CARBON CAPTURE TECHNOLOGIES IN ENABLING CLEAN COAL ENERGY DELIVERY

J. C. Diniz da Costa[1,2], j.dacosta@uq.edu.au
S. Smart[1], s.smart@uq.edu.au
K. Thambimuthu[2], k.thambimuthu@uq.edu.au
[1]FIMLab – Films and Inorganic Membrane Laboratory and [2]CCETech – Centre for Coal Energy Technology, The University of Queensland, Brisbane Qld 4072, Australia.

Abstract. Coal is the fuel of choice for power production in Australia. The problem is the coal combustion is a significant contributor of greenhouse gases. Therefore, there is a strong commitment of the Australian Government and Industry to reduce CO_2 emissions. There are currently thirteen proposals of carbon capture and storage at different levels of development and deployment in Australia. This work assesses the potential technologies available for carbon capture and under consideration under the Australian program of low emission coal technologies for air blown and oxy-fuel coal combustion, and coal gasification.

Keywords: coal air combustion, oxy-fuel, gasification, carbon capture.

1. INTRODUCTION

Australia energy production is heavily dependent on coal. Coal is the most abundant fossil fuel on the planet, with current estimates at 261 years recoverable reserves in Australia at current usage rates (British Petroleum, 2002). Coal will outlast the oil and natural gas reserves by centuries (Shoko et al. 2005), with suggestion that coal reserves will possibly last for over 500 years (Williams, 2001). Currently coal contributes to 42% of Australia's energy requirements, and predominantly as fuel for electricity production, with approximately 84% produced from coal (Riedy and Diesendorf, 2003). The problem with coal utilisation for power generation is the emission of greenhouse gases which are linked to climate change. In order to reduce greenhouse gas emissions, the most commonly proposed solution is capturing the carbon dioxide and storing it in safe geological strata, a concept called carbon capture and storage (CCS).

In this work, we review the current and potential advanced technologies for carbon capture, with particular attention paid to energy production systems using coal as a fuel. The technologies that are reviewed have potential application in air blown and oxygen blown coal combustion and coal gasification. Five major gas separation technology options are reviewed: cyrogenics, absorption, adsorption, membranes and chemical looping. These technologies are part of some of the thirteen CCS projects currently proposed or underway in Australia (Cook, 2008).

2. CARBON CAPTURE TECHNOLOGIES

Chemical and physical absorption (scrubbing) is a mature technology employed by the chemical and oil industries for over 60 years (DTI, 2003). The CO_2 in a flue gas reacts with a chemical solution in a scrubbing tower while the remaining CO_2 free flue gas is vented to the atmosphere. Most commonly, mono-ethanolamine (MEA) in aqueous solution of 15-20 wt% is used as a chemical solvent. The CO_2 reaction with the chemical solvent is reversible, and the CO_2 is recovered in a regeneration tower by application of heat (usually as steam) to release CO_2 at very high purity and a regenerated amine solvent ready for recycling. The process operates at approximately 40^oC in the scrubbing tower and 120^oC in the regeneration column. Physical solvents are cold methanol (Rectisol process), dimethylether or polyethylene glycol (Selexol process), propylene carbonate (Fluor solvent process) and sulpholane for CO_2 absorption. Physical solvents have a low CO_2 absorption capacity and thus are applicable for CO_2 capture in high operating pressures such as coal gasification.

Chemical looping using solid absorbents works in a similar way to amine scrubbing, and is attracting considerable attention in the research community at the moment. This process typically uses well known carbonation reactions in which the absorbent reacts with CO_2 from a gas stream at around 450-700°C and near atmospheric pressure (Lackner, 2003). The spent sorbent is then removed and may be regenerated by high temperature calcination (>900°C) to release relatively pure CO_2 and regenerated sorbent.

Pressure swing adsorption (PSA) or temperature swing adsorption (TSA) can be also utilised to capture CO_2 from a flue gas stream, and separate H_2 from synthesis gas (syngas) or O_2 from air by using solid sorbents such as zeolites and activated carbon. Both pressure and temperature influences the capacity of sorbents. The process is made up of a set of beds which are switched sequentially in the order 'adsorption, 'blowdown', 'purge' and 'pressurisation' to deliver high gas purities.

Membranes are classified as organic (e.g. polymers) and inorganic (ceramics, metals and silica). The conditions of separation vary greatly depending on the nature of the membrane, temperature, pressure and the properties of the gases. Polymeric membranes are more advanced for CO_2 capture from natural gas and flue gas, while metal and silica membranes are more suited to separate H_2 in coal gasification at simultaneously high temperatures and pressures.

In addition, ceramic membranes based on perovskite materials can deliver 100% O_2 purity for air separation units (Sunarso et al., 2008).

Cryogenic distillation is generally used as the technology of choice for O_2 separation from air with potential applications in coal gasification and oxy-fuel coal combustion processes incorporated with CO_2 capture. It is a very energy intensive process due to low temperatures (down to -200°C) and elevated pressures. Mild cryogenic (-50°C) separation can also be applied to additionally purify the high concentration CO_2 stream emerging from an oxy-fuel combustion system.

3. TECHNOLOGY AND PROCESS INTEGRATION

Chemical absorption is likely to be the "first generation" technology to be adopted in air blown combustion power plants in a system called post carbon capture (PCC). In this process, a PCC train is set at the back end of a coal power plant. The problem here is that absorption or adsorption processes only work efficiently at low temperatures. An additional problem is that excess air is the reactant of choice in air blown coal combustion, thus generating large volumes of flue gas which will have to be cooled down to temperatures as low as 40°C. These processes are energy intensive and likely to reduce the efficiency of the best power plants from 40% down to 30%. This means that 25% more coal will have to be burnt to maintain the same base power load. Consequently, the price of electricity is likely to double when including CO_2 transportation and storage (Davison and Thambimuthu, 2009). A second problem is the degradation of amines in flue gas demonstration (Goff and Rochelle, 2004), and research efforts are now being directed to improving the performance of amine compounds. Polymeric membranes could be deployed, though the flue gas will have to be compressed or the permeate stream operated under vacuum to provide a driving force for the capture of CO_2. All these modifications clearly attract energy penalties.

Cryogenic air separation is an aging technology and likely to be the "first generation" technology of choice in oxy-fuel coal power plants. Coupling a cryogenic air separation unit at the front end of an oxyfuel coal power plant is likely to reduce power generation up to 10%, similarly to PCC systems. An alternative is ceramic membranes (Leo et al. 2009) which offer the potential to achieve energy savings and reduce O_2 production costs by 35% or more (Stiegel, 2004). There is major support by the US DoE for the development of perovskite membranes with Air Products. A variant of chemical looping combustion using metal oxides in a reduction and regeneration cycle to provide O_2 has been proposed, though the development of stable metal oxides is at an early stage of laboratory research.

Similarly to the previous coal power processes, coal gasification is likely to employ mature and aging technologies as first generation demonstration plants with CO_2 capture. Cryogenics will supply pure O_2 at the front end while physical solvent extraction will separate CO_2 from H_2 at the back end of the plant. The issues with energy penalties associated with these technologies remain the same as discussed above. Coal gasification operates at high pressures (~32 bar) and high temperatures (>400°C). These operating conditions favour the employment of embryonic technologies such as metal silica and palladium alloy membranes for H_2 and CO_2 separation (Diniz da Costa et al. 2006). In addition, syngas shifting and separation can be carried out at the same time in a membrane reactor as a single operating unit. Again perovskite membranes are of great interest for reducing energy use penalties and cost to supply tonnage O_2.

4. CONCLUSIONS

Indeed it is possible to build a carbon capture ready coal power plant at the moment by deploying conventional, mature technologies. The problem is related to energy penalties which reduce plant efficiencies and, consequently, increasing the price of electricity. The technological gaps are related to developing novel materials with the capabilities to handle high temperature and pressure operation where further energy efficiencies and capital cost reduction can be realised.

References
BP, 2002. BP statistical review of world energy.
Cook, P., 2001. "Demonstration and Deployment of CCS in Australia", Energy Procedia, Vol. 1, pp. 3859-3866.
Davison, J., and Thambimuthu, K., 2009. "An overview of technologies and costs of carbon dioxide capture in power generation". Journal of Power and Energy, Vol. 223, pp. 201-212.
Diniz da Costa, J. C., Sholl, D., Reed, G., and Thambimuthu, K., 2006. "Gas separation in Coal Gasification". AIChE Spring Meeting, Orlando Fl, USA, 24-28 April 2006, vol 1, 142f pp 1-7.
DTI, 2003. "Review of the feasibility of carbon dioxide capture and storage in the UK". UK Department of Trade and Industry.
Goff, G. S., and Rochelle, G. T., 2004. "Monoethanolamine Degradation: O_2 Mass Transfer Effects under CO_2 Capture Conditions". Industrial Engineering and Chemistry Research, Vol. 43, pp. 6400-6408.
Lackner, K. L., 2003. "A guide to CO_2 sequestration". Science, Vol. 300, pp. 1677-1678.

Leo, A., Liu, S., and Diniz da Costa, J. C., 2009. "Development of Mixed Conducting Membranes for Clean Coal Energy Delivery". Journal of Greenhouse Gas Control, Vol. 3, pp. 357–367.

Riedy, C., and Diesendorf, M., 2003. "Financial subsidies to the Australian fossil fuel industry". Energy Policy, Vol. 31, pp.125–137.

Shoko, E., McLellan, B., Dicks, A. L., and Diniz da Costa, J. C., 2006. "Hydrogen from Coal: generation and utilisation technologies". International Journal of Coal Technologies, Vol. 65, pp. 213-222.

Stiegel, R., 2004. "UD DoE - Important advances in gas separations for gasification applications", in: Separations Technology VI: New perspectives on very large scale operations, Oct. 3-8, 2004, Fraser Island, Australia.

Sunarso, J., Baumann, S., Serra, J. M., Meulenberg, W.A., Liu, S., Lin, Y. S., Diniz da Costa, J. C., 2008. "Mixed Ionic-Electronic Conducting (MIEC) ceramic-based membranes for oxygen separation". Journal of Membrane Science, Vol. 320, pp. 13-41.

Williams, R. H., 2001. "Toward zero emissions for transportation using fossil fuels". VIII Biennial Conference on Transportation, Energy and Environmental Policy, Monterey, California.