

The possibility of energy saving in chemical absorption technology integrated with low concentration emission sources

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ABSTRACT

Reducing CO₂ emissions from fossil fuel combustion is emergent, especially for China. As one of the most concerned techniques in CO₂ capture process, the rather high energy consumption and cost in chemical absorption process is the leading obstacle interfering the development and deployment of CCS. In this paper, the energy consumptions during chemical absorption process in the literatures were collected, where the data distributions indicate that developing advanced absorbents may be a more efficient way in energy saving compared with improving separation process. Thus, a further verification is carried out based on idea separation process. Results show that improving separation process has limited possibility in reducing energy consumption compared with developing advanced absorbents, and the potential in improving separation efficiency for the former is one third as much as the latter.

Keywords: CO₂ capture, CO₂ separation, CCS, chemical absorption, energy saving

NONMENCLATURE

Abbreviations

Q_{re}	reboiler heat duty (GJ/t CO ₂)
Q_{des}	heat absorb by desorption reaction (GJ/t CO ₂)
Q_{sen}	Sensible heat required in stripper
Q_{vap}	water evaporation heat in stripper

T_H	High temperature heat source (K or °C)
T_L	Low temperature heat source (K or °C)
Y	mole fraction in the gas phase
W_{min}	minimum work consumption in separation process (kJ/mol CO ₂)
Symbols	
η_s	separation efficiency
$\eta_{i,p}$	Idea process efficiency

1. INTRODUCTION

Climate change is the main concern due to the large amount of CO₂ emitted by coal fired plant. To deal with such a serious environment problem, CO₂ capture and storage (CCS) is the only one that can realize CO₂ mitigation effectively and reliability, rather than renewable energy. As CO₂ capture accounts for 70-80% energy consumption and cost in CCS[1], focusing on CO₂ capture is undoubtedly the key point to facilitate the development and deployment of CCS technology. Among the current technologies for CO₂ capture, chemical absorption is the most mature technology that has been demonstrated in the commercial plant, such as Boundary Dam and Petro nova projects successfully operated by 2019.

However, there are some inherent drawbacks for chemical absorption process in the current situations, such as huge energy consumption for solvent

regeneration and the corrosion of the container caused by absorbents, while the huge energy consumption is the main obstruction in the large scale application of chemical absorption in coal-fired plants.

To the present, the improvement measures for chemical absorption technique include developing advanced absorbents[2] and improving separation process[3]. The typical absorbent in chemical absorption process is 30 wt % MEA, where the energy consumption of stripper is around 3.6~4.0 GJ/t CO₂ with 90% CO₂ removed for flue gas with 10-15 kPa CO₂ at 40°C[4]. New absorbents for chemical absorption has been ongoing for a number of decades, such as a blend solution of PZ and AMP, which shows better performance than MEA with energy consumption of 3 GJ/t CO₂[5]. Further, the reboiler duty of K₂CO₃ solution drops to 2 GJ/t CO₂ for CO₂ chemical removing process[6].

Another method in energy reduction has also received lots of attention. For a certain absorbent, absorber intercooling[7], stripper interheating[8], split flow absorber[3], flashing of rich solution[9] can be regarded as process optimization measures to achieve energy saving. For 30% MEA process, Stec[3] studied a series of strategies in reducing reboiler duty, results showing that when intercooling was introduced, the energy consumption dropped to 3.79 GJ/t CO₂, while split-stream may contribute 5% energy saving. Li et al. [8] conducted an advanced CO₂ separation process, which included absorber inter-cooling, rich-split process and stripper inter-heating. Results indicate that the process modifications reduced the energy consumption by 13.5%.

Most of previous studies show that absorbents and process optimizing are two effective ways in reducing energy consumption during chemical absorption process. However, there is no studies that specifically quantify their possibilities or potentials in energy saving. Thus, in this study, the comparison between developing advanced absorbents and improving separation process is carried out.

2. MODELING AND METHODOLOGY

2.1 Modeling

The chemical absorption process typically consists two columns, including absorber and stripper, where the chemical reaction happens. At the beginning, the flue gas containing CO₂ enters the absorber, in which CO₂ contacts and reacts with the lean solution from stripper, after that the rich solution is sent to the stripper for

regeneration with the external heat provided by the reboiler, and a heat exchanger is settled between absorber and stripper for preheating and cooling the rich and lean solution. Finally, the pure CO₂ flees out from the top of the stripper, while the lean solution continues to remove the CO₂ in flue gas through the same circulation.

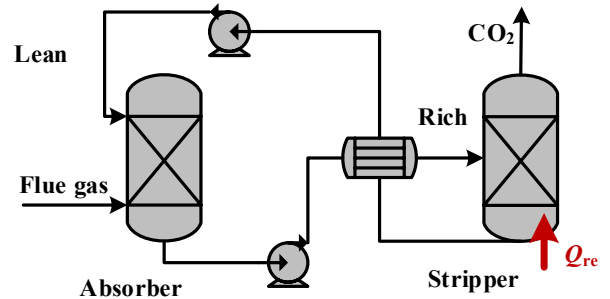


Fig 1 Flow diagram of chemical absorption process

2.2 Regeneration energy penalty

The regeneration energy penalty in chemical absorption process is decoupled into three parts[10], including desorption reaction heat Q_{des} , sensible heat for heating rich solution Q_{sen} and evaporation heat for producing stripping steam Q_{vap} .

2.3 The Ideal separation process

The separation efficiency for chemical absorption process can be defined as:

$$\eta_s = W_{min} / Q_{re}$$

Where W_{min} is the minimum separation work to realize CO₂ separation, and Q_{re} is reboiler duty.

For ideal separation process, it can be considered similar to the generality Carnot cycle, where working flow absorbs heat from high temperature resources and releases heat to low temperature resources to output work under reversible process, and reboiler is the heating resource to provide external heat achieving regeneration of solution, while environment is the cooling resource. The difference of diffusion exergy before and after separation is regarded as output work. Thus, the separation efficiency can be defined as:

$$\eta_c = 1 - T_0 / T_H$$

Where T_0 is the environment temperature.

Considering that the Carnot cycle does not consider what the exactly working medium is, it is the limitation of efficiency based on the first law of thermodynamics for any working medium. Thus, the Carnot efficiency quantifies the potentials of both exploring advanced absorbents and improving the separation process. More

importantly, how to decouple the potentials of these two strategies is critical and vital.

3. RESULTS AND DISCUSSION

To visualize the energy consumption of chemical absorption process, data from literatures have been collected[2, 3, 6, 9, 11-18]. As shown in Fig.2, the green triangles represent the cases of 30%MEA with different upgrading strategies, while other absorbents adopted in chemical absorption process are shown as the purple star. Here, all the data collected are based on the same boundary conditions and assumptions, where only reboiler duty is considered in chemical absorption process and the recovery ratio of CO₂ in flue gas is larger than 85%. Compared with 30%MEA, the non-aqueous solvent explored by Lail[2] exhibits dramatically reduction in reboiler duty, due to its lower Q_{des} , lower c_p

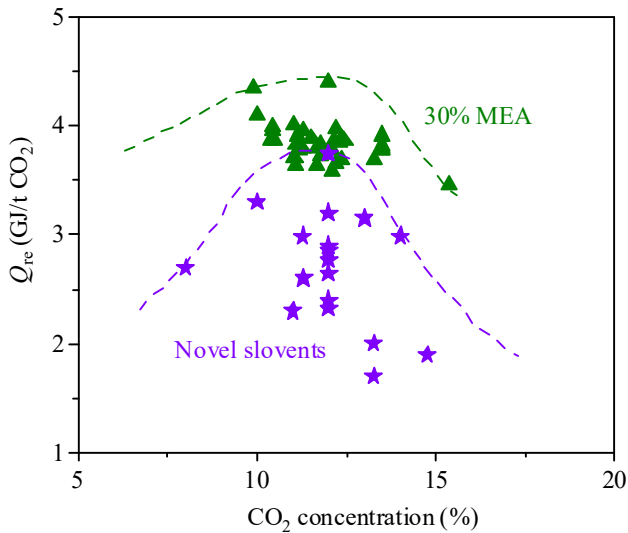


Fig 2 Literature energy consumption in chemical absorption process

and larger loading capacity with lower Q_{sen} and none water contained with negligible Q_{vap} , resulting in reboiler duty dropping from 3.68 to 1.7 GJ/t CO₂. From the data distribution of existing studies, the energy saving potential of exploring novel solvents seems greater than improving the process.

In order to verify and quantify the potentials of these two strategies, the simulation for chemical absorption process are conducted. The specific calculation conditions are listed in Table 1, where Aspen Plus V9.0 is adopted to perform the thermodynamic and dynamic characteristics during separation process based on the rate-based model of the Radfrac module using the electrolyte NRTL property method for liquid phase and Redlich-Kwong equation of state for the vapor phase of

the MEA-CO₂-H₂O system both for absorber and stripper. The CO₂ removal efficiency is set as 90%.

Table. 1 Flue gas specifications [19]

Parameters	value
Mass flow (kg/s)	666.1
Temperature (°C)	40
Pressure (bar)	1.2
CO ₂ (%vol)	14

The calculation results are shown in Fig.3. the separation efficiency for 30% MEA and 35% AMP is 4.98% and 6.06%, respectively, due to the lower reaction heat of 80.9 kJ/mol for AMP compared with 85 kJ/mol for MEA, and lower water contained in 35% AMP. The idea process efficiency based on the limitation of Carnot cycle is 25.2% and 25.1% for 30% MEA and 35% AMP due to the difference of reboiler temperatures. In order to

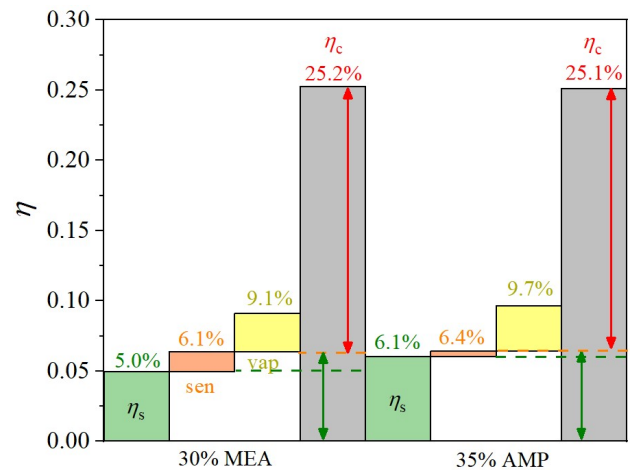


Fig 3 The possibility in reducing energy consumption

quantify the potentials between exploring absorbents and improving separation process, the desorption heat, evaporation heat and sensible heat are made clear relationships for these two methods to evaluate the potentials. It is obviously that Q_{des} is almost entirely determined by the type of absorbents due to the temperature change during chemical absorption process is minimum, which may have little influence on Q_{des} . Besides, considering that Q_{vap} can be calculated by the ratio of partial pressure of volatiles and CO₂, it is related to phase equilibrium between rich solution and gas at the top of stripper, which is directly related by the rich loading and temperature at top and indirectly determined by the type of absorbents. Thus, Q_{vap} can be regarded totally the potential of developing advanced

absorbents. However, for Q_{sen} , it comes from the temperature difference between absorption tower and stripper, which shows the additional energy consumption due to the irreversibility of heat transfer. Therefore, it can be expected to approach zero from improving separation process. At the same time, exploring novel absorbents with lower c_p , higher cyclic capacity can also reduce Q_{sen} , which can also be regarded as the potential for absorbents. Furthermore, the energy consumption reduction due to optimization of operation parameters is the potential of improving processes, and the minimum efficiency for the deteriorating condition is zero. Finally, we can draw the conclusion that, the potentials for developing advanced absorbents is about 3 times larger than improving separation process for both 30% MEA and 35% AMP, as shown in Fig.3.

4. CONCLUSIONS

The possibilities of reducing energy consumption in chemical absorption process is specifically calculated in this paper, and the distributions of energy consumptions in literatures are also collected to give a support. For chemical absorption process, the potential availability in reducing energy consumption for the conventional methods, including developing advanced absorbents and improving separation process, is different, while the former shows greater possibility in energy saving than the latter, which is about three times larger. Thus, improving separation process should be an auxiliary means to reduce energy consumption for advanced absorbents rather than the focused point.

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