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coCAPco

Combined low-cost, pre-treatment of flue gas and capture of CO_2 from brown coal-fired power stations using a novel integrated process concept

Final report (executive summary) – Milestone 9

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Commercial-in-confidence

Contents

Acknowledgements

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Project technical and economical conclusions

AGL Loy Yang (AGL LY, formerly Loy Yang Power), EnergyAustralia (EA, formerly TRUenergy), Federation University Australia (FUA, formerly Monash University (MU)), and the Commonwealth Scientific and Industrial Research Organisation (CSIRO) have joined forces to develop a technology that integrates the pre-treatment of flue gases from brown coal-fired power stations and post-combustion capture of CO_2 (PCC). The resulting technology aims to significantly reduce the costs of avoided CO_2-emissions.

As a major first step in its development, the integrated capture of SO_2 and CO_2 has been developed within the *coCAPco* project; from January 2011 till December 2014. In Milestone Reports 1, 2 and 3, Process A and Process B have been defined; Process A was baptised as the *CASPER* process, which has been developed through the collaboration of CSIRO with TNO (Netherlands Organization for Applied Scientific Research) in the *iCap* project – www.icapco2.org. That process and its technical evaluation has been described in the Milestone 5 report of the *coCAPco* project – *Evidence of finalised campaign 1*. Process B was defined as CSIRO's patented *CS-Cap* technology and its technical evaluation has been discussed in Milestone 6 report. Last not least, a detailed cost engineer exercise has been carried out for the *CASPER* process translating a German 800MW case to a Victorian 500MW case and a qualitative assessment for *CS-Cap* in the Milestone 7 report. An initial outline of the commercialization trajectory has also been developed and is presented in the Milestone 8 report.

Main technical conclusions from these reports:

- *CS-Cap* has been successfully patented (Puxty et al., WO2012/097406) as depicted in Figure 1;
- CASPER and CS-Cap have both been proven to capture all SO_2 at whatever concentration it enters the capture plant. Both technologies have experienced SO_2 concentrations as high as 600-700ppmv, whereas 140 ppmv is the average value;
- CASPER and CS-Cap both can capture over 90% CO_2 from the flue gas [note: for CASPER a non-confidential amino acid blend had been used as a model. As a consequence suboptimal results were obtained from a capture rate and an energy consumption's perspective.];
- CASPER's maximum uptake of SO_2 is limited by the solubility of potassium sulphate. A side stream of the CO_2 lean solution is cooled to precipitate potassium sulphate as crystals. The process is accelerated by the contributing ionic strength of amino acids;
- The maximum Sulphur concentration in the liquid phase is determined by the pH for CS-Cap. At a pH of between 4 to 5 SO_2 in the flue gas breaks through the first column, which represents the bottom section of the CS-Cap technology, and amine, from CO_2 capture loop, needs to be added to increase the pH and thereby capturing all SO_2 from the flue gas in that 'bottom' section. Any remaining SO_2 was captured in the second absorber column and no SO_2 was emitted from the capture process. In the process the pH has dropped as low as 2.6 and still no precipitation was observed. A model, which was developed in-house, describing the sulphur chemistry and predicting SO2 exit concentrations as a function of SO2 and CO2 inlet concentrations and liquid absorbent composition, has been validated.
- CS-Cap requires further investigation before long term trials would be considered. There is a lot of room for optimization and foremost fundamental understanding of the regeneration technologies. As a result coCAPco[2], a new project that started in March 2014, is dedicated to the regeneration of sulphur loaded amine blends.

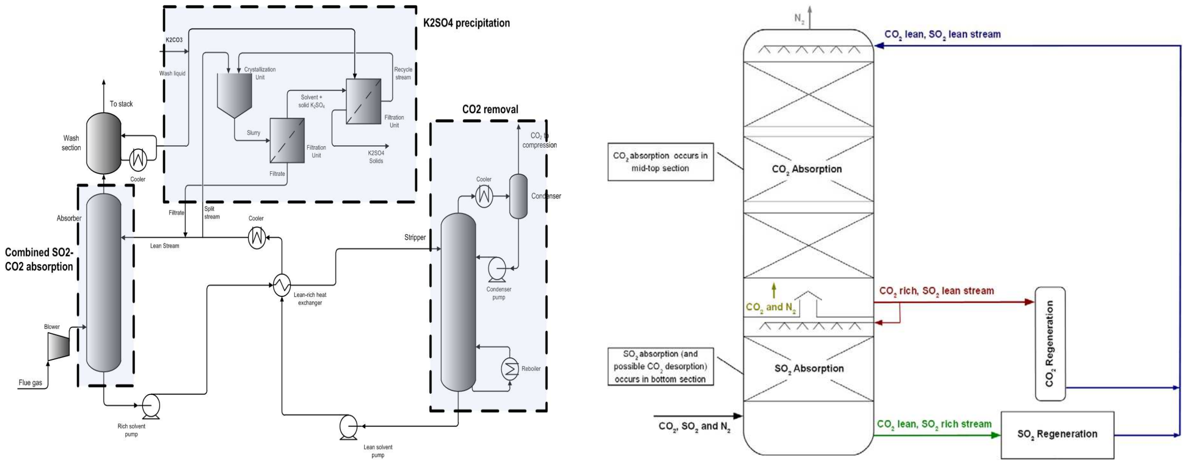

Figure 1: Process A, a.k.a. *CASPER* conceptual flow diagram of combined capture process by CSIRO and TNO (left) and Process B, a.k.a. *CS-Cap* –by CSIRO (right).

Main economical conclusions from the reports:

- Both technologies have the potential to capture SO_2 and CO_2 at the same time, thereby deleting the need of a flue gas desulphurisation (FGD) unit. An FGD unit would costs about $200-270m for a 500 MW power plant in the Latrobe Valley. In contrast, the extra facilities to capture SO_2 into the liquid stream and process it are cost engineered to values between $10-50m. The cost saving of the modified process is therefore about $200m per 500 MW plant.
- The business case of PCC for Australia is currently not favourable and for accelerated development of these particular technologies the team ought to collaborate with overseas opportunities. Greenfield projects (China/India/Ukraine/South-East Asia) and retrofitting power plants without FGD installed are of most interest.
- Collaboration with the EU consortium was very successful. Highly promising discussions on the continuation of the collaboration have been postponed due to declining German business appetite surrounding PCC.

Impact

Publications

Yaser Beyad, Graeme Puxty, Steven Wei, Marcel Maeder, Robert Burns, Erik Meuleman and Paul Feron, *Integrated Single Stream CO_2 and SO_2 Capture*, Int. J. of Greenhouse Gas Control, **31** (2014) 205-213.

Katarzyna Heffernan and Cristina Sanchez Sanchez, Pauline Pearson, James Jansen, Yuli Artanto, Vince Verheyen, Erik Meuleman, Peter van Os, Earl Goetheer, *Australian – Dutch collaboration: Demonstration of combined CO_2 and SO_2 removal from flue gas*, Nederlandse Procestechnoloog, 2014.

Presentations

Erik Meuleman, Graeme Puxty, Narendra Dave, Thong Do, Paul Feron, Integrated capture of CO_2 and SO_2 from coal-fired power stations: Process design and pilot plant preparation, IEA Clean Coal Conference 2013, Thessaloniki, Greece.

Erik Meuleman, Alicia Reynolds, A. Cottrell, V. Verheyen, P. Pearson, J. Jansen, S. Huang, N. Slater, Y. Artanto, A. Cousins, *Accelerated ageing of MEA with real flue gas*, Clearwater Clean Coal conference 2013, FL, USA.

A Cousins[1], E Meuleman[1], P Pearson[1], G Puxty[1], J Jansen[1], W Conway[1], N Slater[1], E Curtis[1], A Monch[1], P Feron[1], V Verheyen[2], K Misiak[3], A Huizinga[3], C Sanchez Sanchez[3], P van Os[3], E Goetheer[3], P Castelow[3], *Combined low-cost pre-treatment of flue gas and capture of CO_2 from brown coal-fired power stations*, International Industry Symposium: Innovation or a sustainable future, 2014. [1] CSIRO Energy Technology; [2] Monash University, Gippsland campus; [3] TNO Gas Treatment Group, The Netherlands.

Erik Meuleman, Pauline Pearson, James Jansen, Erin Curtis, Andreas Monch, Graeme Puxty, Paul Feron, Integrated capture of CO_2 and SO_2 from coal-fired power stations – pilot plant and economic assessment results, Clearwater Clean Coal conference 2014, Clearwater, FL, USA.

Erik Meuleman hosted by Leigh Sales, ABC 7:30pm report. *Carbon capture caught in a rut?* http://www.abc.net.au/7.30/content/2012/s3430889.htm (2012).

SUPPORTED THROUGH COCAPCO DURING COCAPCO CAMPAIGN TRIALING:

Mai Bui, Indra Gunawan, T. Vincent Verheyen, Erik Meuleman, Paul Feron, *Dynamic operation of post-combustion CO_2 capture in Australian coal-fired power plants*, GHGT-12, Kyoto, JPN; and in: Energy Procedia 2013.

Alicia J. Reynolds, T. Vincent Verheyen, Samuel B. Adeloju, Erik Meuleman, Paul Feron, *Towards commercial scale post-combustion capture of CO_2 with mono-ethanolamine solvent: Key considerations for solvent management and environmental impacts*, Environ. Sci. Technol., **46** (2012) p3643-3654.

Alicia J. Reynolds, T. Vincent Verheyen, Samuel B. Adeloju, Alan Chaffee, Erik Meuleman, *Quantification of aqueous mono-ethanolamine concentration by gas chromatography with flame ionisation detection*, Ind. Eng. Chem. Res., 53 (2014) p4805-4811.

At least six more papers on Dynamic operation and Breakdown products of amines during PCC have been submitted for publication.

Visitors

On average we have catered for typically 3 visits per year of individuals or groups:

- IHI, Japan, which has resulted in a project, funded by BCIA;
- Matthias Saimplart – Ecole National des Mines, France;
- Jillian Dickinson, Alicia Reynolds, Mai Bui, Vince Verheyen, Sam Adeloju (Monash and Federation University);
- Anna Kunze – Dortmund University, Germany;
- VTT, Finland (2 groups);
- CSIRO Mineral Resources Flagship;
- RMIT students doing a PCC related industry project using MEA as a baseline;
- High-level EU-delegation on CCS.

Other

CarbonNet has requested insight in the coCAPco developments and have received information under a confidentiality agreement with approval by BCIA, AGL Loy Yang and EnergyAustralia. The technology has been assessed for CarbonNet by an independent party (Parsons Brinkerhoff).

Whilst developing our plant operation skills, procedures and associated analytical techniques (affected by Sulphur-related compounds uptake and accelerated ageing of amine blend(s)) the coCAPco project has supported several other projects:

- GCCSI emissions project where accelerated ageing was preferred to study effects on emissions and environmental impact;
- BCIA funded PhD-student Alicia Reynolds developing techniques to identify and quantify amine originating breakdown products;
- CSIRO OCE-top-up PhD-student Mai Bui developing engineering modelling tools to describe dynamic operation in collaboration with Monash University at the Churchill campus;
- Recovery of heat stable salts from real PCC processed MEA through Nanofiltration and membrane electrodialysis with the Melbourne University.

Local suppliers

As an informal rule we order from local companies by preference. Below is a list of most of the companies we have used in the coCAPco project.

Jaycar, Enzed, Gippsland Bolts and Fasteners, Supercheap Auto, Clark Rubber, Nak Signs, Trim and Canvas, Electel, GBS Recruitement, Hayden, Office Works, Total Tools, Bunnings – all in Traralgon;

Kempe, Blackwoods, Hydraulic and Pneumatic - both in Morwell, Swagelock, Eastern Instrument Services – both in Sale;

Renseal, Ramdraft, FoxAllFidera, ECEFast, Prochem Pipeline Products, Sandvik, ThyssenKrupp, Huntsman, Redox, Rhine Ruhr, Midway Metals, GLP - Gas Liquid Processing, Process Flow Systems, Pyrosales, Bayswater,Ambit Instruments, Thermo Fischer Scientific, South Eastern Gaskets – All in Victoria.

Finance

In this paragraph the total expenditures over the life of the coCAPco project are presented. After capturing more than 95% of the costs of coCAPco project related activities of CSIRO, AGL Loy Yang and EnergyAustralia the below table is the result of the project between 2011 and 2014.

For convenience the same numbers have been split up in cash and in-kind contributions resulting in the following tables where the first is consolidated from all partners and the second is Industry only.

Table 1 – Consolidated finance table of project cost for all parties subdividing costs to 'cash' and 'in-kind'.

coCAPco - Consolidated	Cash		In-kind	
	Budget	**Actual**	**Budget**	**Actual**
Funding received	1,500,000	1,335,000	-	-
Project Labour	763,224	635,629	1,006,776	1,124,073
Overheads			1,294,000	1,692,628
Equipment	86,000	0		
Materials	126,000	124,704		
Subcontract	100,000	120,415		
Travel	74,000	136,208		
Other			250,000	251,632
Total	1,149,224	**1,016,956**	2,550,776	**3,068,333**

Table 2 –Finance table of project cost for all industry subdividing costs to 'cash' and 'in-kind'.

coCAPco - Industry	Cash		In-kind	
	Budget	**Actual**	**Budget**	**Actual**
Funding received	-	-	-	-
Project labour	-	-	382,320	128,985
Overheads	-	-	279,504	255,690
Equipment	18,576			
Materials	27,216			
Subcontract	21,600	62,467		
Travel	15,984	77,085		
Other			54,000	224,351
Total	83,376	**139,552**	715,824	**609,026**

The tables show that the project has resulted in significant Industry contributions on a cash and in-kind basis. This is a pleasing result as some of the industry project team left AGL Loy Yang during periods of structural adjustment. The project was also impacted by a (minor) environmental incident that required a range of AGL personnel and subcontractors to become involved. On a positive note some excellent and chemical analyses of both campaigns was undertaken by AGL Loy Yang Chemists to determine the sulphate concentration that was increasing in the liquid absorbent. This information was critical for safe operation (not damaging equipment) and quality of the campaign trial.

The delay of the project has resulted in a significant increase of the in-kind contribution by the CSIRO (+$435k). CSIRO’s depreciation of the pilot plant (~$100k per year) has not been included in these in-kind contributions; though this depreciation is a real cost to the project. In addition, a shift has been made from equipment to materials. Main reason is that most equipment becomes a consumable over the period of the project due to unpredictable accelerated corrosion as a result of the high concentration of impurities in the liquid absorbent. The CASPER process was foreshadowed to be a spray-column technology and many spray column tests have been carried out in the iCap project (EU collaboration) by TNO. Surprisingly, however it was found that CO2-loaded amino acids (at the bottom of the absorber) had a higher solubility for sulphate than the lean amino acids (bottom of the stripper). As a result the sulphate was solidified before entering the absorber and not during the absorption process, and therefore a spray column isn’t warranted.

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