Effect of various Key Process parameters on the Reboiler heat duty of CO₂ capture unit using single and blended amine system

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Abstract

Chemical absorption-Regeneration technology is the most viable technology used to separate CO₂ from the industrial flue gas stream. Among the various solvents used, aqueous alkanolamine solution is widely used reagent in the acid gas separation unit. The present study investigate the effect of various key process parameters for different solvents (PZ + MDEA, MEA + MDEA, MEA, MDEA) such as solvent flow rate, amine concentration, CO₂ lean loading, and the solvent rich IN temperature etc. on the reboiler heat duty requirements using Aspen Plus V8.8 platform. The sensitivity analysis give an inference about the results obtained from the comparative study of all four systems. The Aspen Plus simulation study of carbon capture plant using amines is the stepping stone for the more complex and tedious rate based studies as its gives us an estimate of different properties and constraints.

Keywords: CO₂, Absorption, Amine, Reboiler heat duty.

1. Introduction

Carbon capture and storage (CCS) is considered as the most viable and matured technology practised worldwide for mitigation of atmospheric green house gases and minimizing global warming effects. Carbon dioxide (CO₂) is considered as the major green house gas, and the coal based thermal power plants are its major contributors.

The conventional solvent such as monoethnaolamine (MEA) based Chemical absorption technology, which has been used for decades for the absorption of carbon dioxide (CO₂) from a post-combustion process suffers from high energy penalty [1]. The high energy consumption for the regeneration of the solvent is one of the main shortcomings of this technology. Regeneration energy accounts for about 70% of the overall operating cost [2]. Thus, the study of regeneration heat duty (Qreg) for chemical solvent regeneration is very important.

In the industrial CO₂ capture process, the Qreg, consists of three parts: (1) \(q_{\text{abs}}\) heat of absorption for the dissociation of chemical bonds between CO₂ and the solvent, (2) \(q_{\text{sen}}\) sensible heat for raising the temperature of solution, and (3) \(q_{\text{vap}}\) vaporization heat for evaporating liquid water to water vapor for CO₂ stripping. Hence, the Qreg can be significantly affected by both solvent properties and operating conditions. Therefore, a comprehensive study of the Qreg requirement for amine regeneration is crucial to provide accurate and reliable operating parameters for the design and economic evaluation of the amine-based CO₂ capture process.

2. Aspen Plus simulation

The Carbon dioxide absorption phenomena with amines are simulated with ELECNRTL Property Method in Aspen plus V 8.8 platform. ELECNRTL model is selected for the present simulation as it is the most versatile model and can handle both very low and high concentration of aqueous and mixed solvent systems. The solubility of gases is modeled with Redlich–Kwong equation of state. The implemented process flow diagram has been shown in Fig. 1. Both the absorber and the desorber column in the template are of the type RadFrac, which is a column selected from the Aspen Plus model bank. The operation data from the experimental works of Tibor Nagy et al. [3] were used to specify feed conditions and unit operation block specifications in the model and data for chemical reactions and thermodynamic property parameter were obtained from literature study. The effects of different operating parameters on Reboiler Heat duty were studied as follows:

3. Result and Discussion

3.1. Solvent flow rate

Reboiler duty increases almost linearly with the increase in the flow rate of LEAN-IN. As seen in Fig.2, increase in flow rate improves CO₂ absorption but alongside it also increases the heat requirement of regeneration. In the absorption/desorption process for CO₂ capture, solvent flow rate is a key operational parameter. It greatly influences the mass transfer performance in both the absorber and desorber columns. The Qreg reduces with decrease in solvent flow rate because the effective
Interfacial area in the striper was increased [4], resulting in the enhancements of both mass and heat transfer performances.

This is also due to the fact that higher the temperature, easier is the reversibility of the reactions occurring in the absorber column to strip out CO$_2$.

### 3.3 Amine concentration

Higher amine concentrations can lead to more CO$_2$ being absorbed in the absorber and desorbed in the regenerator at the same solvent flow rate. [5]

An increase in amine concentration from 23 wt% to 38wt% leads to a reduction of the $Q_{\text{reg}}$. This is because higher amine concentration can lead to the more CO$_2$ being absorbed per unit volume solution. In other words, to release the same amount of CO2 at the same lean/rich CO2 loadings, a higher amine concentration will require less solvent flow rate, resulting in a reduction of sensible heat. Also, at a given CO2 loading, the equilibrium CO2 partial pressure increases with the concentration of alkanolamine. This suggests that more concentrated solution can be regenerated at a greater CO2 partial pressure, consuming less energy for evaporating a lower amount of water vapor at the reboiler.

### 3.4 CO$_2$ Loading

In the carbon capture process, the CO$_2$ lean loading has a significant effect on the $Q_{\text{reg}}$ since it directly influences the equilibrium partial pressure of CO$_2$ and the driving force for mass transfer in the system.
It can be found from Fig.5 that the \( Q_{\text{reg}} \) decreased as the CO\(_2\) lean loading increased. The \( Q_{\text{reg}} \) reduced from 198 kW to 130 kW for MEA and 130 kW to 84 kW for MDEA, respectively as the CO\(_2\) lean loading increased from 0.22 to 0.38 mol/mol and 0.22 to 0.48 mol/mol. This is because the increase of CO\(_2\) lean loading results in the increase of equilibrium partial pressure of CO\(_2\), leading to less amount of water vapor requirement to achieve the equilibrium CO\(_2\) partial pressure, thereby lowering \( Q_{\text{reg}} \) consumption.

The minimum lean-CO\(_2\) loading is an indication of the liquid circulation rate to be used in service. That is, a higher minimum lean-CO\(_2\) loading suggests a greater liquid circulation rate. For instance in Fig 5, MEA requires a greater liquid circulation rate than MDEA to capture a given amount of CO\(_2\). Such trend is attributed to two main factors. The first factor is heat of reaction of alkanolamine with CO\(_2\). MEA has the highest heat of reaction with CO\(_2\) among the four alkanolamines used. It requires as high as 85.6 kJ/mol of CO\(_2\) to break the chemical bonds, while MDEA require 60.9 kJ/mol of CO\(_2\), respectively [3].

The second factor is the heat of water vaporization associated with the operating CO\(_2\) partial pressure. MEA requires the lowest operating CO\(_2\) partial pressure compared to MDEA to establish the driving force for CO\(_2\) stripping [6]. This suggests that the largest amount of water vapor must be produced for MEA, leading to the largest energy consumption for water vaporization [5].

Fig.5. Effect of CO\(_2\) Loading on the Reboiler heat duty

4. Conclusion

The effect of various process parameters on the reboiler heat duty have been investigated over a broad operating conditions. Based on the sensitivity analyses, we found that primary amine such as MEA has high CO\(_2\) removal efficiency but at the cost of high energy demands for regeneration. MDEA, being a tertiary amine requires least reboiler duty among the solvents compared and has higher absorption capacity but has lower CO\(_2\) removal efficiency. The reboiler heat duties of blended alkanolamines are between those of the parent alkanolamines, suggesting a combined energy requirement. For example, MEA-MDEA requires regeneration energy less than MEA, but more than MDEA. Similar behavior was also found in the cases of MDEA-PZ. This combined effect demonstrates that adding a primary amine (MEA) or an activator (PZ) to the tertiary alkanolamine (MDEA) can reduce the reboiler heat duty of the CO\(_2\) capture process.

References