PCC Pilot plant operation in Australia: Practical experiences with a concentrated piperazine solution

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1. Introduction

CSIRO is operating a Post-combustion CO\textsubscript{2} Capture (PCC) pilot plant program at three different locations in Australia: Loy Yang power station in Victoria, Vales Point power station in New South Wales and Tarong power station in Queensland. The general objective of the program is to evaluate prospective liquid absorbent processes under the relevant flue gas conditions in Australia. The program targets those technologies that show considerable promise in reducing the cost of PCC in Australia. A process based on aqueous concentrated piperazine solutions (CPZ), under development at the University of Texas in Austin, USA\textsuperscript{1} was identified as a potential candidate to achieve the cost reductions. The attributes of the concentrated piperazine solvent and solvent process are such that they have the potential to reduce the costs of capture and compression of CO\textsubscript{2} by 50\% in the Australian context. This expectation is based on extensive laboratory based research at the University of Texas in Austin, which indicated that:

- The CPZ solvent is more reactive than the standard MEA-solutions, leading to a reduction in absorber sizes and hence lower capital cost.
- The CPZ solvent is robust enough to allow regeneration at high temperature resulting in the release of CO\textsubscript{2} at high pressure, thus reducing compression costs.
- The thermal energy for solvent regeneration is less than for MEA.
- The solvent vapour pressure is lower than that of MEA resulting in lower solvent losses.

This contribution will report on the results from an experimental program with concentrated piperazine utilising the Stanwell owned PCC pilot plant at Tarong Power Station.

2. Description of the Tarong PCC pilot plant\textsuperscript{2}

The Tarong pilot plant treats a slip stream of flue gas from the power stations units 3, capturing CO\textsubscript{2} at a rate of \~100 kg/hr (roughly 1000 tpa). The pilot plant consists of three main columns, shown in their standard configuration in Figure 1. The first column is a pre-treatment column. Here the hot flue gases (\~100-110 °C and 1 atm) are scrubbed with a dilute caustic wash, cooling the flue gases (to \~45 °C) and reducing the acid gas and particulate matter content. The cooled flue gases then pass through the blower, raising their temperature slightly (amount
dependant on flow rate) before entering the absorber column. In the absorber the flue gasses are contacted with the absorption solvent (in this case 8m piperazine) in order to capture the CO$_2$. The absorber column contains Sulzer Mellapak M250X structured packing. The CO$_2$ lean flue gas passes into a water wash section at the top of the absorber column to remove any traces of solvent carried over in the gas stream. The CO$_2$ rich solvent enters the stripping column for regeneration and separation of the CO$_2$. The stripping column contains Sulzer Mellapak M350X structured packing. Hot gases leaving the stripping section enter the condenser section (also containing Sulzer Mellapak M350X structured packing) at the top of the column. Lean solvent leaving the bottom of the stripping column is cooled and recycled to the absorber column.

Lean and rich solvent samples are collected just prior to and after the absorber column respectively. Gas measurements are recorded either side of the pre-treatment column, prior to and after the absorber wash column, and in the gas stream exiting the stripping column condenser section. The gas composition is determined by Fourier Transform Infra-Red Spectroscopy (FT-IR) with an accuracy of 2% of the measurement range for each species. Solvent CO$_2$ loadings and piperazine concentration are determined offline by acid-base titration. The flue gas properties entering the pilot plant depend on a number of factors including: whether the power station was operating unit 3 at full load and ambient conditions. A typical flue gas composition entering the pilot plant was 76 vol% N$_2$ (by back calculation), 10 vol% CO$_2$, 8 vol% H$_2$O, 6 vol% O$_2$, 200 ppm SO$_2$, 150 ppm NO$_x$.

![Process Flow Diagram of the Tarong CO$_2$ capture pilot plant](image)

**Figure 1: Process Flow Diagram of the Tarong CO$_2$ capture pilot plant**

### 3. Pilot plant program with concentrated piperazine

The project utilised the Tarong PCC pilot plant in Queensland for this purpose because of its built-in flexibility to enable trialling of different solvent processes. A program of mainly experimental activities was conducted aimed at assessing the anticipated benefits of the concentrated piperazine process:

- Preparation for pilot plant experiments with concentrated piperazine
After a detailed review of HSE procedures provisions were made for the preparation of the solution on site. Dedicated start-up and operating procedures were developed, including a procedure related to building up the necessary solvent concentration in the plant. The preferred operating conditions were also defined.

- **Modification of the Tarong PCC pilot plant**
  - Several modifications of the Tarong PCC pilot plant were implemented, which included replacement of the column gaskets throughout, installation of a larger lean/rich cross heat exchanger and installation of an inter-cooling circuit on the absorber column
  - **Commissioning of the modified PCC pilot plant at Tarong Power Station with the CPZ solvent**
  - The commissioning of the PCC pilot plant with concentrated piperazine involved the careful building up of piperazine concentration levels to desired concentration level and achieving steady operation at the preferred operational conditions. Major goals of this activity were to maintain the water balance and ensure the CO$_2$-balance was achieved.
  - **Parametric variation of process operating conditions**
  - The pilot plant was operated under a range of conditions involving variation of liquid flow rate, variation of regenerator temperature and use of absorber intercooling to achieve a variation of the absorber temperature. The impact of these changes in operating conditions on the reboiler duty and absorption rates has been determined, resulting in the identification of the optimal process conditions for the pilot plant.
  - **Duration experiments at preferred conditions**
  - Duration experiments lasting 2 months were performed with the aim to assess the solvent degradation and its impact on the process performance.
  - **Methodologies for reduction of harmful emissions**
  - A literature study was carried out to assess the options for avoiding emissions of harmful compounds, in particular nitrosamines, either through reduction of nitrogen oxides in the flue gas or removal of nitrogen oxides or nitrosamines from the solvent in a chemical treatment process.
  - **Process evaluation**
  - The results of the experimental campaigns were used to evaluate the overall performance of the process for Australian conditions using a simulation model of a typical Australian coal fired power plant. Estimates for the electricity generation costs and the costs per ton CO$_2$ emission avoided will be reported upon.

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5. **References**


2. Cousins A, Wardhaugh LT, Feron PHM, 2011, Preliminary analysis of process flow sheet modifications for energy efficient CO$_2$ capture from flue gases using chemical absorption, *Chemical Engineering Research and Design* 89, 1237-1251