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Explorative analysis of advanced solvent processes for energy efficient carbon dioxide capture by gas–liquid absorption

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ABSTRACT

CO_2 capture by gas–liquid absorption needs solvents able to overcome existing barriers for wide-scale adoption including high energy requirement, slow reaction rate, insufficient CO_2 loading capacity, solvent degradation and corrosiveness, poor selectivity or limited operating window. It is challenging if not impossible for single or blended solvents to satisfy all these requirements and reach technology readiness level sufficient for economically viable deployment in large-scale CO_2 capture systems, especially in the energy sector. Therefore, innovative advanced solvent processes (ASPs) attract attention as a new technology that may overcome existing barriers in CO_2 capture by gas–liquid absorption. Due to significant research funding in the area of advanced solvent processes over a few recent years many new ASPs have been developed. Thus this study delivers an explorative analysis of ASPs suitable for energy efficient CO_2 capture by gas–liquid absorption. The emphasis is put on ASPs such as two immiscible liquid phases, precipitating solvents, catalysed solvents, microencapsulated solvents, liquid membrane solvents, ionic liquids, and polarity-swing-assisted solvents. The analysis shows that some of recently developed ASPs made huge progress in terms of reduced energy requirement for capturing CO_2. However, most advanced solvent processes have insufficient technology readiness level and, in addition, there is still place for further energy efficiency improvement. Therefore, research efforts capable of bringing ASPs to commercialisation and wide-scale adoption in real large-scale CO_2 capture applications are required in next few years.

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Nomenclature

AA	aqueous ammonia
AAS	amino acid salt
ASP	advanced solvent process
BDA	1,4-butanediamine
CA	carbonic anhydrase
CAP	chilled ammonia process
CAPEX	capital cost
CO2BOL	CO_2 binding organic liquid
DBU	diazabicyclo[5.4.0]-undec-7-ene
DEEA	2-(diethylamino) ethanol
DMCA	*N*,*N*-dimethylcyclohexylamine
DMEDAH	dimethylethylenediamine
DMPDAH	dimethylpropylenediamine
DPA	dipropylamine
FP7	7th framework programme
GAP-0	1,3-bis(3-aminopropyl)-1,1,3,3-tetramethyldsiloxane
iCAP	FP7 project acronym
IL	ionic liquid
IPADM-2BOL	1-((1,3-dimethylimidazolidin-2-ylidene)amino)propan-2-ol
MAPA	3-(methylamino)propylamine
MEA	monoethanolamine
MOF	metal–organic framework
OPEX	operating cost
PC	pulverised coal
RESD	Renewable Energy and Sustainable Development (RESD) group
TMG	1,1,3,3-tetramethylguanidine
TRL	technology readiness level
TSIL	task specific ionic liquid
%wt	percent by weight

1. Introduction

The problem of thermodynamically efficient and scalable CO_2 capture (Kuramochi et al., 2012) is a true grand challenge for modern energy scientists. CO_2 capture by gas–liquid absorption has undergone a remarkable progress over recent few years and clearly remains among competitive candidates for large-scale CO_2 capture applications. Especially, recent developments in the area of advanced solvent processes (ASPs) have potential to dramatically reduce energy penalty associated with separating CO_2 from flue gases in the energy sector.

Advanced solvent processes rely on employing specific physical or chemical phenomena that enhance a capture process and facilitate solvent regeneration thus minimising energy requirement of the CO_2 separation step. ASPs being capable of integrating into realistic CO_2 intensive plant configurations (Neveux et al., 2013) could dramatically reduce energy penalty associated decarbonisation of the energy sector as well as others CO_2 intensive sectors of the economy.

Gas–liquid absorption is suitable for a post-combustion mode of CO_2 capture because reactive solvents are able to efficiently separate CO_2 from highly diluted gases. It is also suitable for a pre-combustion mode due to low temperatures required in CO_2 removal by liquid solvents, and hence it may separate CO_2 even from flammable fuel gases such as hydrogen or methane without increasing the risk of oxidation of such fuels. Temperatures in CO_2 capture by gas–liquid absorption are lower than in solid sorbent carbon capture technologies and higher than in cryogenic capture systems. This property is usually beneficial for low energy intensive separation and facilitates integration into power plants. Especially cryogenic systems are unsuitable for integration into high-temperature power cycles (Fu and Gundersen, 2012) due to consuming a lot of usable power and generating often unusable low grade thermal energy.

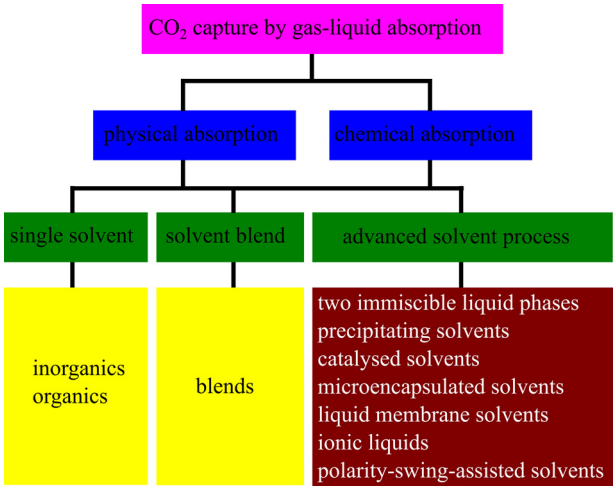

Fig. 1. Structure of solvents used in CO_2 capture by gas–liquid absorption.

Fig. 1. schematically illustrates the structure of solvents used in CO_2 capture by gas–liquid absorption. Single solvents and solvent blends have received a lot of attention in the literature since they are realistic for large-scale deployment in the short run. For these solvents a remarkable body of literature is currently available, e.g. (Abu-Zahra et al., 2013; Budzianowski, 2015). Unfortunately, in relation to advanced solvent processes, the published results are insufficient to start commercialisation of many such technologies in near future. In addition, literature focusing on ASPs is limited and several important gaps need to be filled.

As it may be observed in Fig. 1 the diversity of single solvents and solvent blends is limited compared to the diversity of ASPs. This diversity of ASPs increases the likelihood of creating a truly optimised technology for a given capture application. Therefore, this study has been undertaken in order to synthesise state-of-the-art knowledge strictly focusing on advanced solvent processes. The emphasis is put on potential benefits and challenges associated with the use of a range of ASPs. The study is aimed at contributing to the progress in CO_2 capture by gas–liquid absorption and advanced solvent processes are considered as an essential tool that may achieve this goal.

This study is organised as follows. Section 2 identifies technological barriers limiting wide-scale adoption of CO_2 capture by gas–liquid absorption some of which may be successfully addressed by ASPs. Section 3 discusses research undertaken in recent projects on CO_2 capture by gas–liquid absorption involving ASPs. In Section 4 essential developments of CO_2 capture by gas–liquid absorption involving ASPs are critically analysed and Section 5 provides conclusions drawn from the study and outlook for the future.

2. Technological barriers limiting wide-scale adoption of CO_2 capture by gas–liquid absorption

CO_2 capture by gas–liquid absorption has been employed in commercial applications for almost a century. However, the scale of these applications has always been relatively small compared to the scale relevant to applications in the energy sector. The scale of CO_2 capture is a real challenge for achieving energy efficiency because even small improvements may lead to remarkable benefits