Amine Regenerator Control

Part 1: Where to Locate Temperature Sensors

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There are several strategies used to control amine regenerator performance. Some work better than others, and some do not work at all. But all of them rely on measuring and controlling the temperature somewhere in the regeneration system to produce a lean solvent product with a specified acid gas loading. This article is the first in a two-part series on regenerator control. It deals with the question of where to locate the temperature sensor for best controllability. The second part will address various approaches to control.

Amine Regenerator Characteristics

Overall Function

The regenerator's primary function is as a stripping column where, below the rich amine feed tray, it removes mostly acid gases from the solvent by stripping with steam. In modern regenerators where rich amine is fed below the top tray, the trays above the feed tray might be considered to be rectification trays. In reality, however, in this section of the tower, condensate is returned as reflux (mostly water) which is used simply to wash any amine from the vapour before it enters the condenser. This virtually eliminates amine vapourisation losses from the regenerator, and it also minimizes entrainment losses.

Stripping Vapour

Stripping vapour, mostly steam, is generated at the base of the column by providing energy to a reboiler, or in rare cases there might be live steam injection. The reboiler is driven by heating with low-pressure steam or by heat transfer fluids such as hot oil. Fired heaters are not generally used in this service because heat transfer surface skin temperature and heat flux must be limited to prevent amine degradation and to maintain stable operation by avoiding vapour blanketing of the heat transfer surfaces. In some remote gas plant locations, fired heaters cannot be avoided. Stripping vapour provides the energy needed for breaking the protonated amine chemically bound to the acid gas; it also dilutes the acid gases and reduces their partial pressures, thereby increasing the concentration difference available to drive acid gases from the solution. The final function of the stripping vapour is to furnish sensible heat to raise a subcooled feed to the column feed amine to the boiling point inside the stripping column.

Reboilers

Reboilers come in a myriad of designs paired to various column bottom arrangements. The most common designs for amine regenerators are kettle, vertical thermosiphon, and forced circulation. Part of the solvent stripping takes place on the trays in the regenerator; however, a significant fraction of the stripping actually occurs in the reboiler which acts roughly as an equilibrium device. Lean amine loading is usually a profoundly determining factor in establishing absorber performance and treated gas quality, so it is very important to achieve the right lean-solvent acid gas loading value for H_2S or CO_2. This is really the parameter one would like to control; however, solvent loading is almost impossible to measure directly *in situ* in a control system. Temperature is usually used as a proxy for lean loading.

Lean Amine

In many applications, stripping to very low residual loadings is necessary to produce gas with a sufficiently low impurity level. In others, such as carbon capture, the extent of carbon dioxide removal is severely limited by restricting energy flow to the reboiler so that residual CO_2 in the lean solvent is a left fairly high. A regenerator produces two product streams, namely bottom and top products. The most important is the bottom product, the lean amine. The top product is acid gas.

Acid Gas

The acid gas product is less important than the lean amine, although depending on the destination for the acid gas, important considerations include its water content, amine vapourisation and entrainment losses, and possibly the presence of the contaminants such as ammonia, hydrocarbons, and methanol in the acid gas. For example, methanol is an environmentally regulated component that cannot be freely discharged to atmosphere. If the acid gas is to feed a sulphur recovery unit (SRU), excess water is an undesirable diluent that needlessly limits SRU capacity. Excessively high water content also robs water from the amine system and must be replaced with boiler feed water quality material.

Usually there is no top liquid product, but to control and remove methanol and ammonia there may be a small purge stream removed from the condensate as blowdown. Most of the condensate is returned to the regenerator as reflux although on occasion, a sizeable portion of the condensate may be diverted to the top of the absorber where it is used to water wash the treated gas to recover amine vapour and capture entrainment. Most amine systems sustain water losses that must be made up using boiler feed water. In those case where water must be removed from the system to maintain amine strength, it is usually withdrawn as condensate blowdown from the reflux system.

Reflux is generated by cooling and condensing water from the overhead vapours. The condenser is always a partial condenser because the acid gases themselves are noncondensible, and they are only sparingly soluble in the condensate. As much cooling as possible is preferred, but it is limited by such constraints as the temperature of the cooling medium. The most common cooling media are water and air, but sometimes heat integration is applied by using cold process streams as the coolant, or by using refrigeration.

Temperatures in Amine Regenerators

Amine regenerators (and other towers that strip dissolved gases from solvents) are quite different from multicomponent hydrocarbon distillation columns. In amine systems, the bulk of the liquid phase is water (~90 mol %), followed by amine (8–12 mol %) and 1–2 mol % acid gases. Part of the water in the liquid solvent is converted to steam in the reboiler, part of the acid gases volatilize into the vapour, but the

amine is barely volatile so it mostly remains in the solvent phase with very little present in the stripping vapour. Steam is the diluent and carrier for the acid gases and, through gradual condensation on the trays, it also provides the thermal energy needed to break down the reaction products that formed between acid gases and the amine during the absorption process. At a given column top pressure and pressure gradient across the column, the regenerator temperature profile which is very accurately simulated by the ProTreat® model follows the pressure-temperature saturation curve for the aqueous solvent. On each tray the temperature is such that vapour pressure of the solvent is equal to the pressure on the tray. In other words, on each tray the liquid is at its bubble temperature. The bubble temperature is mostly a function of the acid gas content of the solvent at any point in the column—the water and amine content are almost constant throughout—only the acid gas content (or partial pressure) changes.

The tray-to-tray temperature profile in the regenerator is directly related to the acid gas content of the solvent. In a system that is regenerating well, there are sharp temperature and composition changes immediately below the feed tray in the regenerator for several reasons. One is that the rich solvent feed is often subcooled entering the column. It does not reach the feed tray temperature instantly; rather, feed heating is done by condensation of steam from the vapour into the liquid; first, the steam has to diffuse through the inert acid gas components in the vapour to get to the liquid interface before it can condense. This is a finite-rate mass transfer process so the liquid temperature on the tray will lag behind the vapour temperature. But more importantly, acid gases will start to strip from the solvent very quickly near the feed tray where their concentration in the liquid is greatest. As the gases desorb, the vapour pressure of the solvent tends to decrease so a higher temperature is required to maintain it at the local system pressure. Thus temperature rises as solvent descends through the column, and it rises most quickly where there is the most acid gas to desorb. It is often forgotten that in order to release the acid gases from the amine, a chemical reaction must be reversed. This requires heat. Temperature change translates into compositional change, and hence can infer where the separation of the acid gas is happening inside the stripping column.

Trays approaching the bottom of the column do not show such rapid separation and temperature increases more and more slowly. In fact, temperature variation in response to process disturbance is least there, loadings are smallest, and therefore the temperature response to necessarily small loading changes is small itself. This suggests that temperature near the bottom of the regenerator may not be a useful proxy for lean loading and especially for its control.

In a single-absorber, single-regenerator treating unit, the purpose of the regenerator is to produce a lean solvent that allows the treating objective specified for the single absorber to be met. In that sense, then, the set point is the acid gas concentration in the treated gas and the reboiler duty is manipulated to reach and remain at that set point. In a treating plant where a single regenerator services multiple absorbers, there is not a single treating specification. In such cases, the regenerator has to be controlled so that the lean solvent produces on-specification gas from the most demanding absorber. Solvent is then distributed to the multiple absorbers via flow control, for example. Thus, in general terms, the regenerator has to be controlled to meet a lean-solvent-loading set point. Since loading cannot be reliably and directly measured in the operating plant, the question becomes one of where is the best place to measure its proxy temperature, i.e., where is the best place to locate the temperature transmitter (TT)?

There are numerous other process control loops in an amine regenerator but their function is not to control treating *per se*. Rather, their purpose is to maintain stable operation and recover quickly from process upsets caused by changing flow rates, rich solvent loading, solvent feed temperature variations,

and pressure fluctuations. The objective is system stability. Of course, the ultimate objective is to achieve a specified solvent lean loading or a specified acid gas level in the treated gas. In that sense, none of the control loops is independent—they are all affected to some degree by the others.

Optimal Temperature Control Location in a Regenerator

Kister[1,2] has outlined a procedure for locating the best place for a temperature transmitter control element in an operating column. The procedure relies on process simulation:

- Define the tray-to-tray temperature profile in the base-case column. This base case is the operating state of the column under the most desirable conditions. The tray-wise temperature profile is calculated via process simulation. However, if the simulator is based on ideal stages, the calculated temperatures do not correspond to real trays—they refer to idealizations or, at best, approximations made using assumed or estimated tray efficiencies. This is where a true mass transfer rate-based model such as ProTreat® shines because its calculations use only real trays. No questions arise from using approximations.
- Generate additional temperature profiles for each disturbance variable of, say, up to ±2–3% perhaps in increments of ±1%. Disturbance variables to pick might include reflux ratio or stripping ratio, boilup rate (reboiler duty), rich amine feed temperature, condenser temperature, and rich amine loading.
- After plotting all temperature profiles on a common-scale chart it becomes easy to pick the best TT location as the one where the temperature response is greatest and most linear.

Example

Figure 1 shows a P&ID for an amine regenerator. There are a number of control loops shown in the drawing, but the ones of interest to controlling solvent lean loading are marked in green. Of these, which is the best one for cascading to the reboiler steam flow control to set the reboiler duty?

The temperature profiles in Figures 2 and 3 record the temperature of the vapour leaving each tray in the column and show that Trays 10–24 are in the "polishing" zone of this 24-tray column where temperatures change hardly at all in response to changes in reboiler duty. Lack of sensitivity declares these trays to be unsuitable for locating the TT. By the same token, the reboiler is the least suitable of all, although recommendations to control on reboiler (or bottoms) temperature are often and mistakenly voiced.

Figure 4 shows the tray-by-tray differences between the perturbed temperature and the base case temperature as a function of the perturbance to the boilup rate. Trays closer to, but below or on the feed tray (Tray 3) are much more responsive, so they are more suited to locating the TT. Trays above the feed tray are just as responsive, and noting that the vapour leaving the top tray is the same as the vapour in the overhead line suggests the temperature in the overhead line is perhaps the most suitable of all. If there is significant variability in condenser or cooling water temperature however, the overhead vapour line temperature is also likely to suffer the same variability, and the temperature slightly below the feed tray may give equivalent but less-noisy sensitivity. Figure 5 shows the linearity of the temperature response on Tray 6 to boilup. The response on all trays above Tray 7 as well as the overhead vapour line are equally linear.

There is a temptation to think that this kind of analysis can be done with whatever simulator is readily to hand—all that is needed is vapour-liquid equilibrium for the acid gas-amine system. Not even reaction kinetics is involved because the regenerator runs so hot all reactions are essentially instantaneous reversible. But, not so fast! Acid gas stripping performance is mass transfer rate controlled. It is not an equilibrium process so the mass transfer characteristics of the tower internals play a crucial role in determining stripper performance. The real mass transfer performance of trays is not part of any ideal-stage, efficiency-modified simulator. It's not part of any other simulator that claims to be rate-based but does not include the *internals mass transfer characteristics* directly into the tray calculations. Using efficiencies based on estimated mass transfer disqualifies such simulations from being legitimately rate based—they remain ideal-stage-plus-efficiency models regardless of how the efficiencies are determined—they still only approximate real trays.
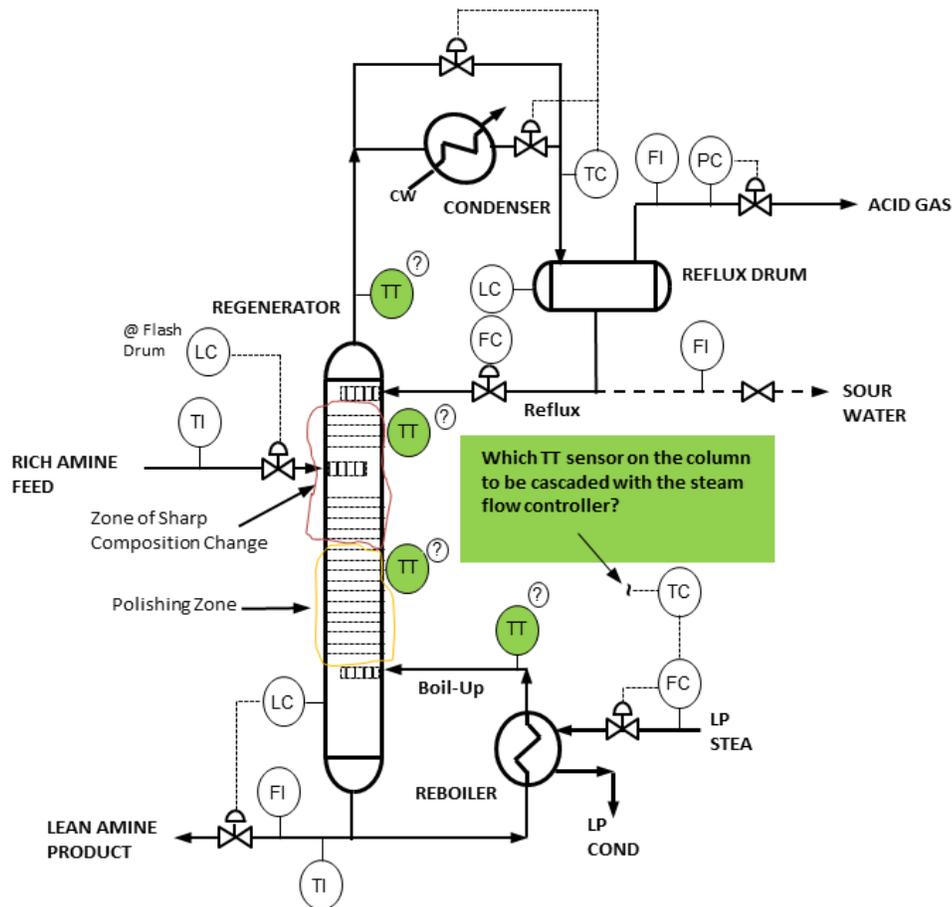

Figure 1   P&ID of Regenerator

ProTreat simulation uses rigorous amine-acid gas VLE, mass transfer limitations in both phases, and reaction kinetics. It relies integrally on the effect of tray (and packing) hydraulics, not just for pressure drop and flood, but for the mass transfer performance of the column internals. The thermodynamics provides rigorous activity-based models for strong ionic solutions, including salting-in and salting-out of acid gases caused by ionic species. ProTreat includes the effect of a long list of heat stable salts on acid gas solubility and their effect on solvent loading and reboiler energy requirements. Columns, including

regenerators are modeled on the basis of the real internals and the real contaminants in the solution; there are no adjustment factors. ProTreat® gives reliable and accurate results without them. Finally, it should be noted that for packed columns it is not customary to place a temperature measuring device within the packed bed itself, so the temperature is almost always measured in the overhead vapour line or the column's head space would be suitable, too.
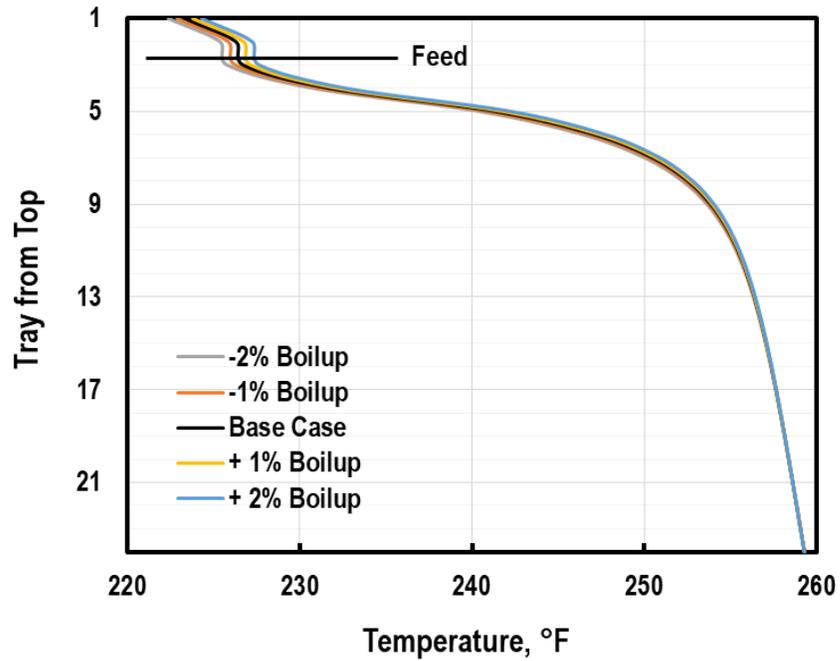

Figure 2   Response of Temperature Profiles to Change in Boilup Rate
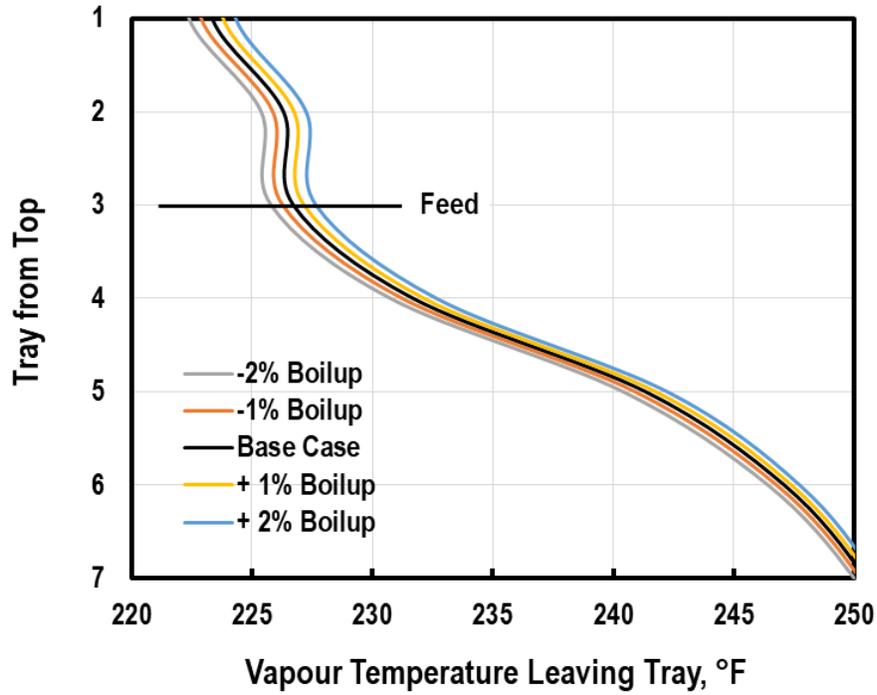
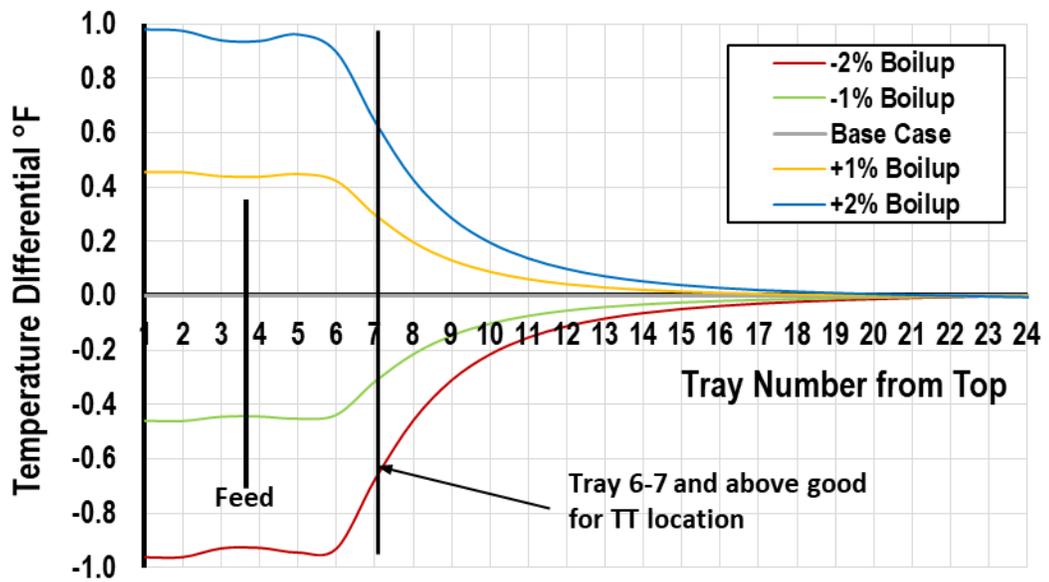Figure 3   Magnified View of Temperature Profiles

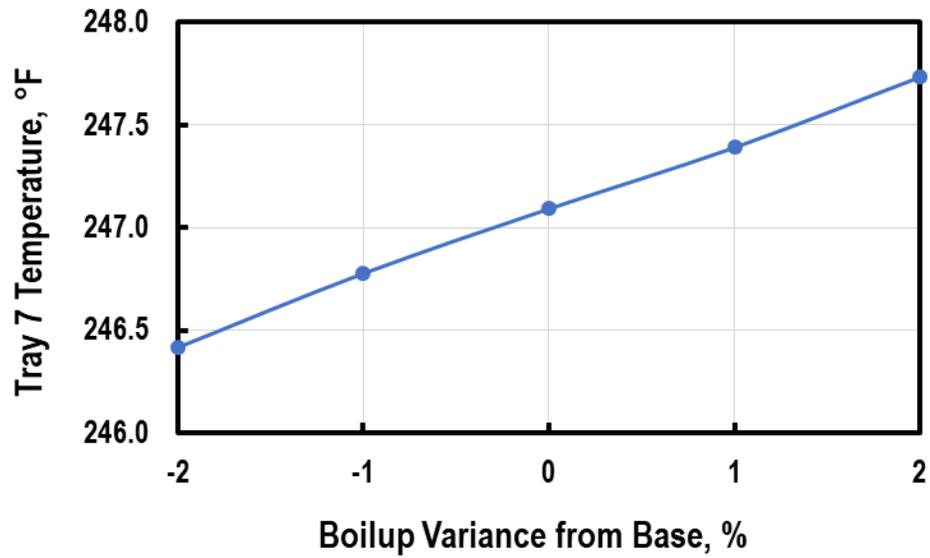Figure 4   Temperature Differential to Base-case Profile

Figure 5   Linearity of Tray 6 Temperature Response to Boilup

References

1. Kister, H. Z., *Distillation Operation*, Ch. 18, McGraw-Hill, New York, NY, 2000.
2. Kister, H. Z., *Distillation Troubleshooting*, Ch. 27, §27.1, John Wiley & Sons, Hoboken, NJ, 2006.