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Performance of MEA and amine-blends in the CSIRO PCC pilot plant at Loy Yang Power in Australia

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ABSTRACT

Chemical reactive liquid absorption in post-combustion carbon capture (PCC) has sparked an interest of many researchers for improvement in creating high CO_2 absorption capacity and minimising the reboiler heat duty for regeneration.

This paper discusses results from performance trials on different solvents: mono-ethanolamine (MEA-baseline), a mixture of MEA with 2-amino-2-methyl-1-propanol/AMP (Blended Amine 1) and Blended Amine 2 (a propietary solvent developed by Research Institute of Innovative Technology for the Earth (RITE), Japan). The trials were carried out in CSIRO's PCC pilot plant at Loy Yang Power. The pilot plant receives flue gas from this 2.2 GW brown coal-fired power station in the Latrobe Valley, Victoria. The study has shown the benefits of using blended solvents for CO_2 capture in terms of CO_2 recovery and reboiler duty for solvent regeneration.

The correlation of CO_2 recovery and process parameters, i.e., liquid and gas (L/G) ratio and lean loading, has been established for the range of solvents tested. The results show that, in general, an increase of L/G ratio increases the CO_2 recovery. It is also noted that a solvent at higher lean loading requires a greater solvent (recycle) flow rate, or vice versa, in order to capture a given amount of CO_2. The effect of reducing the stripper's bottom temperature from 115 to 112 °C reduced the CO_2 recovery of both MEA and Blended Amine 1 as their solvent lean loadings are raised. The same temperature change, however, did not significantly decrease CO_2 recovery of Blended Amine 2, as it also shown by insignificant changes in solvent lean loadings.

The results also indicate that the reboiler heat duty is dependent upon L/G ratio, solvent lean loading and blending solvent type. For the MEA-115 °C, a minimum reboiler heat-duty as a function of L/G ratio is clearly observed and the Blended Amine 1–112 °C has also shown a similar pattern. In contrast, Blended Amine 1–115 °C showed excessive energy duty, which indicates unfavourable condition for this solvent. This is not the case for Blended Amine 2. It is observed that the reboiler heat duty decreases as stripper bottom temperature decreases, which in turn raises the lean loading for both MEA and Blended Amine 1. On the other hand, the lean loading of Blended Amine 2 in the temperature range examined did not affect the reboiler heat duty changes. The investigation also found that the magnitude of reboiler duty is decreasing following the order MEA > Blended Amine 1 > Blended Amine 2.

In order to obtain CO_2 recovery of 85%, the Blended Amine 2–115 °C (L/G = 3.60) has similar reboiler duty relative to that of MEA-115 °C with L/G ratio of 4.12. For the Blended Amine 1 (L/G = 3.04), however, the reboiler heat duty increased by 51% at a similar temperature. The temperature reduction to 112 °C decreased the reboiler heat duty of both Blended Amines 1 and 2 by 11% (L/G = 4.01) and 14% (L/G = 3.60) respectively. Further raising the CO_2 recovery to 90–95%, in comparison to that of MEA at 115 °C with L/G ratio of 4.20, the reboiler heat duty of Blended Amine 1 has risen by 49% (L/G = 3.95) and of Blended Amine 2 dropped by 5% (L/G = 3.52) under a similar temperature. At 112 °C, the reboiler heat duty of Blended Amine 1 decreased by 18% (L/G = 5.02). Blended Amine 2 may give a similar reboiler heat duty if run at a larger L/G ratio.

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Overall, the result of the MEA baseline and blending solvents has shown different behaviours of CO_2 stripping. The distribution of the components of reboiler heat duty may explain this difference. For MEA, the condenser heat, which equals the heat needed for water evaporation, is a major contributor to the reboiler duty. For both Blended Amine solvents, the magnitude of sensible heat and the heat of CO_2 desorption are more pronounced than the condenser heat. At the minimum reboiler duty reached by MEA and Blended Amine 1, the condenser heat share is lower than the other reboiler duty components. Therefore, further works involve optimisation of the PCC process with blended Amines and other blends.

1. Introduction

The brown coal-fired power generation is the source of about half of Victoria's current greenhouse gas emissions [1]. It is therefore clear that CO_2-emission reduction strategies aimed at the existing power stations are urgently needed to provide a path towards environmental sustainability of the Victorian brown coal industry. The use of carbon capture and sequestration (CCS) is essential for this path and Victoria is well placed due to the vicinity of vast storage capacity in the Gippsland basin, which equals to more than 100 years of CO_2 produced in Victoria at current rates [2]. Post-combustion capture (PCC) is an important first part of the CCS chain. The implementation of PCC in the Victorian case requires specific focus towards its technological development in regards of three following issues:

1. Brown coal is not sold into a world market due to its high moisture content in contrast to black coal, oil or natural gas. Therefore, it is expected that brown coal prices will remain at low price levels thus continuing to provide the basis for low cost electricity for Victoria. The capture of CO_2 will result in a large increase in the cost of electricity generation, which needs to be addressed;
2. Brown coal flue gases are available at high temperature, have high water content and contain alkaline ash. This provides a challenging environment for chemical absorption processes;
3. The combined process of coal mining, power generation and PCC should use less water than current power generation as ground water level retreats to an unsustainable situation.

Several CO_2 separation techniques such as absorption into a liquid, adsorption onto a solid and membrane permeation processes [3] have the potential to capture CO_2 from flue gases. Due to a high volume flow rate and low CO_2 partial pressure of gas stream from a coal-fired power plant [4], chemical absorption into a liquid is currently the most suitable option for capturing CO_2 from flue gas [3,5,6]. The use of mono-ethanolamine (MEA) as the liquid absorbent or solvent is a commercial activity in a small scale (< 30 ton CO_2/h) and it may soon be use in full-scale for the CO_2 separation from flue gases in coal fired power stations [3]. This is due to its low cost, its ability to capture CO_2 from low pressure flue gas and its fast reaction kinetics with CO_2. The PCC unit can also be retrofitted to an existing and/or easily integrated to a new power station [7–9]. A large amount of energy is required for solvent regeneration resulting in a large drop in power station efficiency [6,8,9]. Degradation and solvent losses are also identified as an important environmental and cost factor, particularly in full-scale applications. Furthermore, in a financial cost analysis of an MEA-based PCC plant, Veawab et al. [10] concluded that absorption and desorption (solvent regeneration) equipment sections are the largest contributors to capital cost investment. They also specified that up to 70% of the total operating costs will be needed to provide the heat duty for the solvent regeneration (desorption section) [10].

The solvent scrubbing technique is considered to be the most advanced post-combustion capture technology [11]. A strategy of optimising absorber conditions, in order to maintain a higher mass-transfer rate by controlling minimum reboiler heat duty required, is a way to introduce a trade-off approach in order to make the PCC plant feasible. In this paper, discussion on initial focus to look at MEA based results as a baseline and an attempt to reduce regeneration energy (reboiler heat duty) without impeding the CO_2 capture performance are presented. This may be achieved by utilising MEA-based blends and/or a new mixture solvent as an alternative solvent.

CSIRO has devised a transportable pilot plant based on MEA. For the Latrobe Valley Post-combustion Capture project CSIRO operates the pilot plant, based on amine technology, which is connected to flue gases from Victorian brown coal-fired power station at Loy Yang Power (2.2 GW). The objective of the PCC pilot plant trial program is to set a baseline based on 30 wt.% MEA and benchmark other solvents against this baseline. Up to date, our work has examined two different solvents, i.e., Blended Amine 1, which is a mixture of MEA and 2-amino-2-methyl-1-propanol (AMP) and Blended Amine 2, which is a proprietary solvent. The results for these two solvents are compared to the MEA baseline results in terms of CO_2 recovery and reboiler heat duty required.

2. Experimental

2.1. Chemicals and feed gas composition

Concentrated MEA and NaOH 32 wt.% are obtained from Water Treatment Services (Aus) Pty Ltd. 20 wt.% MEA and 10 wt.% AMP are blended for making Blended Amine 1. The concentrated AMP is also supplied by the Water Treatment Services (Aus) Pty Ltd. Blended Amine 2 is supplied by Research Institute of Innovative Technology for the Earth (RITE), Japan. These solvents (except NaOH 32 wt.%) were diluted with mains water prior to use.

Table 1 shows important flue gas constituents and its concentration in the flue gas from Loy Yang Power used during the operation. Furthermore, the flue gas contains significant amounts of SO_2 and NO_x. The SO_2 is washed off in the pre-treatment column with 32 wt.% NaOH.

2.2. Description and operation of the PCC pilot plant at Loy Yang Power

The transportable PCC pilot plant at Loy Yang Power was designed to capture CO_2 from real flue gases using 30 wt.% MEA. This generic solvent is a suitable baseline case due to the availability of

Table 1
Typical gas composition from Loy Yang 'A' power station going to the pilot plant.

Element	Composition
H_2O (vol.% – wet)	20–23
CO_2 (vol.% – wet)	10–11
O_2 (vol.% – wet)	4–5
Impurities (wet ppm volume)	
SO_2	120–200
NO_x (~99% NO, balance NO_2 and N_2O)	150–250
Temperature (°C)	160–180