The CONTACTOR™
Published Monthly by Optimized Gas Treating, Inc.
Volume 10, Issue 10, October, 2016

# Approach to Equilibrium: Part 1 — Absorbing a Single Acid Gas

The *Approach to Equilibrium* (A2E) is viewed sometimes as a good indicator of how close an absorber is being operated with the rich solvent fully saturated with acid gas. Another interpretation is how much margin there is for the absorber to accommodate increased acid gas flow. In applications where there is only one acid gas being removed, the concept can sometimes be useful. However, when a mass transfer rate model is used, and there are two acid gases present (usually $H_2S$ and $CO_2$), the A2E concept can range from deceptive to useless as a measure of how close the rich solvent leaving an operating tower is to saturation and how much margin there is to accommodate an increase in acid gas flow. This issue of The Contactor™ is the first in a three-part series intended to address the *Approach to Equilibrium* concept. In this the first part, we discuss definitions of the *Approach to Equilibrium* and use a case study with a single acid gas, $CO_2$ absorption by MEA, to indicate when it might be useful, and when is provides deceptive information. In Parts 2 and 3 we will look at the application of the concept to situations involving the absorption of the two acid gases $CO_2$ and $H_2S$.

## Approach to Equilibrium

The *Approach to Equilibrium* is a measure of the extent to which the solvent leaving the bottom of an absorber is in equilibrium with the raw gas feed, usually expressed as a percentage. Often there are two gases present, $CO_2$ and $H_2S$, so there is a value for the A2E for each of the two gases. The A2E can be defined in two ways:

*Definition 1*

Basis is partial pressures of acid gas components:

$$A2E(PP) = \frac{p_{Gas\ above\ Rich\ @\ Equilibrium}}{p_{Gas\ in\ Feed}} \times 100\%$$

*Definition 2*

Basis is solvent loading:

$$A2E(Loading) = \frac{Actual\ Rich\ Load}{Equilibrium\ Rich\ Load} \times 100\%$$

When two acid gases are present, the equilibrium rich loading of each gas is calculated at the same time as the other. In other words the acid gases influence the other. However, that's a story for the November issue.

## Streams with a Single Acid

A2E *may* be a useful measure of the solvent capacity used up or spent† when the treating objective is nearly total removal of a single acid gas. An example is removing as much of the $CO_2$ as possible with 28.8 wt% MEA. In this case study, the absorber contains 44 ft. of a packing and operates at a pressure of 533 psig. There is no $H_2S$ present. In this ProTreat® simulation study, all parameters are held constant except the raw gas $CO_2$ content which is varied from 1–10%.

As Figure 1 shows, when the $CO_2$ is below about 5.6%, gas is treated to a constant level but at 5.6% the treated gas *$CO_2$ content* rises extremely rapidly. There, the *A2E on a loading basis* suddenly levels off (Figure 2). However, it does not reach 100% indicating the outlet rich solvent is not quite saturated at the outlet solvent temperature.

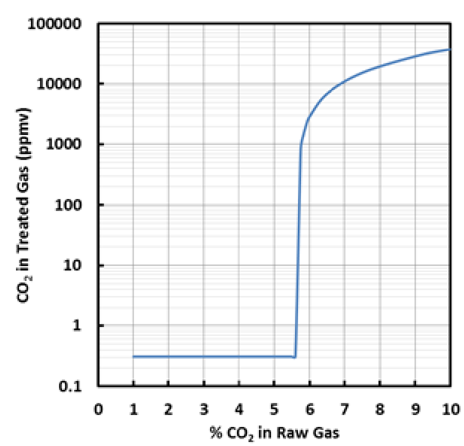


**Figure 1 Treating Various $CO_2$ Levels in Raw Gas**

† [100 – A2E] purports to measure remaining % capacity.

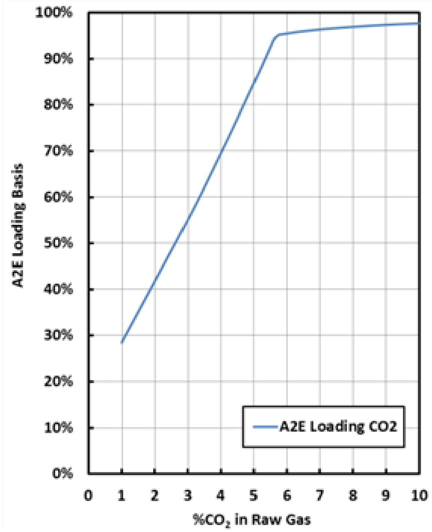


**Figure 2 Loading-Based Approach to Equilibrium**

An important parameter to understanding events around the 5.6% CO2 levels is the size of the temperature bulge and its extent. Figure 3 shows how the size of the bulge depends on the CO2 being fed into and absorbed by the column.

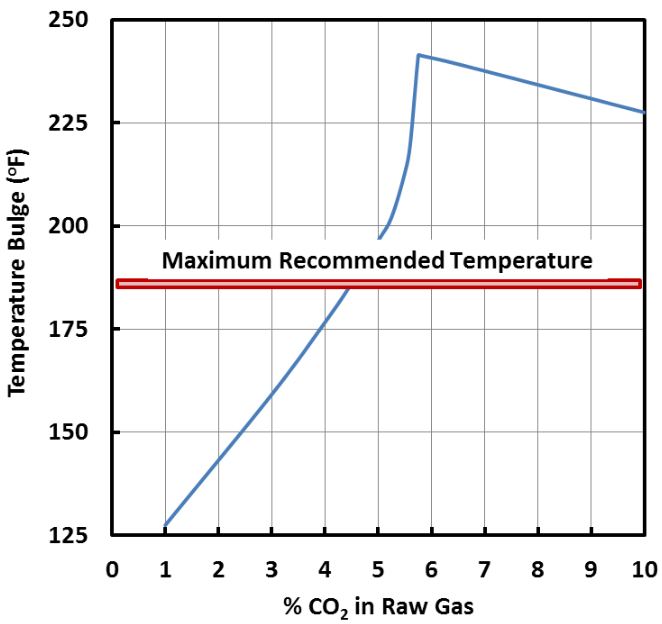


**Figure 3 Size of Temperature Bulge Depends on How Much $CO_2$ Is Absorbed**

The temperature bulge itself is a sharp well-defined peak at low amounts of CO2 absorption but as the CO2 in the raw gas increases, the bulge widens. At 5.6% CO2 in the feed gas, the bulge is at 220F and occupies roughly the *bottom 10 feet* of the bed. At 5.75% CO2, the temperature bulge is 240F, and it occupies *all but the top 7 or 8 feet* of the bed. The width (shape) of the temperature profile changes radically in this range of inlet CO2 concentrations and this is exactly where treating changes radically, and the A2E plots show a break in slope (see Figure 4 for the partial-pressure-based A2E plot).

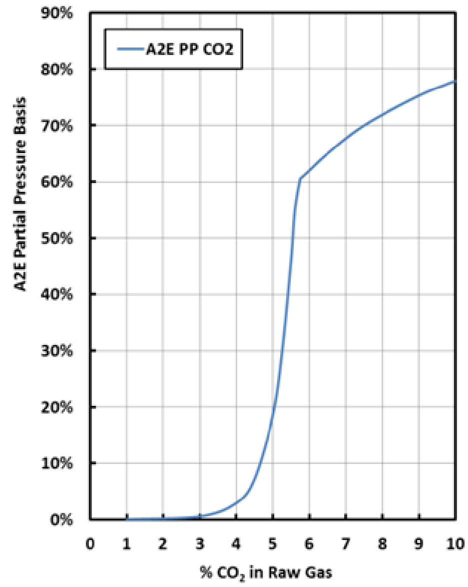


**Figure 4 Partial-pressure-based A2E**

At high raw gas $CO_2$ content, treating is completely controlled by the high temperature inside the tower, not by rich end loading. Unfortunately, A2E is based on rich end conditions so the tower capacity it expresses is not a very good metric. Partial pressure depends exponentially on acid gas solvent loading and, as Figure 4 shows, it is an even more deceptive measure of the A2E.

The ProTreat® mass transfer rate model has within it a highly reliable method for determining whether the capacity exists to process additional gas flow or higher concentrations, namely a comparison plot between actual and equilibrium acid gas concentration profiles right across the column. *Ultimate column performance is always limited by pinches*. Analyzing pinches and doing a good sensitivity study via rate-based simulation is the only reliable way to establish the robustness of a new design. With a lean-end, rich-end, or bulge pinch the actual and equilibrium lines will coincide for the pinched component at the pinch location. The approach to equilibrium is deceptive and unreliable at best and plain wrong at worst—it is no substitute for a pinch and sensitivity analysis.

~.~.~.~.~.~.~.~.~.~.~.~.~~.~.~.~.~.~.~.~

To learn more about this and other aspects of gas treating, plan to attend one of our training seminars. Visit www.protreat.com/seminars for details.

***ProTreat***® and ***The Contactor***™ are trademarks of Optimized Gas Treating, Inc.