Experimental investigation of low-temperature CO\(_2\) separation for carbon capture in the cement industry

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Abstract

As discussed in earlier studies (Berstad, Anantharaman et al. 2013), the use of low-temperature CO\(_2\) capture by liquid-vapor phase separation can increase the efficiency for several carbon capture applications where the CO\(_2\) concentration is high. Low-temperature separation has been thoroughly investigated for oxy-combustion flue gases with high CO\(_2\) concentrations, but has been given little attention for flue gas and synthesis gas separation. A comparison of an IGCC with low-temperature capture to a baseline with Selexol capture, showed that the electric efficiency can be improved with 0.8 – 1.0 % (Berstad, Anantharaman et al. 2013).

CEMCAP is an international R&D project under the Horizon 2020 Programme, preparing the ground for the large-scale implementation of CO\(_2\) capture in the European cement industry. One of four capture technologies investigated in CEMCAP is hybrid flue gas separation by using polymeric membranes for a bulk separation process (Bouma, Vercauteren et al. 2017), giving a crude CO\(_2\) permeate with typically 60–70 mol% purity, followed by CO\(_2\) purification and compression using low-temperature CO\(_2\) liquefaction.

To investigate the performance of the low-temperature liquid-vapor carbon capture process, a laboratory rig with the capacity to capture approximately ten tons of CO\(_2\) per day has been built. A principle schematic of the experimental setup is given in Figure 1 below. The gas mixture is synthesised to give CO\(_2\) concentrations corresponding to what is achieved using post-combustion membrane technology for flue gas separation.

Figure 1. Main process components in the experimental set-up
The gas mixture is first compressed to about 45 bar or 120 bar through either two or three compression stages with inter- and aftercoolers. After the compression, the gas mixture is cooled in a process-to-process heat recuperator where heat is exchanged with the final liquid CO$_2$ stream. An auxiliary refrigeration cycle further cools the mixture to the separation temperature. Alternatively, the auxiliary refrigeration cycle can be bypassed and the mixture is rather cooled by expansion to a lower pressure. The mixture is then separated in the first separator stage at temperatures below -50°C. The decarbonised gas from the separator is heated and expanded before it returns to the mixing tank, while the liquid, CO$_2$-rich phase, is expanded to a lower pressure and separated in a second separator to purify the CO$_2$ stream. Flashed gas returns to the mixing tank while the liquid CO$_2$ stream enters the process-to-process heat recuperator before returning to the mixing tank.

The rig is well instrumented with mass flow meters, temperature sensors and pressure sensors at important points in the process. Additionally, the process is connected to a gas chromatograph at five locations to control the separation feed and product streams.

The experimental setup is intended for mixtures of CO$_2$/N$_2$ in the first experiments, but is ready to be used for CO$_2$/H$_2$ mixtures at a later stage. In the first experimental campaign, different CO$_2$/N$_2$ mixture compositions, pressure levels and temperature levels will be investigated, and the performance with regards to CO$_2$ capture ratio and purity of the captured CO$_2$ stream will be evaluated.

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**References**

