Post-Combustion Carbon Capture, and it's place in HyNet

HyNet is the one of the UK's leading industrial decarbonisation projects, and will use a wide range of technologies to deliver decarbonisation. This includes Hydrogen production from electrolysis and CCS enabled, both of which will comply with the UK low carbon hydrogen standard. It has CO_2 transport and storage, Hydrogen pipeline network from producer to end use, and salt cavern storage for Hydrogen to smooth out demand peaks and troughs.

Though one the of the most abundant technologies being employed is post-combustion carbon capture. These are primarily being developed to decarbonise industrial processes where there isn't another practical or cost-effective solution, such as electrification or fuel switching, or where CO_2 is a byproduct of the chemical process. This includes Energy from Waste, Cement Production and Refinery operations.

Post-combustion carbon capture is incredibly effective at removing CO_2 from these processes. The plants under development are targeting CO_2 capture rates of 95% of the current emissions, i.e. for every 100 tonnes of CO_2 in the flue, 95 tonnes will be captured and sent to storage with the remaining 5 tonnes being vented to atmosphere. A greater percentage of CO_2 capture could be achieved, but the increase in energy required to capture the last few percent of CO_2 increases exponentially making it uneconomic. When viewed as a complete installation the process can seem very energy intensive, though when viewed at a per unit level of CO_2 capture it is one of the most cost-effective methods of carbon reduction.

The plants under development in HyNet range in size of annual emissions to atmosphere of between 400,000 to 1,000,000 tonnes per year of CO_2. The addition of post-combustion capture on these industrial processes presents a similar challenge with broadly the same technological solution. Though each of the plants have their own unique integration challenges and opportunities on the existing sites to optimise the design.

This article will walk through the major process steps with a post-combustion capture plant. To aid the description, a process flow diagram for a basic 1 MTPA (million tonnes per year) capture plant has been shown, this was developed by Progressive Energy Ltd using Thermoflex 31 using an Amine based CO_2 chemical absorption process.

The start of the process begins taking the existing stack away from the stack where it is vented to atmosphere, and instead ducting it towards to the capture plant. This will typically involve flue gas at a temperature in excess of 100°C, contain a CO_2 concentration of between 8% and 12% by volume, and be only marginally above atmospheric pressure. The flue gas is also likely to contain impurities that need to be stripped out prior to the absorber column, as they can deleteriously impact performance and longevity of the Amine used to capture the CO_2.

The first major step in the process is where flue gas enters a direct contact cooler (DCC) to bring the flue gas temperature down to between 40 and 50°C. This temperature is required for optimal operation of the Amine in the absorber tower. This is achieved through a flue gas blower, or fan, pushing the flue gas through the process. In this case this the blower/ fan is upstream of the DCC, but alternative designs exist with the fan downstream of the DCC. The DCC typically incorporates some flue gas clean up, such as SO2 removal (not shown in this simplified example). The clean, cool flue will exit and make it way to the absorber column, and a substantial quantity of relatively clean water will exit the bottom of the DCC. This water will usually be treated with NaOH to maintain the correct pH level for re-use.

The second major step is through the absorber column where the cooled flue gas enters at the bottom and flows vertically upwards. The absorber column is typically made up of 2 sections.

1) The CO_2 absorption section, where lean amine solvent flows downward to react with the flue gas flowing upwards. This is where a chemical bond is formed with the carbon dioxide contained in the flue gas, in this example up to 95%. In a plant this size it would occur over multiple beds of packing with the solvent evenly distributed across each bed; and

2) A water wash section – located at the top of the absorber serving to cool and scrub any entrained solvent from the treated flue gas.

The clean flue gas exits the top of the absorber column to atmosphere, and the CO_2 rich solvent exits the bottom of the column and is pumped via a heat-exchanger to the 3rd major step of the process, the stripper column.

In the stripper column the rich CO_2 solvent is heated using relatively low-grade steam. Typically, between 130°C to 200°C, and between 3 bar and 15 bar. In this example the temperature is 170°C and 4 bara. The steam mixing with the rich solvent breaks the chemical bond between the CO_2 and the amine, generating a flow of saturated CO_2 and lean amine solvent. The amine solvent flows from the bottom of the stripper column to the reboiler where it is regenerated, and sent back to the absorber column for re-use. The CO_2 exits the top of the column where it is cooled.

The stripper column and reboiler step is where the majority of the steam is consumed, and is often quoted as a headline figure for energy consumption for per unit for CO_2 captured. A generic amine solution, such as MEA, could offer a rate of 3 GJ/tCO_2, whereas a proprietary amine from one of the major carbon capture technology suppliers can be as low as 2.3 GJ/tCO_2. In the process diagram example, a rate of 2.5 GJ/tCO_2 has been used, though for clarity it is expressed in kJ/kgCO_2.