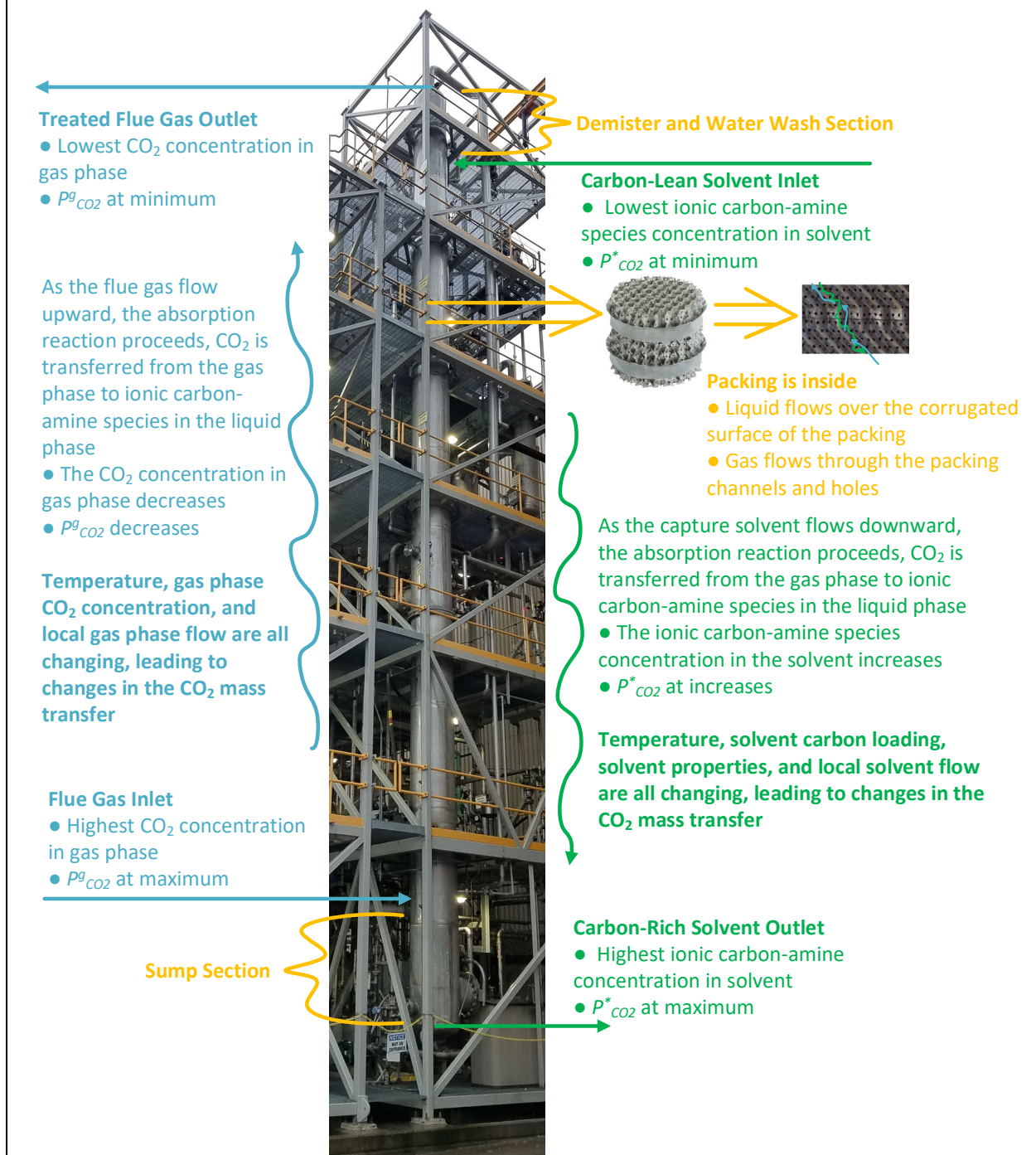


This is the UK IDEA Engineering Scale CO<sub>2</sub> Absorber. It was designed, installed, operated and analyzed since 2011, with funding primarily from U.S. Department of Energy National Energy Technology Laboratory through Cooperative Agreement DE-FE0007395, in Research Partnership with PPL Corporation, and with other funding and support received from PPL Corporation, Duke Energy, Electric Power Research Institute, Inc., Kentucky Power and the Kentucky Department for Energy Development.



The CO<sub>2</sub> Absorber

Inside the absorber column is where the CO<sub>2</sub> is transferred from the flue gas to the capture solvent.

The flue gas enters toward the bottom of the column, above the sump section, and flows upward, while the carbon-lean capture solvent enters toward the top of the column, below the demister and water wash sections and flows downward. Where the CO<sub>2</sub> in the gas phase encounters an amine group in the liquid phase, a chemical absorption reaction occurs. The CO<sub>2</sub> combines with the amine to form ionic carbon-amine species in the liquid phase. The concentration of the ionic carbon-amine species in the solvent is referred to as the carbon loading. When the capture solvent first enters the absorber, it is referred to as carbon-lean, meaning it contains very few ionic carbon-species. As the carbon-lean solvent travels down the column, more and more CO<sub>2</sub> is absorbed by the solvent, and more and more ionic carbon-amine species are formed within. When the solvent collects in the sump section of the absorber, it is referred to as carbon-rich, meaning it contains many ionic carbon-amine species. The chemical absorption reaction is exothermic, meaning one of the products is heat and as CO<sub>2</sub> absorption reaction proceeds, as CO<sub>2</sub> is transferred from the flue gas to the capture solvent, the temperature increases.

The CO<sub>2</sub> concentration in the gas phase is highest at toward bottom of the column, where it enters, and decreases as flue gas flows upward. The concentration of ionic carbon-amine species is lowest toward the top of the column, where the carbon-lean solvent enters and increases as the solvent flows down. The absorption reaction is fastest toward the top of the column and a temperature bulge results in the top portion. Temperature is often controlled with one or more intercoolers along the column height.

So, the gas phase CO<sub>2</sub> concentration, the solvent carbon loading and the temperature all change throughout the absorber column.

The mass transfer of the CO<sub>2</sub> from the flue gas to the capture solvent is defined by this **Equation 1**.

**Equation 1.**

$$\text{Gas Mass Transfer} = A \cdot K_G (P_{gas}^g - P_{gas}^*)$$

Here gas is CO<sub>2</sub>, A is the contact area between the gas and the liquid; K<sub>G</sub> is the overall mass transfer coefficient and; (P<sub>gas</sub><sup>g</sup> - P<sub>gas</sub><sup>\*</sup>) is the difference between the gas phase partial pressure of CO<sub>2</sub>, P<sub>CO<sub>2</sub></sub><sup>g</sup>, and the equilibrium partial pressure of CO<sub>2</sub> resulting from the loading in the solvent, P<sub>CO<sub>2</sub></sub><sup>\*</sup>. This difference in partial pressure terms is referred to as the driving force for CO<sub>2</sub> capture. Increasing any, and all, of these terms is how mass transfer in the absorber is increased.

The area, A, is often manipulated by the column internals, such as packing, which provide a physical place for liquid and gas to come into contact. Different kinds of packing can be applied, but always with a trade-off between efficiency and capacity. But A is also affected by local solvent and gas flow rates and the solvent properties such as hydrophilicity, viscosity, surface tension. The solvent properties are affected by the carbon loading and temperature. Likewise, the mass transfer coefficient, K<sub>G</sub>, is affected by diffusion of the CO<sub>2</sub>, the amine concentration, and the absorption reaction chemistry, all of which are also affected by carbon loading and temperature. Finally, the driving force for CO<sub>2</sub> absorption is affected by gas phase CO<sub>2</sub> concentration, the solvent carbon loading, and the temperature.

**Analogy to WFGD**

The CO<sub>2</sub> absorber has similarities and differences when compared to wet flue gas desulfurization units (WFGDs) already applied at coal-fired utilities, as summarized below.

| Aspect                                | WFGD                                      | CO <sub>2</sub> Capture                |
|---------------------------------------|---|--|
| Flow Configuration                    | Counter-current                           | Counter-current                        |
| Inlet Concentration                   | 3000-5000 ppm SO <sub>2</sub>             | 10-13 vol% CO <sub>2</sub>             |
| Outlet Concentration                  | 10-50 ppm SO <sub>2</sub>                 | 1.5-2 vol % CO <sub>2</sub>            |
| Absorbing Chemical Concentration      | 0.026 mol/m <sup>3</sup> Ca <sup>2+</sup> | 1200-1500 mol/m <sup>3</sup> amine     |
| Column Internals                      | Spray (with/out tray)                     | Film on packing                        |
| Gas Velocity                          | 10-15 ft/s                                | 3-6 ft/s                               |
| L/G (mass/mass)                       | 10  | 3.5                                    |
| Temperature Profile                   | Top 55, bottom 60 °C                      | Top 40, middle 70, bottom 50 °C        |
| Effective Wet Surface per Unit Volume | 1523.85 m <sup>2</sup> /m <sup>3</sup>    | 200 m <sup>2</sup> /m <sup>3</sup>     |
| Diffusivity                           | 1.2x10 <sup>-5</sup> m <sup>2</sup> /s    | 2.0x10 <sup>-9</sup> m <sup>2</sup> /s |
| Reaction Kinetics, K <sub>2</sub>     | 10000 m <sup>-2</sup>                     | 3000 m <sup>-2</sup>                   |
| Log Mean Driving Force                | 0.07 kPa                                  | 4.33 kPa                               |

Starting with  $A$  from **Equation 1**. The WFGD applies a spray of limestone, Ca<sub>2</sub>CO<sub>3</sub>, slurry while solvent distributed and flowing over structured packing is applied in the CO<sub>2</sub> absorber. The FGD spray droplets are ~150-200 μm and the limestone slurry to gas mass flow ratio is ~10. The liquid/gas specific surface area is ~1500 m<sup>2</sup>/unit volume. But for 250Y structured packing, commonly applied in the CO<sub>2</sub> absorber, the surface area is only 200 m<sup>2</sup>/unit volume.

Considering  $K_G$  from **Equation 1**. The overall mass transfer coefficient, capital  $K_G$ , is a function of both the gas phase mass transfer,  $k_g$ , and the solvent mass transfer,  $k'_g$ , as shown in **Equation 2**. Gas phase mass transfer is much faster than liquid phase, which is to say that overall mass transfer is limited by the liquid phase mass transfer.

$k'_g$  is a function of diffusion,  $D_{CO_2}$ , reaction kinetics,  $K_2$ , the absorbing species concentration,  $[solvent]$  and the Henry's constant, as shown in **Equation 3**.

**Equation 2.**

$$\frac{1}{K_G} = \frac{1}{k_g} + \frac{1}{k'_g}$$

**Equation 3.**

$$k'_g = \sqrt{\frac{D_{gas} \cdot K_2 \cdot [solvent]}{H_{gas}}}$$

The calculated value of  $k'_g$  for CO<sub>2</sub> and a fast solvent, like piperazine (PZ) is about twice as that for SO<sub>2</sub> scrubbing. We must also remember the great difference in the Ca<sup>2+</sup> and amine concentrations, by 5 orders of magnitude, which favors CO<sub>2</sub> absorption mass transfer. The diffusivity of CO<sub>2</sub> within the liquid is lower

than that for SO<sub>2</sub>, disfavors CO<sub>2</sub> absorption mass transfer. The reaction kinetics for CO<sub>2</sub> absorption are much lower than for SO<sub>2</sub> absorption, disfavoring CO<sub>2</sub> absorption mass transfer.

Finally, consider the driving force for absorption. The vast difference in the inlet and outlet concentrations, 10-50 vol% to 1.2-2 vol% for CO<sub>2</sub> capture and 3000-5000 ppm to 10-30 ppm for SO<sub>2</sub>, result in a much smaller driving force for SO<sub>2</sub> absorption.

With SO<sub>2</sub> absorption there is high surface area, higher SO<sub>2</sub> diffusivity, fast kinetics, but a low reactant concentration and low driving force. For CO<sub>2</sub> absorption, the opposite is the case. There is a low surface area, low CO<sub>2</sub> diffusivity, slow kinetics, high reactant concentration and high driving force.

### **Analogy to a Cooling Tower**

As warm water flows down over packing and ambient air is blown upward through and over the water, the water evaporated. The phenomenon of evaporative cooling is what makes a cooling tower work. The same happens inside the CO<sub>2</sub> absorber. Water from the CO<sub>2</sub> capture solvent evaporates as it flows down over the flue gas. Evaporative cooling does also occur within the CO<sub>2</sub> absorber.

### **Quiz**

1. What is inside the CO<sub>2</sub> absorber?
2. What are three main variables affecting CO<sub>2</sub> capture?
3. What other conditions and properties affect CO<sub>2</sub> capture?