Int J Coal Sci Technol (2017) 4(1):1–4
DOI 10.1007/s40789-017-0162-5

Special issue on carbon capture in the context of carbon capture, utilisation and storage (CCUS)

Meihong Wang[1] · Eni Oko[2]

Published online: 17 March 2017

With global energy demand predicted to rise as the world population increases, there is a serious challenge to ensure energy security and also to reduce CO_2 emissions. Atmospheric CO_2 levels will reach about 800 ppm by 2100 resulting in about 4 °C rise in the earth surface temperature if no action is taken (CO_2 Earth 2017). At the 21st Conference of Parties (COP21) to the United Nations Framework Convention on Climate Change (UNFCCC) held in Paris, France from 30th November to 12th December 2015, 195 nations historically agreed to "*combat climate change and unleash actions and investment towards a low carbon, resilient and sustainable future*" with the aim to ensure global temperature rise is kept well below 2 °C (UNFCCC 2015). To achieve this aim, a portfolio of technologies have been proposed, one of which is carbon capture, utilization and storage (CCUS) (Dixon 2016). CCUS comprises of CCS and CCU, both of which involve capture of CO_2 from various sources such as large stationary power plants (Cuéllar-Franca and Azapagic 2015). However, they differ in the destination of the captured CO_2: (1) in CCS, CO_2 is transported and injected into underground storage sites; (2) CO_2 is converted to commercial products in CCU. The energy trilemma including energy security, energy affordability and environmental sustainability makes CCUS the most probable technology for reducing emissions from power plants and carbon intensive industries (IPCC 2014). Without CCUS, mitigation cost is predicted to be as high 138% as shown in Table 1.

CCUS has attracted a great deal of research interest worldwide in recent years. Most research in the context of CCUS focuses on carbon capture since it offers the biggest challenges in terms of capital and operating cost contributing about 70%–80% of the total cost of the full CCUS network including capture, transport conversion/storage (Leung et al. 2014). CO_2 capture is broadly classified into pre-combustion, post-combustion and oxy-fuel carbon capture approaches (Rubin et al. 2015). This is summed up in Fig. 1. In the different approaches, there are different processes for separating CO_2 from gas mixtures such as chemical absorption, physical absorption, adsorption and membrane separation (Wang et al. 2011). Post-combustion based on chemical absorption is the most promising and also mature technologies because it uses very familiar technologies, retrofits more easily to existing power plants and there are already many demonstration projects across the world.

The purpose of this special issue is to create a platform for scientists, engineers and practitioners to present their latest theoretical and technological advancements on carbon capture. In 2013, the EU International Research Staff Exchange Scheme (EU IRSES) funded an international collaboration project between partners in European and Chinese Universities namely the University of Sheffield (UK), the University of Hull (UK), Newcastle University (UK), University of Valenciennes and Hainaut-Cambresis (UVHC, France), Tsinghua University (China), East China University of Science and technology (ECUST, China) and SouthEast University (China). The project titled *Research and Development in Coal-fired Supercritical Power Plant with Post-combustion Carbon Capture using Process*

✉ Meihong Wang
Meihong.Wang@sheffield.ac.uk

Eni Oko
E.Oko@sheffield.ac.uk

[1] Department of Chemical and Biological Engineering (CBE) and Energy 2050, The University of Sheffield, Sheffield, UK

[2] Department of Chemical and Biological Engineering, The University of Sheffield, Sheffield, UK

Table 1 Mitigation cost increases for different scenarios (IPCC 2014)

[% increase in total discounted mitigation costs (2015–2100) relative to default technology assumptions]				
2100 concentrations (ppm CO_2-eq)	no CCS	nuclear phase out	limited solar/wind	limited bioenergy
450 (430 to 480)	138% (29 to 297%) 4	7% (4 to 18%) 8	6% (2 to 29%) 8	64% (44 to 78%) 8

System Engineering technologies (R-D-CSPP-PCC-PSE with Grant agreement No. PIRSES-GA-2013-612230) is aimed at developing and maintaining long term collaborations between partner universities through joint studies in experimental study, model development, process analysis, operation study, controller design and process optimisation for reliable and optimal design, operation and control of coal-fired supercritical power plant integrated with solvent-based post-combustion carbon capture. Some of the outputs from the EU IRSES research project have been reported in this Special Issue. The seven papers published in this Special Issue with researchers from the UK, France, China, South Africa and Ghana involved investigate key areas as summarised in the following paragraphs.

The first contribution of this special issue titled *Current status and future development of solvent-based carbon capture* was contributed by researchers at the Universities of Sheffield and Hull both in the UK. Solvent-based carbon capture technology is generally regarded as the most commercially ready technology for deploying carbon capture in power plants. However, the technology is beset by challenges which has resulted in the cancellation of planned high profile commercial projects. In this paper, the authors reviewed the current status of the technology including commercial deployment, demonstration projects and development of commercial products and evaluated the main challenges facing the technology. They also proposed future research direction to address the challenges. This was summed up as new equipment designs, new solvents and a combination of new equipment and solvent designs. It was noted that different research consortia funded by Engineering and Physical Sciences Research Council (EPSRC) in the UK and EU H2020 were already working in these directions.

In the second contribution, different configurations of post-combustion CO_2 capture process for mono-ethanolamine (MEA) and di-ethanolamine (DEA) solvents are evaluated. The study titled *A comparative study of MEA and DEA for post-combustion CO_2 capture with different process configurations* was carried out by international collaboration of researchers at Tsinghua University (China) and University of Sheffield (UK). Ten different process configurations were evaluated in terms of reboiler duty and total equivalent work. These include inter-cooled absorber, rich solvent split, rich solvent pre-heating, rich solvent flashing, stripper condensate bypass among others. The

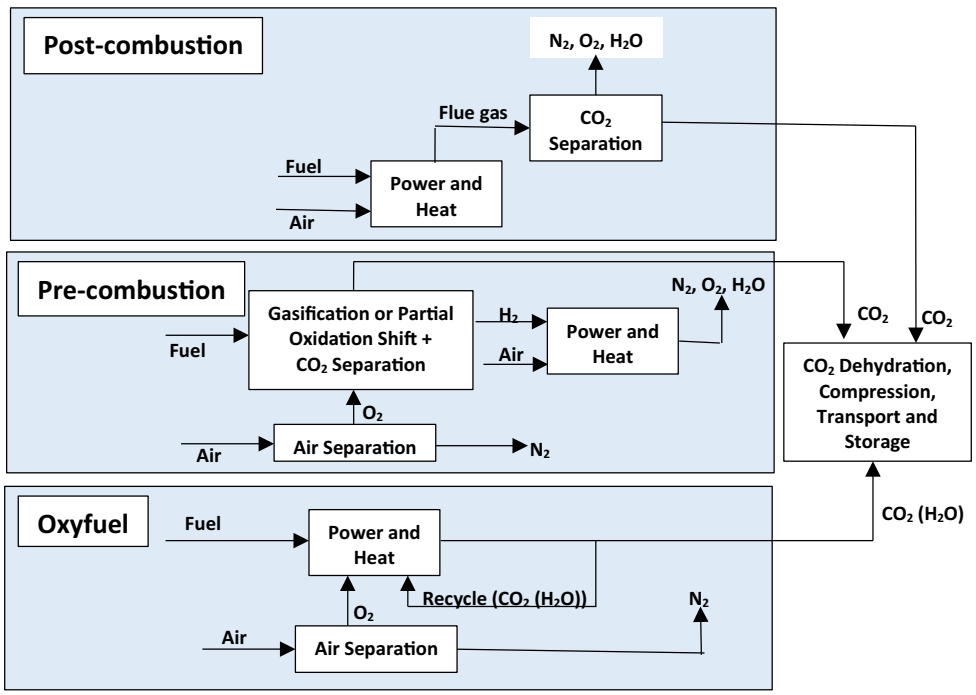

Fig. 1 Carbon capture approaches and technology options (IPCC 2005)

process with DEA was generally shown to have better thermal performances than MEA for all the configurations.

New solvent formulations for CO_2 capture could significantly address current challenges facing the technology including high energy penalty and solvent circulation rate. This is the subject of the third contribution titled *Process simulation and analysis of carbon capture with an aqueous mixture of ionic liquid and monoethanolamine solvent* which was carried out through international collaboration between the University of Hull (UK) and UVHC (France). The research investigated the use of aqueous mixture of 1-butylpyridinium tetrafluoroborate ([Bpy][BF_4]) ionic liquid (IL) and MEA as solvent for carbon capture through process simulations. The process was represented using detailed rate-based model in contrast to similar models in literature which are approximate equilibrium-based models. Their results showed that mixed IL and MEA solvent require lower regeneration energy and solvent circulation rate to achieve similar capture levels as conventional 30 wt% MEA solvent. The result also demonstrated that for economic competitiveness the IL in the mixed solvent should not exceed 5 wt%.

Process models offer an alternative for in-depth study of the process with results from demonstration plants limited in public literature. However, development of carbon capture process models from first principle is time consuming and highly complex. The fourth contribution to this special issue proposes a less laborious but equally reliable approach based on machine learning. The study is titled *Modelling of a post-combustion CO_2 capture process using extreme learning machine* and it was carried out by researchers from Newcastle University and University of Hull in the UK. The bootstrap aggregated extreme learning machine (BA-ELM) model of the process developed in the study provides rapid training and good generalization performance. It is therefore a good option for non-linear optimization of the process.

Development of solid sorbents for post-combustion carbon capture is gaining increasing attention due to the demerits of solvent-based capture including solvent loss, corrosion and high energy penalty. This is the focus of the fifth contribution titled *Synthesis and evaluation of carbon nanotubes composite adsorbent for CO_2 capture: a comparative study of CO_2 adsorption capacity of single-walled and multi-walled carbon nanotubes.* The study was conducted by researchers at University of the Witwatersrand and University of Johannesburg both in South Africa. The study involved characterisation of different carbon nanotube composite adsorbent including single-walled carbon nanotubes (SWCNTs) and multi-walled carbon nanotubes (MWCNTs). The N_2 physi-sorption technique was used to determine the surface area, pore volume and pore size. The morphology and purity were determined using Transmission Electron Microscopy (TEM) and Raman Spectroscopy respectively. Finally, thermos-gravimetric analysis (TGA) was used to evaluate the CO_2 adsorption capacities of the different CNTs. Their results indicated that SWCNTs have better adsorption capacity than MWCNTs.

Solid sorbent development for post-combustion carbon capture is also the focus of the sixth contribution titled *Post-synthesis modification of porous organic polymers with amine: a task-specific microenvironment for CO_2 capture* carried out by researchers at East China University of Science and Technology (ECUST) in Shanghai, China. New solid sorbent developed in their research involves a porous organic polymer with covalent incorporation of amines of different groups such as single amine groups, multi-amine groups of diethylenediamine (DETA) and poly-amine groups of polyethylenimine (PEI). The sorbent reportedly showed excellent porosity, and high CO_2 adsorption capacity and CO_2/N_2 selectivity. The sorbent is also able to be regenerated at high temperature and vacuum condition without losing the adsorption capacity. The solvent is thermally and chemically stable and do not degrade rapidly like liquid solvents.

Pre-combustion CO_2 capture is suitable for carbon capture from high pressure gas mixtures originated from industrial plants and/or Integrated Gasification Combined Cycle (IGCC) plants. The seventh contribution titled *Nanocomposite sodalite/ceramic membrane for pre-combustion CO_2 capture: synthesis and morphological characterization* was carried out by international collaboration of researchers at University of the Witwatersrand in South Africa and University of Ghana. Membrane-based capture incurs less energy penalty and are generally more environmentally-friendly than solvent-based carbon capture. The nanocomposite sodalite/ceramic membrane was synthesised using *pore-plugging* hydrothermal synthesis (PPH) protocol. The methodology involves embedding zeolite crystals within the pores of the supports in the nanocomposite architecture membranes thereby substantially improving the mechanical strength and thermal stability. The membrane was also characterised by determining their morphology and surface chemistry. The research is predicted to be beneficial for development of high performance and cost-effective membrane materials for pre-combustion CO_2 capture.

Many academic colleagues have helped the publication of this special issue by reviewing the manuscripts. We would like to acknowledge their help with thanks.

References

CO_2 Earth (2017). https://www.co2.earth/2100-projections. Accessed in Feb 2017

Cuéllar-Franca RM, Azapagic A (2015) Carbon capture, storage and utilisation technologies: a critical analysis and comparison of their life cycle environmental impacts. J CO_2 Util 9:82–102

Dixon T (2016) Update on CCUS in the global climate picture and IEAGHG activities. Carbon capture utilization and storage conference, Virginia, 13–16th June 2016. http://www.ieaghg.org/docs/General_Docs/IEAGHG_Presentations/CCUS_DC_Dixon_v3.pdf. Accessed Feb 2017

IPCC (2005) IPCC special report on carbon dioxide capture and storage. In: Metz B, Davidson O, de Coninck HC, Loos M, Meyer LA (eds) Prepared by working group III of the intergovernmental panel on climate change. Cambridge University Press, Cambridge

IPCC (2014) Climate change 2014: mitigation of climate change. In: Edenhofer O, Pichs-Madruga R, Sokona Y, Farahani E, Kadner S, Seyboth K, Adler A, Baum I, Brunner S, Eickemeier P, Kriemann B, Savolainen J, Schlömer S, von Stechow C, Zwickel T, Minx JC (eds) Contribution of working group III to the fifth assessment report of the intergovernmental panel on climate change. Cambridge University Press, Cambridge

Leung DYC, Caramanna G, Maroto-Valer MM (2014) An overview of current status of carbon dioxide capture and storage technologies. Renew Sustain Energy Rev 39:426–443

Rubin E, Davison JE, Herzog HJ (2015) The cost of CO_2 capture and storage. Int J Greenh Gas Control 40:378–400

United Nations Framework Convention on Climate Change (UNFCCC) (2015) Historic paris agreement on climate change. http://newsroom.unfccc.int/unfccc-newsroom/finale-cop21/. Accessed in Feb 2017

Wang M, Lawal A, Stephenson P, Sidders J, Ramshaw C (2011) Post-combustion CO2 Capture with chemical absorption: a state-of-the-art review. Chem Eng Res Des 89(9):1609–1624