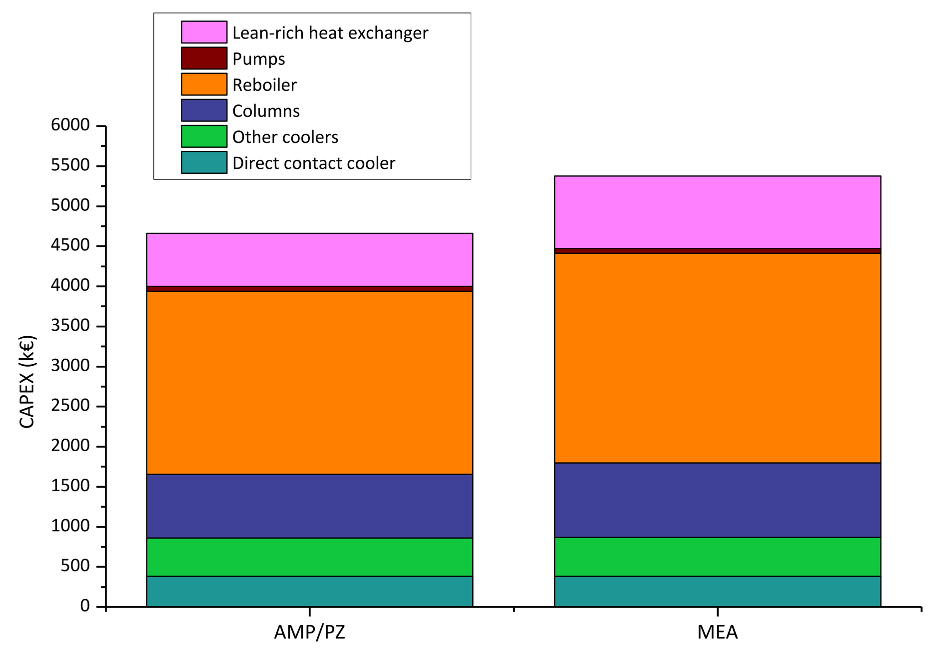
Process flow diagram of the CO_2 capture process (both solvents)

Optimization and economic evaluation

- For both solvents, the operating conditions (size, solvent flow rate, pressure) are optimized to find the tradeoff between cost and energy consumption. At its optimized, nominal conditions, the AMP/PZ unit requires 2.86 GJ/tCO_2 versus 3.61 GJ/tCO_2 for the MEA-based process.
- An economic evaluation is conducted by estimating the CAPEX and OPEX thanks to a methodology that is based on empirical correlations, estimation charts and correction factors. The resulting capture costs favor the AMP/PZ blend (102.14 €/tCO_2 vs. 115.36 €/tCO_2).



Example of optimization results: optimal absorber height in the AMP/PZ system

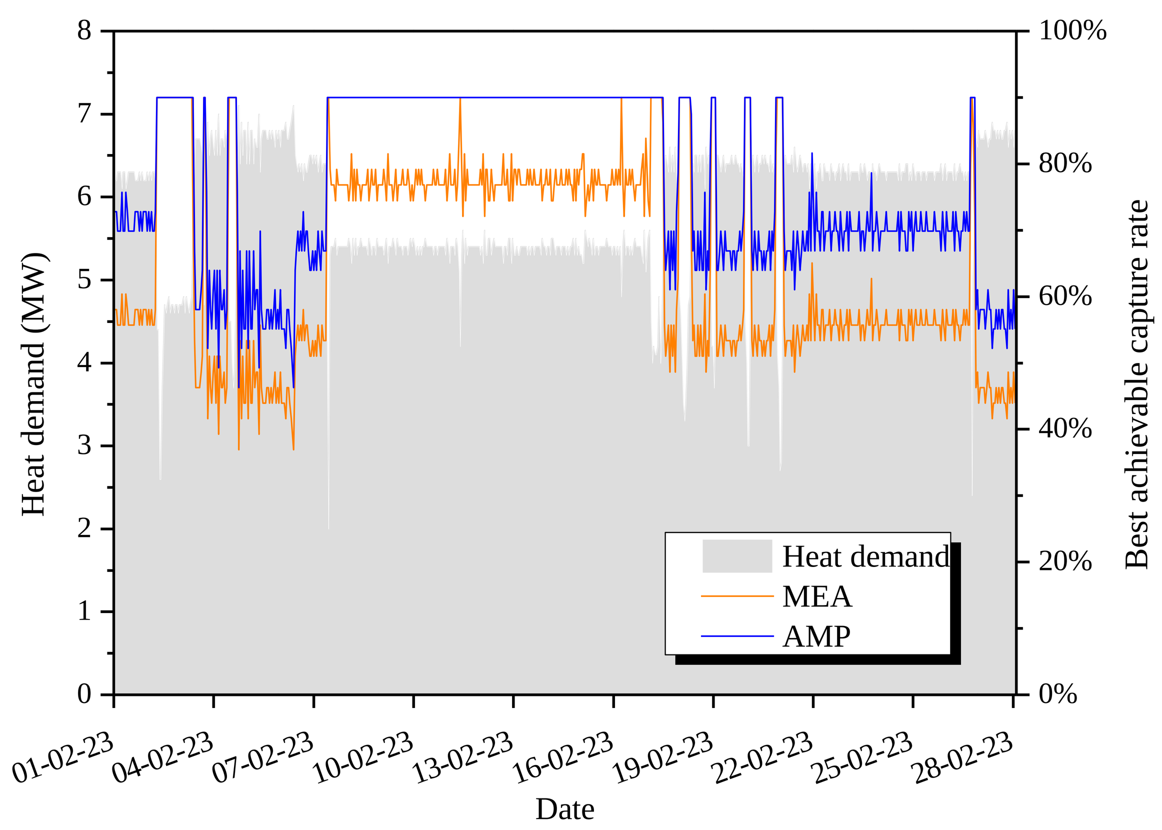


Breakdown of the main contributors to the CAPEX for both solvents

Energy impact on the CHP plant

A simplified mass and energy balance model of the CHP plant is developed. Actual plant data from February 2023 is used to simulate operation during an entire month. The district heating demand is kept as a constraint. Two situations can be distinguished:

1. When the leftover energy is sufficient to reach the 90% capture rate, the loss of cogeneration efficiency amounts to 6.81% (AMP/PZ) vs. 8.54% (MEA). For reference, the initial CHP plant efficiency can reach 70.52%.
2. Every time the CHP plant cannot provide enough energy, the capture rate must be lowered. Over the course of a month, the uncaptured emissions due to this adaptation are halved (48.21%) when the capture unit uses AMP/PZ instead of MEA. If a gas boiler is used to bridge the gap to the 90% target, the cost difference reaches 58.97% in favor of AMP/PZ because of the fuel cost and the emission cost associated with the combustion.



Hourly heat demand over the selected month and the corresponding best achievable capture rates for both solvents. The difference between the curves yields the actual energy gain from using AMP/PZ.

Conclusions

The present study highlights the potential of AMP/PZ as an alternative to MEA for solvent-based CO_2 capture. The results from the simulation model, which is based on an updated thermodynamic model, show that the blend outperforms energy-wise the conventional solvent (21% difference). The economic analysis supports the alternative solvent as well, with a 11.5% reduction in overall capture cost.

While agreeing with the previous conclusions, the evaluation of the energetic impact on the actual plant goes a step further and highlights the relevance of context in techno-economic analyses. Nominal conditions are insufficient to obtain a complete image of the performance in a dynamic system.

In order to consolidate these claims, the study could be extended to longer time periods. In additional, using alternative economic evaluation methods could strengthen the estimated figures. Other potential hosts for CO_2 capture could also be studied similarly.