



Analysis of Renewable Energy Consumption of CO₂ Capture System from Power Plant Flue Gas

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Abstract. With the rapid increase in global greenhouse gas emissions, the development of efficient CO₂ capture technologies is important for mitigating climate change. Evaluation of the energy consumption for regeneration of amine absorbers and assessment of amine absorbers are essential for the development of technically and economically feasible CO₂ capture processes. In this work, the capture method and technology were studied, and a generic renewable energy calculation model was run, using data from the operation of a CO₂ capture and purification system from power plant flue gas. The effects of absorber performance, absorbent characteristics, and heat exchanger capability on renewable energy were investigated in turn. Furthermore, a comparison of renewable energy between MEA and DEA was performed, as well as variations in absorbent concentration and absorbent regeneration level. The results show that raising absorbent concentration, properly mixing absorbent type and content, and improving heat exchanger performance may minimize absorbent renewable energy use.

Keywords: power plant flue gas, CO₂ capture and purification, absorbent, renewable energy consumption.

1 Introduction

Global warming was being driven by a massive release of greenhouse gases. CO₂ emissions were the highest, accounting for around 60% of total greenhouse gas emissions. The CO₂ emissions from power plants where fossil-fue was the main flue accounted for 30% of total CO₂ gas emissions^[1]. According to International Energy Agency (IEA) forecasts, CO₂ capture and storage (CCS) is a critical technology for reducing carbon emissions from power plant flue gases, accounting for 13% of total emissions reductions by 2050^[2]. Chemical carbon capture, as a sort of post-combustion carbon capture technique, is a possible means of lowering carbon emissions from power plant flue gases for power plants that use coal as a source of energy. ^[3]However, the chemical absorption process employs a traditional thermal regeneration process that consumes a large amount of regeneration energy, resulting in an increase in initial investment and power generation costs, as well as a very high cost of carbon dioxide removal, which is not conducive to the popularization and commer

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cialization of the chemical process [4][5]. As a result, the regeneration energy usage must be assessed and reduced.

Kaiqi J et al [6] created a regeneration energy calculation model for capture systems with various absorbents, and regeneration energy consumption can be computed using just laboratory gas-liquid equilibrium (VLE) data. Kim H et al [7].coupled the impacts of absorber vaporization in the pipeline and the MVR energy-saving procedure on regeneration energy consumption to develop a set of mathematical models that compute the system's regeneration energy consumption.

Amine absorber regeneration energy consumption is usually evaluated in the laboratory with the help of equipment such as calorimeters and requires a large number of experiments that are time-consuming and labor-intensive. In contrast, it is more efficient to use a mathematical modeling approach for calculations while maintaining accuracy. The regeneration energy consumption of MEA chemical absorption of CO₂ from flue gas is thoroughly examined in this study, a basic calculation formula is developed, and solutions to minimize regeneration energy consumption are presented.

2 Carbon dioxide capture process from flue gas

Desulphurized smoke gas from the power plant was supplied into the absorption tower via dust separation, temperature reduction to 40-50°C, and flow regulation. During the procedure, an air blower was utilized to force smoke gas into the absorption tower. Pressure was employed to compensate for pressure loss in the gas passing absorption tower. When the temperature of the smoke gas exceeded a certain threshold, the sprinkling attemperation system was activated. To prevent water from contaminating the water balancing system, a cyclone separator was installed before the absorption tower to separate water and solid particles in the smoky gas.

Figure 1 shows the process flow of a conventional chemical method carbon capture device. In the absorption, the smoke gas traveling from down to up connected countercurrently with the absorbent liquid from up to tower, and the CO₂ was removed, and the smoke gas exited via the tower roof. Due to the high steam pressure with MEA, the absorption tower was usually designed into two sections to reduce the absorbent liquid loss in steam with smoke gas. The acid gas absorption was done in the under section, and the rinse was done in the up section to reduce the steam content with smoke gas. The washing water in the recycling was continually enriched, and part of the washing water needed to be delivered to the regeneration tower to be regenerated. The washing water loss was kept via the regeneration cooled water, and the water balance of two sets of loops was maintained. The rich liquid pump delivered the acid-absorbing rich liquid gas to the regeneration tower. To minimize the steam consumption of rich liquid during regeneration, the waste heat of poor liquid was utilized to charge with rich liquid, and the regeneration liquid was cooled. Rich liquid enters the regeneration tower from the top section, desorpts CO₂, and enters the boiler, where the CO₂ is desorbed. The bad liquid flowed from the regeneration tower, excharged using the exchanger, and was cooled before being delivered to the absorption tower. The higher regeneration tower's CO₂ and steam condensation was cooled by a

cooler, separated by a separator, and the cold water was cycled back into the system, while the gas was transferred to the succeeding compression operation. Table 1 shows the process nodes of gas and material in the system.

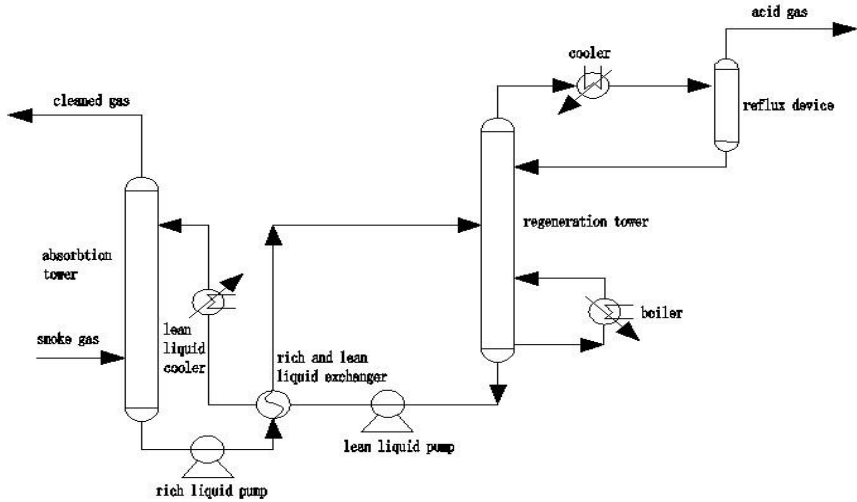


Fig. 1. Carbon dioxide capture pro-cess from fule gas

Table 1. Comparison table of process bit mark of gas material

| Node | Name | Pressure /MPa | Components | | | | | Volume /m ³ /h |
|------|-------------|------------------|----------------|-----------------|----------------|-----------------------|----------------------|------------------------------|
| | | | N ₂ | CO ₂ | O ₂ | SO ₂ | NO _x | |
| 1 | Smoke gas | 0.008 | 79.27% | 14.5% | 4.6% | <830mg/m ³ | 721mg/m ₃ | 128641 |
| 2 | Cleaned gas | 0.002 | 90.59% | 2% | 5.3% | <830mg/m ³ | 721mg/m ₃ | 112560 |
| 11 | Acid gas | | | 99.5% | | | | 15003 |

3 Regeneration energy consumption analysis model

When steam was utilized as a desorber in the process of heat regeneration, the heat quantity in the process (without accounting for regeneration heat loss) was calculated using the following Eq.(1):

$$Q_{str} = Q_s + Q_r + Q_{strg} \quad (1)$$

Q_{str} —— total energy consumption of rich liquid in regeneration, kJ/h; Q_s —— heat required of rich liquid temperature, kJ/h; Q_r —— reaction heat with desorption CO₂, kJ/h; Q_{strg} —— heat with regeneration gas from regeneration tower, kJ/h.

3.1 Thermal heat Q_s

Thermal heat with a rich liquid was provided in the following form:

$$Q_s = C_p m_L \Delta t_{HE} \quad (2)$$

C_p ——specific heat of rich liquid, kJ/(kg·K), usually $C_p = 4.187$ kJ/mol; Δt_{HE} ——performance of rich and poor exchanger, K; m_L ——cycle quality of absorber, mol/h [8].

$$m_L = K \frac{X_{CO_2} \eta}{\Delta \alpha_{CO_2}} \times \frac{M_{abs}}{\Phi} = K \frac{X_{CO_2} \eta}{\alpha_{CO_2}^R - \alpha_{CO_2}^L} \times \frac{M_{abs}}{\Phi} \quad (3)$$

$$Q_s = K \frac{X_{CO_2} \eta}{\alpha_{CO_2}^R - \alpha_{CO_2}^L} \times \frac{M_{abs}}{\Phi} \times C_p \Delta t_{HE} \quad (4)$$

Type: X_{CO_2} ——the molar of CO_2 in smoke gas, mol CO_2 /h; η —— CO_2 removal rate, %; $\Delta \alpha_{CO_2}$ ——the actual loading capacity with CO_2 absorbed, mol CO_2 /mol; $\alpha_{CO_2}^R$, $\alpha_{CO_2}^L$ ——loading capacity with CO_2 absorbed of rich and poor liquid, mol CO_2 /mol; K ——circulation rate of absorb fluid, usually 1.1~2.0; Φ ——liquid concentration of active ingredients in absorb fluid, %; M_{abs} ——the molar of active ingredients in absorb fluid, kg/mol.

3.2 Reaction heat Q_r

The purpose of the reaction heat was to encourage the production of CO_2 absorbed dosage and weak coupling compounds^[9]:

$$Q_r = G_{CO_2} \Delta q_{CO_2} \quad (5)$$

G_{CO_2} —— CO_2 quality, mol CO_2 /h; Δq_{CO_2} ——The average regenerative heat per unit CO_2 , kJ/mol CO_2 .

3.3 Heat with regeneration gas Q_{strg}

The regeneration gas would remove a portion of the heat from the regeneration tower, while the cooling circycle material entering the regeneration tower would absorb a portion of the heat, therefore the following was given:

$$Q_{strg} = h_{strg}(G_{H_2O} + G_{CO_2}) - \Delta h_{H_2O} G_{CO_2} = h_{strg}(1 + R)G_{CO_2} - R\Delta h_{H_2O} G_{CO_2} \quad (6)$$

$$Q_{strg} = R_{rH_2O} G_{CO_2} \quad (7)$$

h_{strg} , Δh_{H_2O} —enthalpy of gas leaving regeneration tower and water circulating, kJ/mol; r_{H_2O} —evaporation heat of hot water in certain temperature, kJ/mol;

$G_{H_2O} = R G_{CO_2}$ —water steam leaving the regeneration, mol/h;

$R = p_{H_2O} \times p_{CO_2}$ —reflux ratio of regeneration tower, 3:1 ~ 1:1^[10]

3.4 System regeneration energy consumption Q_{str}

The system's regeneration energy consumption includes heat reaction heat and heat carried away by regeneration gas^[11].

$$Q_{str} = K \frac{X_{CO_2} \eta}{\alpha^R_{CO_2} - \alpha^L_{CO_2}} \times \frac{M_{abs}}{\Phi} C_p \Delta t_{HE} + G_{CO_2} \Delta q_{CO_2} + R_{H_2O} G_{CO_2} \quad (8)$$

4 The analysis of regeneration energy consumption factors

The impact elements of regeneration energy consumption of CO₂ capture system with chemical absorption technique included absorption tower equipment performance, absorbent liquid characteristics, and heat exchanger performance, among others. With MEA and DEA as absorbent liquids, the impact variables of regeneration energy consumption were investigated.

4.1 The influences of absorbent concentration on regeneration energy consumption

The influence of absorbent concentration on regeneration energy consumption was studied with heat exchanger performance and reflux ratio held constant. M_{abs} , C_p , $\Delta \alpha_{CO_2}$ and Δq_{CO_2} were assumed to be constants for the calculated absorbing liquid, and the reaction heat and leaved heat per unit CO₂ were assumed to be constants, so:

$$q_{str} - \Delta q_{CO_2} - R r_{H_2O} = \frac{K}{\Delta \alpha_{CO_2}} \frac{M_{abs}}{\varphi} C_p \Delta t_{HE} \frac{1}{\varphi} \quad (9)$$

Influence figure of the liquid absorbent's mass concentration φ on heat consumption during regeneration with MEA and DEA were given in Fig.2 and Fig. 3.

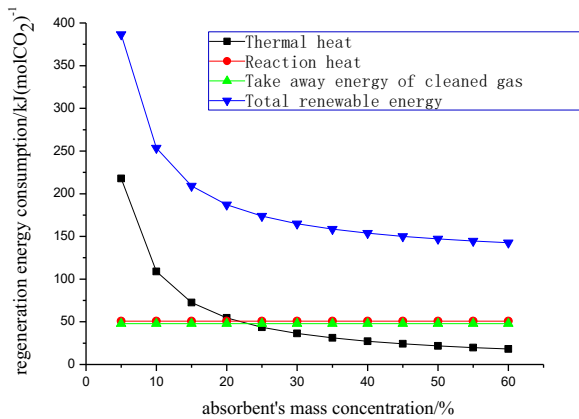


Fig. 2. Renewable energy consumption of MEA

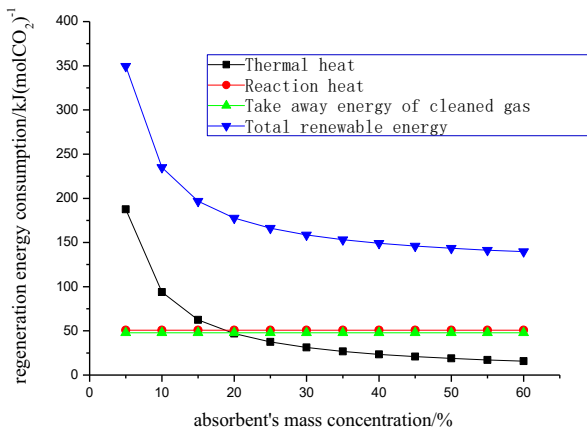


Fig. 3. Renewable energy consumption of DEA

The influence figure of the liquid absorbent's mass concentration on heat consumption during regeneration using MEA and DEA is shown in Figs. 2 and 3. That was the varying trend of total regeneration energy consumption, was the varying trend of shown heat that rich liquid required, and and were the varying trends of reaction heat and take away heat. The greater, the lower and. However, when is added to a certain extent, the downturn of tends to be gradual; for example, when is increased from 20% to 50%, only falls 11.3%. early, is not the best option. In reality, when increases to a certain level, it promotes side effects and corrosion speed, increases sorbent loss, and reduces equipment service life. In actuality, absorbing liquid concentration would very certainly have an upper limit of max^[11].

4.2 Analysis of the actual load ability in absorbent cycle

The CO₂ load of rich fluid was often considered to be by thermodynamic law for specific absorbent liquid and tower equipments, but in real operation, it may frequently be viewed as a constant. As a result, lowering the CO₂ load of poor liquid may increase the regeneration ability ξ of absorbent liquid. and improve There is the following formula to calculate ξ and:

$$\xi = \frac{(\alpha^R_{CO_2} - \alpha^L_{CO_2})}{\alpha^R_{CO_2}} \tag{10}$$

$$q_s = \frac{K}{\xi \alpha^R_{CO_2}} \frac{M_{abs}}{\phi} C_p \Delta t_{HE} \tag{11}$$

Figures 4 and 5 show the effect of the degree of regeneration on the heat consumption during regeneration using MEA and DEA, indicating that the higher the degree of regeneration, the lower the heat consumption and the less the heat consumption.

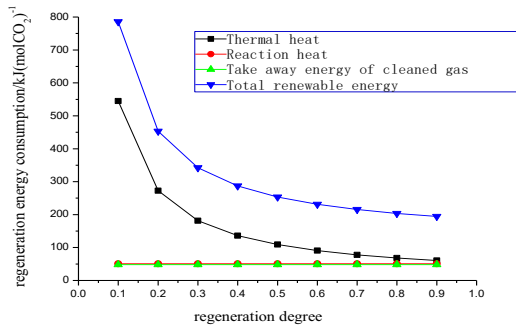


Fig. 4. Renewable energy consumption of MEA

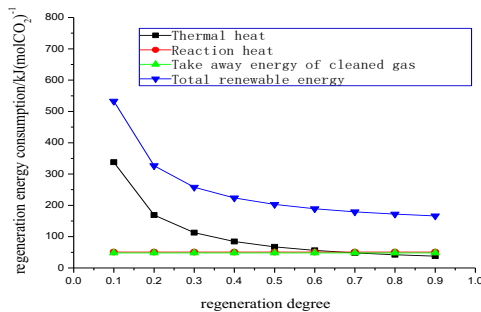


Fig. 5. Renewable energy consumption of DEA

The reason for this pattern may be that the higher the carbon dioxide concentration, the greater the carbon dioxide loading capacity in the absorber cycle and the greater the thrust of the tower. Reducing absorbent liquid circulation flow might decrease, while raising it to a certain level slowed and. Obviously, increasing the regeneration degree of rich liquid might lower regeneration energy consumption, but this benefit was limited. Jassim and Oyenekan^{[12][13]} demonstrated the rule in a simulation of system energy consumption with a low liquid load. should not be less than 0.15molCO₂/molMEA^{[9][10]}, namely ξ was blow 0.667.

4.3 Analysis of performance for poor and rich exchanger

Figures 6 and 7 show the influence figure of the property factor tHE of the lean rich solvent's heat exchanger on heat consumption during regeneration with MEA and DEA.

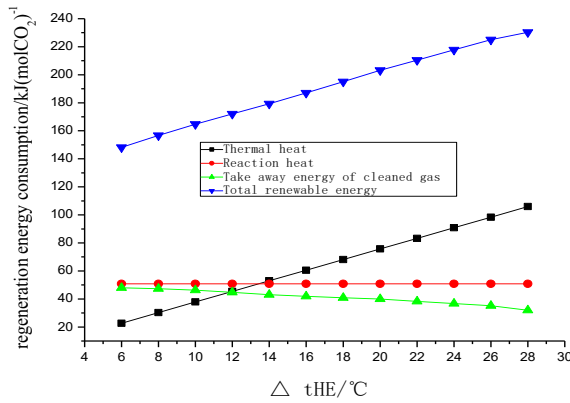


Fig. 6. Renewable energy consumption of MEA

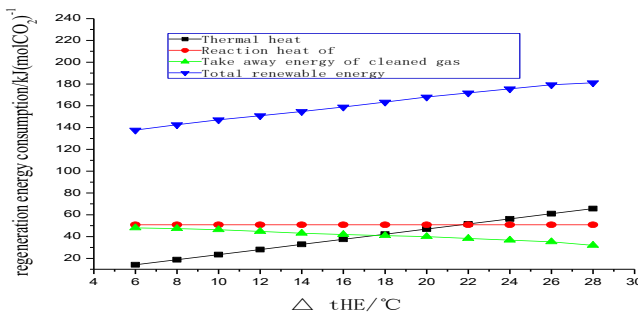


Fig. 7. Renewable energy consumption of DEA

The effect figure of the property factor of the lean rich solvent's heat exchanger on heat consumption during regeneration with MEA and DEA revealed that had a linear connection with heat exchanger performance under specific absorbent liquid circumstances. To increase heat exchanger performance, might effectively lower. When declined, decreased in a straight line, while rose slowly, causing to fall slowly. Analysis revealed that increasing heat exchanger characteristics may decrease overall regeneration heat consumption, but it was not especially clear that lowering would increase heat exchanger investment costs.

5 Conclusion

The regeneration energy consumption in chemical flus CO₂ absorption was thoroughly investigated, and a general calculation formula was developed that is a function of three factors: absorber performance, absorber liquid factor, and heat exchanger performance. When absorption tower performance was trending, adjusting the characteristics of the absorbing liquid and the performance of the heat exchanger may minimize regeneration energy consumption.

(1) Increasing the mass concentration of absorbent liquid may reduce regeneration energy consumption; however, the mass concentration of absorbent liquid was not better; it had a maximum value ϕ_{max} .

(2) Improving liquid regeneration degree might reduce regeneration energy consumption, but regeneration degree must be done in a suitable design.

(3) Improving heat exchanger characteristics might lower overall regeneration heat use, although this is not very obvious. Reducing would increase heat exchanger investment costs. As a result, it must choose a suitable value between energy usage and investment expenses.

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