Simulation and economic analysis of MEA+PZ and MDEA+MEA blends in post-combustion CO2 capture plant

Sina Orangi, Solomon Aforkoghene Aromada, Neda Razi and Lars Erik Øi

September 27, 2021

Simulation and economic analysis of MEA+PZ and MDEA+MEA blends in post-combustion CO_2 capture plant

Sina Orangi, Solomon Aforkoghene Aromada, Neda Razi, Lars Erik Øi

230750@usn.no

Extended Abstract for SIMS2021

Key words: Simulation, Carbon capture, optimization, Aspen HYSYS, cost estimation, CAPEX, OPEX

Abstract

Amine based carbon capture is regarded as the most mature process to decrease or remove CO_2 emission from coal- and gas fired power plants. The process is based upon applying an amine, especially monoethanolamine (MEA) as the most actual amine [1], to dissolve CO_2 from flue gas in an absorption column shown in figure 1. The outlet solution from the bottom of absorber, rich amine, is sent to a stripper column to be regenerated and sent back to the absorber. The process can be controlled by numerous parameters. That is why various simulations and experimental studies have been conducted to improve performance of the process.

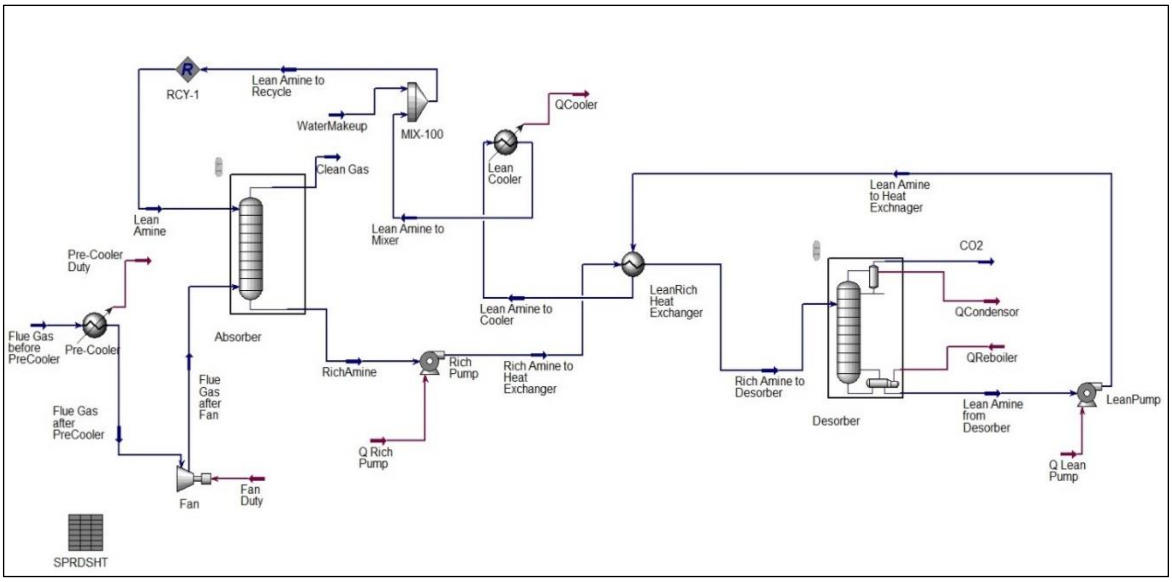

Figure 1: Simulated conventional process of removal CO_2 in Aspen HYSYS version 12

Generally, process improvements can be classified into three different categories, including [2]:

- Different configuration of removal process e.g. vapor recompression
- Optimization of operational conditions e.g. pressure and temperature of absorber and stripper column
- Switch from monoethanolamine (MEA) to other solvents or their blends

Several projects have been conducted at Telemark University College and University of South-Eastern Norway to reach an optimal removal simulation known as base case where 30% MEA solvent absorbs CO_2 from flue gas [3]. MEA is one of the most important absorber liquids and the least expensive [4].

The conventional simulated process, figure 1, has been performed in a 10-stage absorber, a 6-stage desorber and 10℃ as minimum different approach temperature in the lean rich heat exchanger. The removal efficiency is 85%.

The explained process could be performed with other sorts of solvents or their blends. Primary and secondary amines, like MEA, have fast reaction kinetics with CO_2 but with high energy consumption to regenerate amine in the stripper. Tertiary amines, like MDEA, require less regeneration energy but they absorb CO_2 slowly [5] [6]. In addition, corrosion and solvent degradation are drawbacks of MEA while for MDEA maximum loading capacity, lower corrosion and oxidative degradation than MEA are positive [6]. Piperazine (PZ) is added to increase the reaction rate. Thus, mixing amines could provide blends with less shortcomings. Other important parameters as heat of absorption, cyclic loading, CO_2 lean and rich loadings are not the same for different solvents and blends. For instance, [5] experimented heat of absorption for pure amines of MEA and MDEA where MDEA solvent had lower heat of absorption and consequently lower regeneration energy.

The most influential parameter for the total cost of removal plants is regeneration energy. Based on [7], this parameter accounts for up to 70% of energy demand. This study intends to simulate the effect of adding piperazine and MDEA to MEA in term of regeneration energy, cyclic capacity and CO_2 loading. Carbon Dioxide removal plant process have been simulated with 3 different concentrations of (MEA+PZ) where 5 wt%, 10% wt% and 15 wt% piperazine is added to 30 wt% MEA (base case).

The work proceeded with 5 different cases of MEA+MDEA blends where 5 wt%, 10 wt%, 15 wt%, 20 wt% and 25 wt% MDEA have been added and simulated to 30 wt% MEA. The results show that a blend of 30 wt% MEA + 5 wt% PZ is optimum in term of regeneration energy compared to other concentrations of MEA+PZ. Furthermore, 30 wt% MEA + 15 wt% PZ provides the lowest amount of regeneration energy among simulated cases for MEA+MDEA blends. The results are presented in figure 2 and figure 3 below.

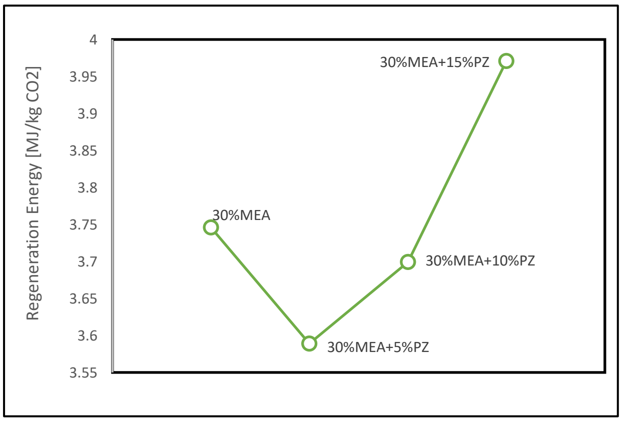

Figure 2: assessment of adding different concentration of piperazine to MEA in term of regeneration energy

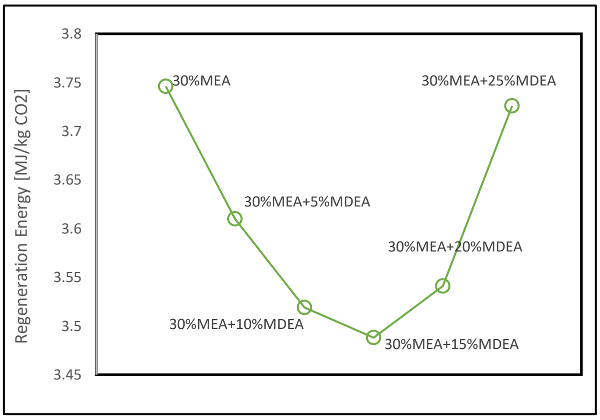

Figure 3: assessment of adding different concentration of MDEA to MEA in term of regeneration energy

Amine blends of (30 wt% MEA+ 5% wt% PZ) and (30 wt% MEA + 15 wt% PZ) led to a decline by 4.9% and 7.5% in regeneration energy compared to base case (30 wt.% MEA) with 3.771 MJ/ kg absorbed CO_2.

An economical study for whole simulated processes has been performed. These studies originate from mass and energy balance equations, resulting in dimensioning all equipment pieces in the plant. Aspen In-Plant Cost Estimator has been used for cost analysis. Calculated CAPEX updating material and other relevant expenses, e.g. engineering costs, direct costs and the Enhanced Detail Factor (EDF) method was applied. Besides, OPEX was calculated with the aid of extracted data from [8]. Summation of CAPEX and OPEX forms total installed costs. The applied Aspen In-Plant Cost Estimator provides data for 2018, whereas the project should be updated to 2021 so that CEPCI (Chemical Engineering Plant Cost Index) was implemented.

Furthermore, both suggested blends have potential to improve the economy in a removal plant. Total amount, including OPEX and annualized CAPEX, for base case is 72.1 million Euro per year. According to economic analysis for simulated cases, both blends, (30 wt% MEA + 5 wt% PZ) and (30 wt% MEA + 15 wt% MDEA), lead to approximately 1.5% and 3.8% savings in total costs for a Carbon Dioxide removal plant which is mainly coming from reduction in required steam.

References

[1] L. E. Øi, "CO2 removal by absorption, chanllenges in modeling," in *Mathematical and Computer Modelling of Dynamical Systems*.

[2] L. Dubois and D. Thomas, "Comparison of various configurations of the absorption-regeneration process using different solvents for the post-combustion CO2 capture applied to cement plant flue gases," *International Journal of Greenhouse Gas Control,* pp. 20-35, 2018.

[3] L. E. Øi, E. Sundbø and H. Ali, "Simulation and Economic Optimization of Vapor Recompression Configuration for Partial CO2 capture," in *58th SIMS* , Reykjavik, Iceland, 2017.

[4] S. Hasan, A. J. Abbas and G. Ghavami Nasr, "Improving the Carbon Capture Efficiency for Gas Power Plants through Amine-Based Absorbents," *Sustainability,* pp. 1-27, 2020.

[5] R. Zhang, X. Zhang, Q. Yang, H. Yu, Z. Liang and X. Lue, "Analysis of the reduction of energy cost by using MEA-MDEA-PZ solvent for post-combustion carbon dioxide capture (PCC)," *Applied Energy,* pp. 1002-1011, 2017.

[6] T. N. Borhani and M. Wang, "Role of solvents in CO2 capture process: The review of selection and design methods," *Renewable and Sustainable Energy Reviews,* 2019.

[7] A. S. Lee, J. C. Eslick, D. C. Miller and J. R. Kitchin, "Comparison of amine solvents for post-combustion CO2 capture: A multi-objective analysis approach," *International Journal of Greenhouse Gas Control,* pp. 68-74, 2013.

[8] H. Ali, N. H. Eldrup, F. Normann, R. Skagestad and L. E. Øi, "Cost Estimation of CO2 Absorption Plants for CO2 Mitigation - Method and Assumptions," *International Journal of Greenhouse Gas Control,* pp. 10-23, 2019.