Are water-lean solvents a game-changer in post-combustion CO$_2$ capture?

P. Brandl$^{1,2}$, N. Mac Dowell$^{1,2,*}$, J.P. Hallett$^4$, D.J. Heldebrant$^3$

$^1$Centre for Process Systems Engineering, Imperial College London, South Kensington Campus, London, SW7 2AZ, UK
$^2$Centre for Environmental Policy, Imperial College London, South Kensington Campus, London, SW7 1NA, UK
$^3$Pacific Northwest National Laboratory, 902 Battelle Boulevard, Richland, Washington 99352, United States
$^4$Department of Chemical Engineering, Imperial College London, South Kensington Campus, SW7 2AZ, London, United Kingdom.

Abstract

Fossil fuel fired power generation will likely remain part of the energy mix in the mid-term and it is widely regarded that large scale Carbon Capture and Sequestration (CCS$^\dagger$) must be deployed in order to meet COP21’s$^\ddagger$ targets. A vast research effort focused on increasing a solvent’s equilibrium capacity to absorb CO$_2$ or on reducing the inherent energy requirement of regenerating the solvent, and led to thousands of new materials being proposed in the last decades.

Chemical solvent based post-combustion capture [1] is the most mature technology, which could be deployed near-term and at large scale. Amine scrubbing is the predominant technology and usually utilises aqueous blends of primary, secondary, tertiary, sterically hindered or cyclic amines. Common examples are monoethanolamine (MEA), diethanolamine (DEA), methyl diethanolamine (MDEA), 2-amino-2-methyl-1-propanol (AMP) and piperazine. State-of-the-art proprietary amine solvents have shown workable capacities up to 5000 tonnes CO$_2$ per day at commercial-scale plants at Boundary Dam and Petra Nova. Water-lean systems include e.g., conventional ionic liquids (ILs), amines in ILs, phase changing solvents, and CO$_2$-binding organic liquids (CO$_2$BOLs), which replace water with alcohol and nucleophilic amines with a non-nucleophilic base [4].

It is common heuristic that increased viscosity is a significant disadvantage, and water-lean solvents are significantly more viscous compared to conventional alkanolamine solvents. Typical viscosities range from 10mPa·s up to 3500mPa·s at their respective operating window. Those values significantly exceed the order of 30wt-% aqueous MEA (2.5mPa·s). Recent results indicate reductions in CO$_2$BOL’s intrinsic viscosity to smaller than 250mPa·s [5,6]. Water-lean solvents show superior mass transfer and kinetics compared to amines, which opens highly non-linear multi-dimensional trade-offs between thermodynamic- and transport-properties (e.g., enhanced kinetics and increased viscosity). Previous results indicate that viscosity dominates the installed costs [2] and even limits the usability of conventional ILs as post-combustion capture solvents [3].

$^*$ niall@imperial.ac.uk Tel: +44 (0)20 7594 9298
$^\dagger$ Including Bioenergy with CCS (BECCS)
$^\ddagger$ 2015 United Nations Climate Change Conference (COP21)
In this study, we present a techno-economic assessment of typical water-lean solvents and evaluate a potential cost benefit over typical aqueous amine solutions for coal-fired power plant flue gas conditions, e.g., $y_{\text{CO}_2}=12\%$. The aim is to identify if the enhanced kinetics outweigh the effect of the increased viscosity on a cost per ton basis. The economic calculation (CAPEX, OPEX) is physically based on properties such as e.g., column height, material or flowrates and is condensed into the total annualised costs (TAC, total cost of ownership) $\$/\text{ton}_{\text{CO}_2}$.

This study quantifies the trade-off between viscosity and kinetics, in order to benchmark an acceptable increase in viscosity with enhanced kinetics for water-lean solvents. A two-dimensional sensitivity analysis and the impact of a solvent’s viscosity and kinetics (expressed as weight fraction of an active compound, which has the same type of kinetics as MEA) are shown in Figure 1§.

The steep incline in TAC between 10mPa∙s and 20mPa∙s is mainly triggered by a transition from turbulent to laminar flow in the heat exchangers [2]. The TAC decreases with increasing weight fraction, which indicates that the enhanced kinetics (e.g., higher absolute rate of reaction) outweigh effects by increased viscosity, i.e., the viscosity does not limit the equipment through e.g., unrealistic absorber’s height [3], because less solvent is needed to absorb the same amount of CO$_2$.

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**Figure 1**: Two dimensional sensitivity analysis of the impact of a solvent’s viscosity and kinetics (expressed as weight fraction of an active component) on the total annualised costs. A 30wt-% MEA (aq.) solution is marked with $x$.

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§ Note that [6] mentions 20mPa∙s as development target for CO2BOLs with some showing viscosities<100mPa∙s.
References: