OPTIMISING CO_2 CAPTURE FROM PULVERISED COAL PLANTS

Post-combustion capture with amine solvents

PROJECT SUMMARY 357

CARBON ABATEMENT TECHNOLOGIES PROGRAMME

JOINTLY FUNDED PROJECT WITH BCURA

BCURA

OBJECTIVES

- To examine optimisation strategies for integrated amine scrubber systems for CO_2.
- To investigate the practicality of implementing promising retrofit plant configurations.
- To compare retrofit performance with published data for other options.
- To estimate the potential market for retrofit applications in the UK and worldwide.
- To explore, for new plant, the effect of varying steam conditions on performance.
- To estimate likely thermodynamic limits for amine-based solvent performance.
- To collaborate with leading research groups, particularly in Canada, USA and Japan.

SUMMARY

This project has spanned, and to some extent contributed to, a period of significant development in the technical, industrial and political aspects of carbon dioxide capture and storage (CCS). The growing awareness of the potential for CCS as a climate change mitigation measure has recently been highlighted by publication of the UK Government's Carbon Abatement Technology Strategy, and CCS played a significant role in the agreed G8 climate change strategy.

Project objectives have all been achieved, and the project has contributed to a general reassessment of post-combustion CO_2 capture from pulverised coal

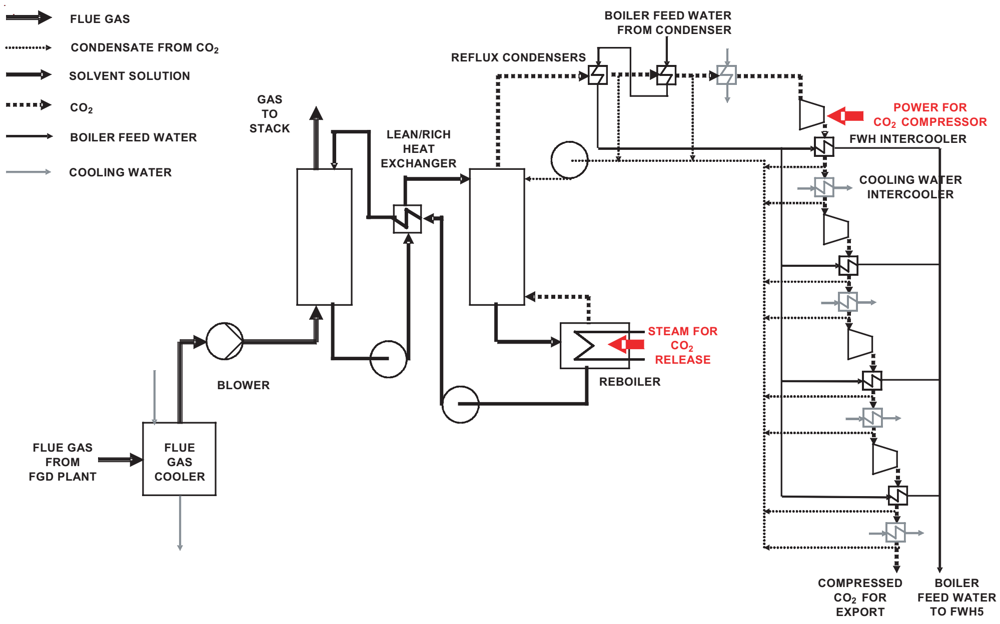


Figure 1. Amine CO_2 capture system process flow diagram (courtesy of Imperial College London)

(PC) plant. A suggested 'standard' pulverised coal power plant with CO_2 capture configuration (Figure 2) has been developed and analysed, using Mathcad and IPSEpro. Depending on the amine solvent used, this approach gives a capture penalty of 8-9 percentage points off the plant lower heating value (LHV) efficiency, and appears to represent the thermodynamic limit without new solvent formulations. This compares favourably with penalty values of ~12 percentage points given in most previous literature. Given the widespread deployment of PC plant, this has obvious strategic relevance for climate change mitigation using CCS.

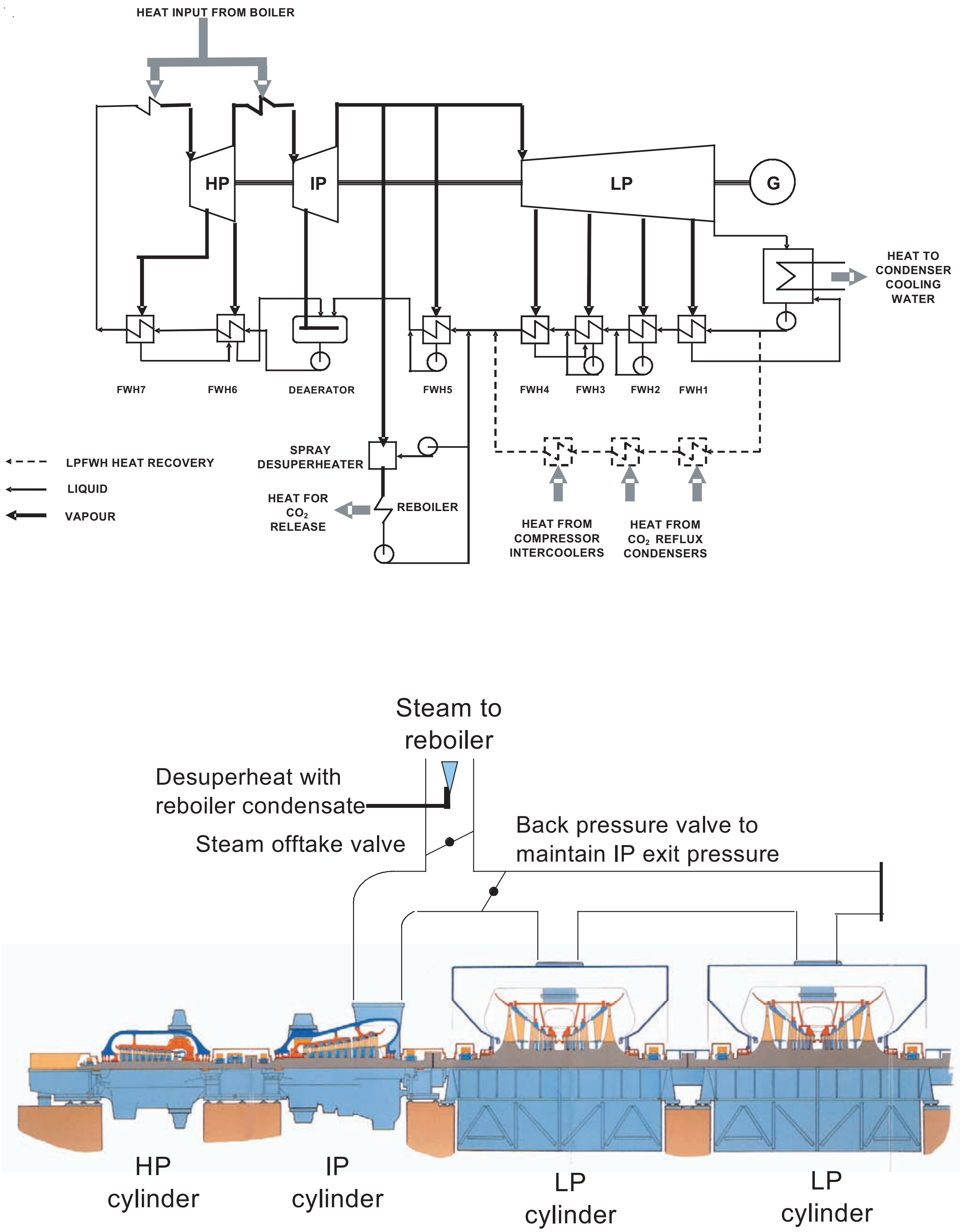
Direct output from the project has included papers describing new retrofit options, optimisation strategies for post-combustion capture and the 'capture ready' concept for 'new build' PC plants. Results from the project have also been applied in an IEA study with BCURA industrial sponsors and were completed in time to be considered for the forthcoming Intergovernmental Panel on Climate Change (IPCC) special report on CCS.

BACKGROUND

As the name implies, post-combustion capture involves removing CO_2 from the flue gases of a power station.

Current technologies use an aqueous amine solution, which undergoes a reversible chemical reaction with CO_2. At low temperatures (~40ºC) CO_2 physically dissolves in the water and then reacts with the amine in an exothermic process. The amine solvent trickles downwards through an absorber column, filled with either random or structured packing to maximise gas/liquid contact and give sufficient liquid hold-up time for reactions to take place. The flue gas then flows up through the column. Before it enters the column, SO_3, SO_2 and NO_2, all of which react irreversibly with amines (although not NO, the larger component of NO_X), must be removed to ideally less than 10ppm total. This is beyond the demonstrated capability of most current FGD systems, since there has previously been no need to achieve such low residual levels, but at least one system (Alstom Flowpac) has been operated routinely at these levels.

As shown in Figure 1, the 'CO_2-rich' solvent solution from the bottom of the scrubber column is first



Alstom Large Steam Turbines brochure

Figure 2. Arrangements for integrating a single reheat steam cycle with an amine system (courtesy of Imperial College London - Turbine section courtesy of Alstom Power)

heated against the hot stream of 'CO_2-lean' regenerated solvent coming from the reboiler and then enters the top of a stripping column. CO_2 is progressively removed from the solvent as it flows down the stripper, until it enters the reboiler and is heated by steam coils to its saturation temperature, to complete the CO_2 release process. The CO_2 leaves the top of the stripper at about 80ºC, saturated with water vapour. The mixture is then cooled and the water is condensed, possibly in several stages to maximise the temperature at which heat can be recovered. The CO_2 is then compressed in a multi-stage process, the last stages of which may involve pumping of high density liquid/supercritical CO_2 rather than gas compression. Additional heat can be recovered during the compression process and the remaining water is removed.

POST-COMBUSTION CAPTURE OPTIMISATION METHODS

To give a formal framework for assessing how likely new and previous post-combustion capture studies are to give the best possible results, six rules that must be followed to achieve optimum post-combustion capture plant thermodynamic and economic performance have been formulated as part of this project. The rules, as framed below, apply particularly to systems using liquid solvents (typically, but not exclusively, aqueous amine solutions) that require low-grade heat (100-150ºC) for solvent regeneration, but are likely to be at least partly relevant for the application of other post-combustion capture technologies (eg CO_2 adsorption on solids).

1. Add heat to the steam cycle at as high a temperature as possible (ie be prepared to use best available steam conditions if commercially justified).

2. Reject heat from the steam cycle, in the steam extracted for solvent regeneration, at as low a temperature as possible.

3. Produce as much electricity as possible from any additional fuel used, consistent with rejecting heat at the required temperature for solvent regeneration.

4. Make use of waste heat from CO_2 capture and compression in the steam cycle.

5. Use the latest solvent developments.

6. Exploit the inherent flexibility of post-combustion capture.

These rules may appear obvious, but have often not been followed in their entirety in published studies of post-combustion CO_2 capture. This does not mean that the results obtained in these studies were in any way incorrect, but it does mean that the results that were obtained probably represent sub-optimal performance or economics when compared with more recent studies based on better plant design assumptions and/or more appropriate post-combustion capture applications.

RESULTS AND CONCLUSIONS

- Depending on the type of commercial amine solvent used, the 'standard' CO_2 capture pulverised coal power plant configuration developed in this project (Figure 2) gives a capture penalty of 8-9 percentage points below the plant LHV efficiency, and appears to represent the thermodynamic limit without new solvent formulations. No benefit has been found for alternative configurations. This compares favourably with penalty values of ~12 percentage points in most previous literature.

- Electricity costs for new pulverised fuel (pf) plant with post-combustion capture are still predicted to be higher than those for Integrated Gasification Combined Cycle (IGCC) plant, principally due to the capital costs of the absorber vessels. Significant cost reductions may, however, be achieved in the future.
- Even with current post-combustion technology options, suitable retrofit applications may still be competitive with new IGCC plant.
- There is a very large and immediate 'market' for 'capture ready' plant technology. This has been specifically identified in the G8 Gleneagles communiqué section on climate change.
- The work has been particularly timely, since results have been available in time to be considered directly, and indirectly through the results of industrial follow-on studies, for the forthcoming authoritative IPCC report on carbon capture and storage.

POTENTIAL FOR FUTURE DEVELOPMENT

The principles developed are being applied in several new DTI projects and other industrial work.

A more detailed evaluation of the scope for implementing flexible operation of power plants with post-combustion capture will be undertaken. This will be linked to a study estimating the value of such flexibility in possible UK electricity supply scenarios (being undertaken as part of the TSEC CCS Consortium project).

Advanced co-optimisation of new solvent formulations, absorber system design and power plant operation is being considered as the next stage in improving the performance of post-combustion capture systems. This may have significant advantages compared to the current practice of optimising the solvent, the capture system and the power plant independently.

Further work to optimise 'capture ready' plant design approaches, particularly for key developing economies such as China, is anticipated.

COST

The total cost of this project was £40,000, with the Department of Trade and Industry (DTI) and BCURA each contributing half.

DURATION

18 months – 1 August 2003 to 31 January 2005

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