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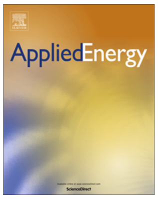

Advancement of ammonia based post-combustion CO_2 capture using the advanced flash stripper process

Kaiqi Jiang [a,b], Kangkang Li [a,*], Hai Yu [a,*], Zuliang Chen [b], Leigh Wardhaugh [a], Paul Feron [a]

[a] CSIRO Energy Flagship, 10 Murray Dwyer Circuit, Mayfield West, NSW 2304, Australia
[b] Global Centre for Environmental Remediation, University of Newcastle, University Drive, Callaghan, NSW 2308, Australia

HIGHLIGHTS

- An advanced flash stripper process for the NH_3 based CO_2 capture was developed.
- Heat requirement of NH_3 regeneration was reduced to 1.86 MJ/kg CO_2.
- Total equivalent work of advanced NH_3 process is 0.164 MW h/ton CO_2.
- Energy improvements reduced the CO_2 avoided cost to US$ 40.7/ton CO_2.

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ABSTRACT

The energy consumption associated with absorbent regeneration remains the most critical challenge for the industrial implementation of chemisorption based CO_2 capture processes. Aimed at reducing the energy consumption, this paper proposes a promising process modification of the ammonia (NH_3) based CO_2 capture process that involves an advanced flash stripper with a cold rich split. We investigated the techno-economic performance of the advanced NH_3 process integrated with a 650 MW coal-fired power plant, and evaluated it technical and energy performance using a rigorous, rate-based model in Aspen Plus. A sensitivity study was also performed to optimise the modelling parameters, i.e. the stripper pressure and the absorbent NH_3 concentration, and minimize the regeneration duty. A very competitive regeneration duty of 1.86 MJ/kg CO_2 was achieved for an optimised stripper pressure of 12 bar and an NH_3 concentration of 10.2 wt%, with a total equivalent work of 0.164 MW h/t CO_2 for absorbent pumping, NH_3 regeneration and CO_2 compression. We also used a validated economic model to estimate the capital investment of the advanced NH_3 process and its corresponding economic performance. With its significant reduction in energy consumption, the proposed process was economically competitive with CO_2 avoided cost was as low as US$40.7/t CO_2. This was 34% and 44% less than the reference NH_3 and monoethanolamine (MEA) processes, respectively. The advanced NH_3 based flash stripper also had technical and economic advantages over other amine absorbents, such as MEA and piperazine (PZ), as well as other advanced stripper modifications, such as inter-heating process, revealing its process viability in commercial application.

1. Introduction

One of the critical challenges for the implementation of post-combustion capture (PCC) through chemical absorption is the attendant large energy consumption. Integrating a PCC plant with a coal-fired power station decreases power generation efficiency by 8–14% (i.e. 20–25% power loss) [1–3]. Particularly, the heat requirement for absorbent regeneration is the largest contributor to the energy consumption, accounting for more than 60% of the total energy requirement for CO_2 capture [4–6]. A statistical review study revealed that a saving of 1 MJ/kg CO_2 in absorbent regeneration energy would increase power generation efficiency of a PCC integrated power plant by 2% [3]. Therefore, research has focused on investigating and modifying the absorbent regeneration process, aiming to reduce the energy requirement of absorbent regeneration. Currently, two major aspects are concerned with reducing the regeneration duty: (i) selecting appropriate absorbents with a low heat of regeneration, and (ii) modifying the processing configuration for regeneration of absorbent.

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* Corresponding authors.
E-mail addresses: kangkang.li@csiro.au (K. Li), hai.yu@csiro.au (H. Yu).

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Monoethanolamine (MEA) is widely applied as a benchmark amine absorbent for CO_2 capture, due to its fast reaction and rich experience in industrial application. However it has a high regeneration duty and is subject to thermal and oxidative degradation at regeneration temperatures [7]. Compared with MEA, aqueous NH_3 has a relatively low heat requirement for CO_2 desorption, no absorbent degradation, low absorbent cost, and can simultaneously remove SO_2 from flue gas [8,9]. Our previous pilot scale implementation of NH_3 based CO_2 capture has demonstrated its technical feasibility, achieving high CO_2 and SO_2 removal efficiency, and a high purity CO_2 product [10,11]. Another study revealed that the regeneration duty of the NH_3 process could be less than 2.5 MJ/kg CO_2 [12], whereas the regeneration duty in MEA is commonly around 3.7 MJ/kg CO_2 [13,14]. Moreover, the NH_3 process can avoid the use of flue gas desulphurisation due to the high removal efficiency of SO_2 (>99%), thus greatly reducing its capital cost [15]. The resultant product can be further used as the sulfur fertilizer for the agricultural industry.

However, the NH_3 based CO_2 capture process has technical drawbacks that hinder its commercialization. Specifically, the strong volatility of NH_3 leads to absorbent loss during absorption. Low temperature absorption can reduce the vaporization of NH_3, which has been demonstrated in Alstom's chilled ammonia process (CAP), by lowering the lean absorbent temperature to 10 °C or below [16]. However, this introduces a significant energy penalty for absorbent chilling, and a higher risk of solid precipitation in the absorber [17]. A proposed two-stage absorption process combined with a flue gas pretreatment unit reduced NH_3 slip by more than 50%, and recovered more than 99% of vaporized NH_3 through the pretreatment unit [6,18]. However the reduction of NH_3 slip comes at the expense of a larger CO_2 absorber, thus causing subsequent higher capital investment. Moreover, NH_3 vaporization causes problems during absorbent regeneration, because solid precipitation tends to be formed in the condenser. This occurred in our pilot plant operation, causing shutdown of pilot plant [19].

In addition to the NH_3 slip, the most critical challenge remains the high energy consumption associated with absorbent regeneration. Although the NH_3 absorbent has relatively low heat of CO_2 reaction, the conventional stripping process (Fig. 1) seems unable to make use of this advantage. This is because it involves an irreversible energy losses from: (1) elevating the temperature of the rich absorbent to the required reboiler temperature, and (2) the vaporization of H_2O and NH_3 with CO_2 in the stripper column, in which wastes the steam heat in the condenser [20]. These energy losses lead to a high regeneration duty of the reference stripping process, for example, the regeneration duty of 4.2–6.0 MJ/kg CO_2 in our pilot plant trials [10] and 3.3–4.0 MJ/kg CO_2 in modelling results [6]. This is evidently much larger than the required heat of CO_2 desorption of 1.5 MJ/kg CO_2 [6]. Hence, process modifications are vital to recover the heat loss of absorbent regeneration and advance the NH_3 based CO_2 capture process. Various modifications and designs of absorbent scrubbing process have been intensively studied, including rich split [21], inter-heating [22], multi-pressure [23], and flash stripping processes [24]. These advanced processing configurations can decrease the energy penalty of absorbent regeneration, and a combination of these processes improves energy performances. However, these advantages suffer the expense of increased process complexity [6,21].

Johnson and Eisenberg [25] first proposed a rich split process that sends a portion of rich absorbent from the absorber directly to the top section of the stripper, while the majority of rich absorbent goes to the middle of the stripper column after the main heat exchanger. This process can recover the heat of steam vaporized with CO_2 inside the stripper, or make use of the steam to heat the cold absorbent through an external heat exchanger, where heat exchange occurs between the vapour and a small amount of cold rich absorbent [26]. The rich split process reduced the regeneration duty in both process modelling and pilot plant trials. For example, the rich split process reduced the reboiler duty from 3.27 to 2.89 MJ/kg CO_2 in a simulated NH_3 process [6]. Lin et al. [21] conducted simulation for piperazine (PZ) using the rich split modification, obtaining a reboiler duty of 2.18 MJ/kg CO_2 compared to the reference case of 2.39 MJ/kg CO_2. Pilot plant trials for MEA based CO_2 capture using rich split modification obtained a regeneration duty of 3.31 MJ/kg CO_2 [27], an 8.1% reduction from the reference case.

Flash stripping has also drawn attention for improving the energy performance of absorbent scrubbing [28]. Instead of using a reboiler connected to the bottom section of a packed stripper, the flash stripping process desorbs CO_2 within a steam heater, followed by a flash tank in which gaseous vapour is separated from the liquid phase. This process increases process reversibility, and thus reduces the energy requirement [29]. Modelling investigations have confirmed the energy benefits when regenerating amine solutions using MEA and PZ [21,22,30,31]. These studies concluded that (i) the single stage flash with a stripper column exhibited

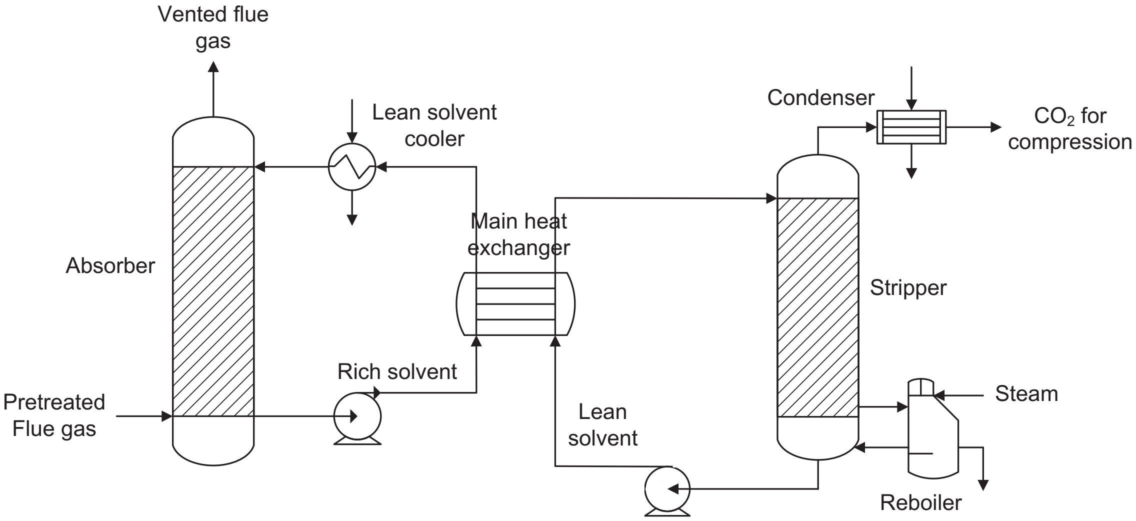

Fig. 1. The conventional CO_2 absorption and desorption process.