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Simulation of the CO₂ capture process using aqueous ammonia

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1. Introduction

This work studies post combustion carbon dioxide capture using aqueous solutions of ammonia. Amine solutions have been commonly used for the commercial production of CO₂ and have been tested for CO₂ capture on pilot scale. The main disadvantage related to the use of amine solutions is the high heat consumption (3.5 - 4 GJ/ton CO₂) and the high degradation rate of the amines.

The capture process using aqueous ammonia exists in two variants. The first variant absorbs the CO₂ at low temperature (2-10°C), is being developed by Alstom and is called Chilled Ammonia Process (Gal, 2006). The second process absorbs CO₂ at ambient temperature (25-40°C). According to the patent, the heat requirement for CO₂ desorption is significantly lower than for conventional amine processes. In addition, by using ammonia, degradation problems can be avoided and a high carbon dioxide capacity can be achieved. Hence, this process shows good perspectives. However, a scientific understanding of the processes is required. In this work, the performance of the CO₂ capture process using aqueous ammonia have been analyzed by simulating the process

In order to describe the system, an advanced thermodynamic model is required. The extended UNIQUAC model for the NH₃-CO₂-H₂O system proposed by Thomsen *et al.* (1999) has been previously upgraded in order to enlarge its valid temperature range to 0-150°C (Darde *et al.*, 2010a). A thermodynamic study with this model has shown the potential for low heat consumption (Darde *et al.*, 2010b). In order to make a process optimization study, flow sheet calculations are required. Therefore the extended UNIQUAC thermodynamic model has been implemented on the commercial simulator ASPEN Plus by applying a user model interface (Mogensen *et al.*, 2009). This allows for using the functionalities of ASPEN Plus coupled with the calculations abilities from the thermodynamic model.

2. Simulation of the capture process: method and results

The carbon dioxide process using aqueous ammonia is more complex than conventional MEA based processes. The absorption at low temperature requires chilling duty that depends on the temperature of the cooling water available. The high volatility of ammonia requires extensive washing of the gas stream exiting the absorber and the

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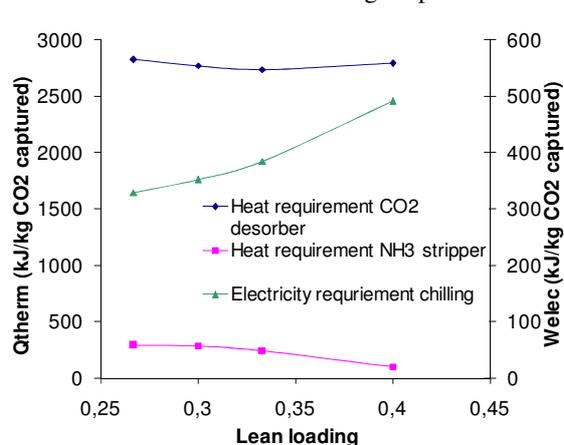
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use of an ammonia stripper to regenerate the washing water. The low temperature of absorption may allow for the formation of precipitate in the absorber. In addition, desorption of carbon dioxide can be made at high pressure thereby saving power during compression. Hence, more parameters can be adjusted and the optimization of the process is therefore not trivial. In this study, three main cases have been analyzed:

- Absorption at low temperature (chilling 10°C) with solid formation
- Absorption at low temperature (chilling 10°C) without solid formation
- Absorption at higher temperature (cooling at 20°C and above)

For each of the cases, two process configurations have been tested: absorption with a single absorber column with recycling and cooling of a fraction of the bottom stream back in to the absorber and absorption with two absorber columns with inter-cooling and without recycling. As shown by our previous experiments are the kinetics of absorption of CO₂ by ammonia solvent rather slow. A Murphee efficiency of 0.1 has therefore been assumed for the absorber.

It has been shown that the heat requirement and the cooling duty are very dependant on the concentration of ammonia, the lean loading, the chilling temperature and the desorption pressure. The temperature of the cooling water available also has a strong impact on the electricity consumption. An estimate of the consequences for



integration with the power plant has been made. Figure 1 shows as an example the influence of the lean loading on the heat requirements in the CO₂ desorber and the NH₃ stripper and on the chilling duty for absorption at low temperature without precipitation (ammonia concentration 4.8wt%, chilling temperature 10°C, cooling water temperature 8°C, desorption pressure 10bar, capture rate 90%). Increasing the lean loading reduces the volatility of ammonia in the absorber and therefore the heat consumption in the NH₃ stripper, but increases the flow rate of solvent and therefore the chilling duty. A minimum can be observed for the heat consumption in the CO₂ desorber. The sum of the heat duties in the two strippers is below 3000 kJ/kg CO₂ captured in this case without precipitation.

Figure 1

3. Conclusions

Following main conclusions can be drawn from the calculations:

- Lowest heat duties are achieved for low temperature absorption with solid formation thanks to the possibility of high ammonia concentrations. However, additional low quality heat is needed to dissolve the solids in the CO₂-rich from the absorber.
- When no precipitation is allowed, limited ammonia concentration has to be used. However, the heat requirement is still competitive with amine processes.
- When absorption at ambient temperatures is applied, the concentration of ammonia has to be limited to control vaporization, the heat consumption CO₂ desorber comparable to the low temperature absorption, but heat consumption in the NH₃ stripper higher, however no chilling duty is required.
- This work has shown the potential of applying ammonia for post combustion capture, both with or without precipitation and with or without extensive cooling duty.

4. References

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