Amine Regenerator Control

Part 2: Strategies for Controlling Lean Loading

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There are several control strategies for ensuring good amine regenerator performance. As will be seen, some work better than others, and some do not work at all. But all function by monitoring and controlling the temperature somewhere in the regeneration system. In the first part of this article, it was shown that anywhere from the overhead vapour line to just below the feed tray are satisfactory measuring points. In this Part 2 we address various approaches to control. The article uses specific operating cases to show the benefits and shortcomings of several strategies. Discussion of the various approaches is made concrete by using MDEA as a selective solvent in a typical natural gas processing plant; however, most of the discussion applies equally well to most other amines and gas treating applications.

Reboilers in the amine regeneration section of a treating plant come in a number of varieties, including kettle, once-through thermosiphon, and recirculating thermosiphon, and they can be steam heated, hot oil heated, process-gas heated, and direct fired. Regardless of type though, reboilers have the main purposes of providing:

- Sensible heat to raise the rich amine feed to the boiling temperature inside the regenerator,
- Heat to reverse the reactions between acid gases and the amine, and
- Energy to generate the dilution steam necessary for providing the acid gas partial pressure that directs dissolved gases from the solvent into the vapour.

Energy requirements to reverse the acid gas-amine reactions are very amine specific. Energy needed to raise solvent temperature and generate steam are less so because the solvent heat capacity is dominated by water as is the heat of vapourisation (mostly of water) from the solvent.

Regenerator performance is usually measured in terms of the solvent lean loading(s) produced. Strategies for controlling lean loading include:

- Manipulate reboiler steam or hot oil flow to meet a target regenerator bottoms temperature or reboiler temperature,
- Manual reboiler steam or hot oil flow control,
- Maintain a fixed flow ratio of steam or oil to the solvent flow, and
- Allow the ratio of steam to solvent flow rates to be biased or reset to control overhead temperature.

Each of these strategies is examined in turn using ProTreat® mass transfer rate based simulation as a guide to the quantitative response and behaviour of an example amine unit.

Manual Flow Control

Provided the absorber is operating in a region where its performance is not controlled by solvent capacity limitations, and it is not running close to an operational cliff, absorbers and amine systems are usually very well behaved and they can lend themselves to manual control of the heating medium flow rate to the reboiler, as well as solvent temperature and circulation rate. However, operators need to have a good understanding and grasp of how the system responds to change and how parameters interact. Without such understanding it is very easy to move a set-point in a direction that intuitively seems correct, only to find that it is the opposite of what is actually needed. If tight specifications on gas purity do not have to be met and treating demands do not change rapidly, manual control may well be adequate; otherwise, automatic control is almost essential.

Controlling to Regenerator Bottoms or Reboiler Temperature

The material in a reboiler is at its boiling point which by definition is the temperature at which the total vapour pressure of the (loaded) solvent is equal to the total pressure in the reboiler. In any well-stripped solvent, the partial pressure of the acid gases in the solvent is almost always very low; otherwise, high gas purity would be impossible to achieve. (The exception is amines used for carbon capture where 10 to 15% of the CO_2 is to be slipped through the absorber, so lean loadings are purposely kept quite high and CO_2 exerts a significant partial pressure.) So in almost all gas treating applications, the acid gas partial pressures are very low and the boiling point is barely affected at all by lean solvent loading. For a well-stripped solvent, the boiling temperature is almost solely a function of the solvent strength and the column pressure, i.e., T = f (P, %wt amine).

Figure 1 is a schematic of the regenerator with relevant process data. If the regenerator is part of a tail gas treating unit (TGTU) the target lean loading on H_2S will likely have quite a small value; however the high rich solvent loadings exemplified here would not pertain. A high reflux ratio (high reboiler energy flow) will be needed to produce a low lean loading. On the other hand, if H_2S is being selectively removed from a high pressure natural gas, solvent lean loading will not have to be as low and can be achievable with more modest reflux ratios and reboiler energy demands. But regardless of the application, over the H_2S loading range from 0.0003 to 0.004 produced using reboiler duties from 1.4 to 7.3 MW (5.0 to 25 MMBtu/h), the reboiler temperature in this example does not vary by more than 0.05°C (0.1°F). This is far outside the capability of any commercial temperature measuring device in process service. Even the tower sump temperature varies by only slightly more than 0.5°C (1 °F). As discussed in Part 1 of this article, this realisation makes absolutely ludicrous the whole notion of controlling regeneration by using reboiler or tower sump temperature as a measure of lean loading. Such a strategy has no possibility of working reliably. In order to see a reasonable response to the controlled variable, the lean loading has to be grossly off specification. Letting the unit go out of environmental compliance for the control strategy to work is not a viable strategy at all.

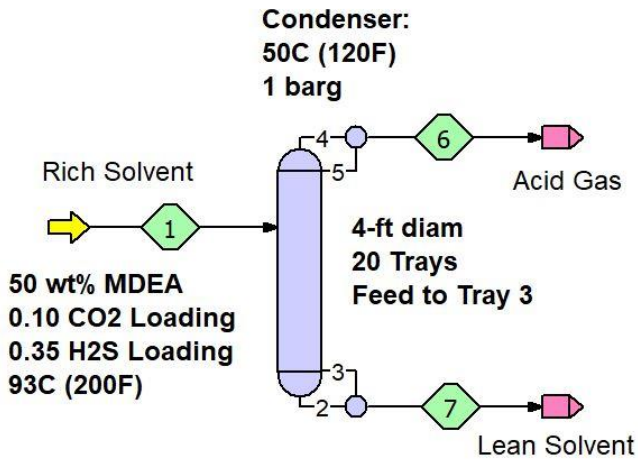

Figure 1 Regenerator Specifications

Controlling Overhead Temperature

Solvent lean loading is highly responsive to reboiler duty; however, lack of instrumentation for measuring this quantity makes it almost impossible to use it directly in a dynamic or process control setting. And neither reboiler nor tower sump temperature is a suitable substitute. However, regenerator overhead temperature shows significant, useful variation with reboiler duty, i.e., with lean loading. For the case already discussed, Figure 2 shows how H_2S and CO_2 lean loadings can be controlled by using the regenerator overhead temperature as a proxy. Of course, the loadings of the two acid gases cannot be individually controlled. Once the regenerator is operating to produce a specified lean loading with respect to one acid gas, the other is then completely determine by the now-established operating conditions, by the vapour-liquid equilibrium, and by the mass transfer characteristics of the tower internals as they pertain to the second acid gas.

Properly calibrated (not just zeroed and spanned) instrumentation can usually be relied upon to measure and control temperature to within ±1°C (±2°F) so, in the present case, measuring and controlling to the overhead temperature will likely provide adequate control of the critical lean loading and, therefore, of treating itself in most instances.

The main detractor against this control strategy is that the control is entirely feedback based. Rapid changes in amine circulation may limit the effectiveness of the controller response to the inherent time delay in the system.

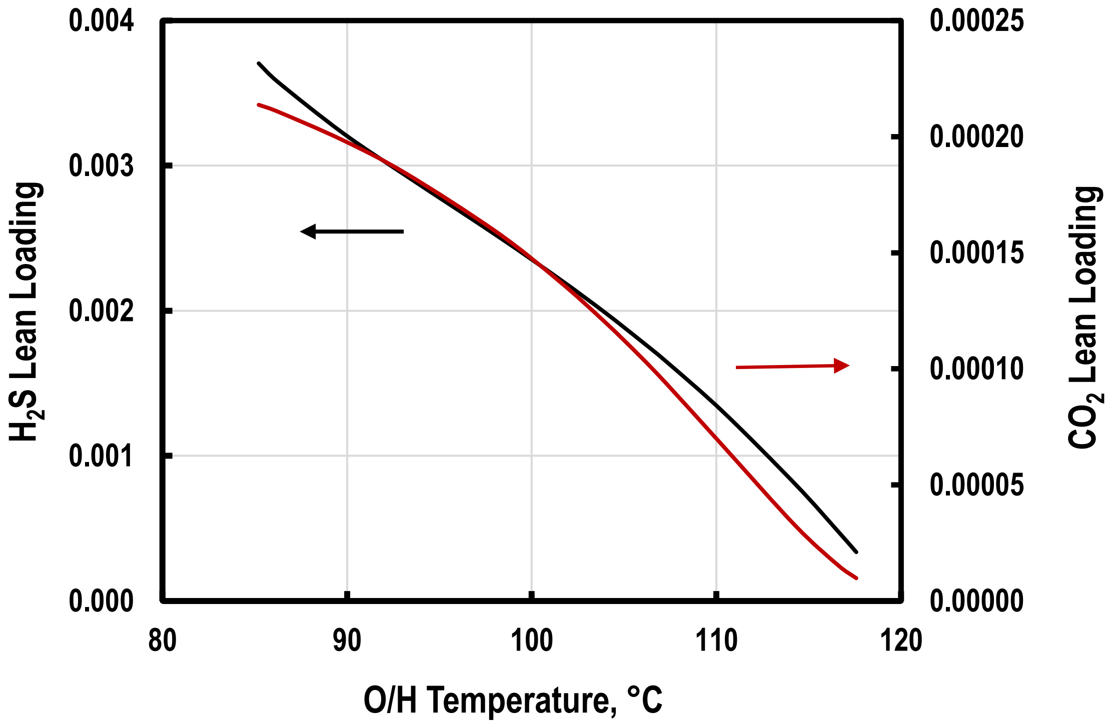

Figure 2 **Regenerator Overhead Temperature as a Proxy for Solvent Lean Loading**

Setting the Heating Medium to Solvent Flow Ratio

A rough guideline for setting reboiler duty in amine regenerators is to use a value from 120 and 180 kg of 3.5 barg steam per standard m^3 of solvent (1-1.5 lb of 50 psig steam per standard USgal). Figure 3 shows the H_2S and CO_2 loadings produced over a tenfold range in solvent rates when the reboiler energy input is maintained at the somewhat high value of 200 kg of 4 barg steam per standard m^3 of solvent (needed to reach a low enough H_2S lean loading in this gas plant). The trays were kept hydraulically well balanced (equal jet and choke flood values) by assigning 10% downcomers; flood ranged from 9.7 to 97% in the 1200-mm diameter column. The simulated overhead vapour temperature over this range of circulation rates varied by less than 0.5°C, probably because the regenerator is being boiled quite hard. A somewhat wider temperature range might be expected with more modest boilup. Regardless, the variation in overhead vapour temperature can be expected to be small using such a control strategy.

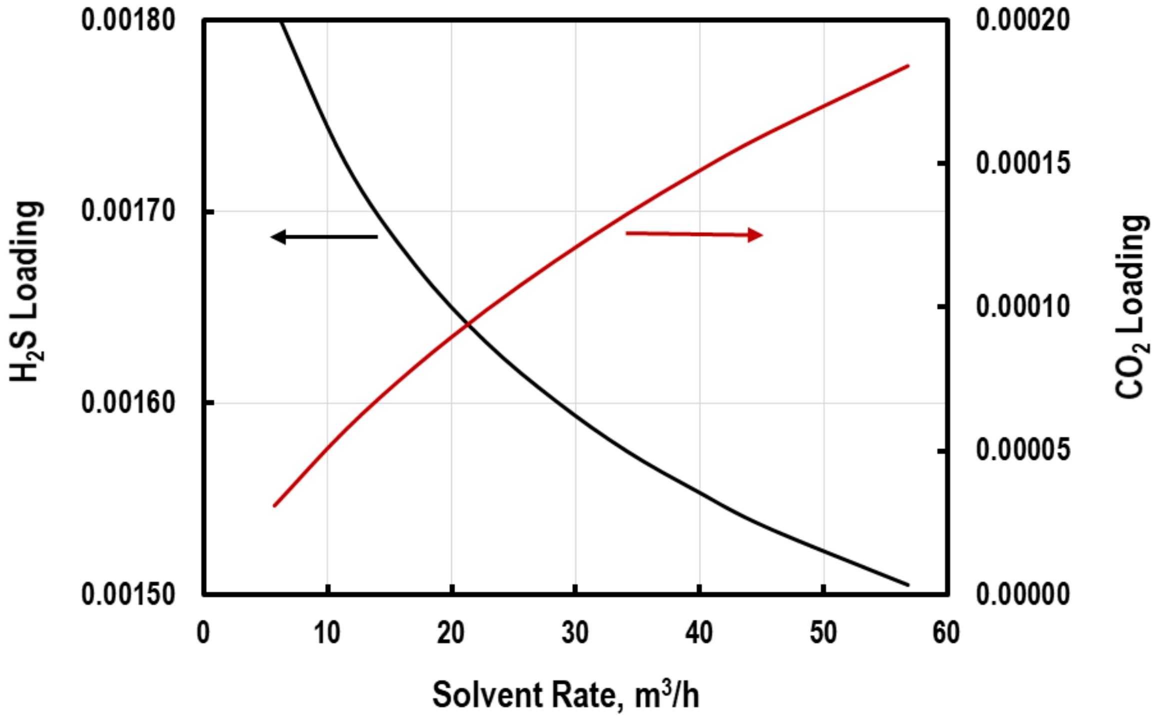

Figure 3 How a Fixed Amount of Reboiler Energy per Unit of Solvent Keeps H_2S Loading in a Narrow Range over a Wide Range of Circulation Rates

Using a reboiler duty that is directly proportional to the circulation rate allows the unit to respond well to solvent flowrate changes. The solvent H_2S lean loading varies only a little over a tenfold range of flow rates. In a relative sense, the CO_2 lean loading varies by a factor of ten; however, in terms of absolute loading values the CO_2 loading response is quite similar to H_2S: both experience a change in loading of 0.0002 to 0.0003 loading units. Reboiler conditions play a large role in determining regenerator performance because a large fraction of solvent stripping actually takes place there. From the lowest to the highest solvent rates, reboiler pressure varied from 1.149 to 1.279 barg (16.67 to 18.55 psig) and reboiler temperature ranged from 127.9 to 129.9°C (262.2 to 265.8°F).

The mass transfer performance of trays improves with both vapour and liquid flow rates. Both are increasing as the circulation rate through the fixed size regenerator increases. On that basis, one might expect both the H_2S and CO_2 lean loadings to improve with solvent rate. The H_2S loading does; the CO_2 loading does not—instead it grows worse, by about the same number of loading units (0.0002) as H_2S loading improves (0.0003). Although both H_2S and CO_2 mass transfer rates benefit from the higher mass transfer coefficients that accompany increased traffic through the regenerator, the effect is stronger on H_2S desorption than on CO_2 because of a higher reaction enhancement effect. Somewhat more of the additional energy, therefore, is used to strip just a little more H_2S, leaving slightly less available for removing CO_2. This is the reason for the counteracting effect, and for the relative total stripping remaining roughly unchanged.

Adjusting Steam-to-Solvent Flow *Ratio* to Control Overhead Temperature

Maintaining a constant steam-to-solvent ratio allows simple, accurate control of stripping under varying conditions of *solvent flow rate*. As also already shown, adjusting the steam flow allows control of solvent lean loading under varying *rich amine loading* conditions. Therefore, it only stands to reason that a combination of the two will allow control of lean loading when *both solvent rate and rich loading* are changing. This is done via cascading the control system and, of course, it is used to control the regenerator's overhead (or feed tray) temperature as a proxy for lean loading. The two individual controls have already been discussed and this approach is just a marriage of the two.

As an example, a sudden increase in rich loading will cause overhead temperature (more or less equivalent to the boiling point) to drop. The physical response should be to increase reboiler steam flow to bring the temperature back up to the set point value. However, the rich solvent flow has not changed so the flow-ratio controller wants to keep the same steam rate; thus, a control system with only a simple flow-ratio controller cannot respond except by violating the prescribed flow ratio. The basic strategy is to institute a second level of control to override the set flow-ratio controller and allow the steam rate to be increased, all the while resetting the ratio to the new value needed to maintain the set point temperature. The reboiler steam flow changes in response to the measured solvent flow, while the steam-to-solvent flow ratio adjusts in response to rich loading as indicated by the temperature measured at an appropriate location in the regenerator.

Summary

Most attention is usually focused on the absorber because this is the equipment that actually processes the gas. However, absorber performance is controlled to a very large extent by the regenerator and how it performs in providing a satisfactory lean amine solvent. Thus, one could easily take the position that solvent regeneration is really the key operation, and its accurate and reliable simulation is at least as important as the absorber's.

The ProTreat® simulator uses a mass transfer rate-based regenerator model similar in every respect to that for the absorber, allowing it to predict the performance of the entire amine unit with uncanny accuracy. This includes the effect of heat stable amine salts (HSSs) on both retarding absorption and enhancing regeneration, leading to either better or worse overall amine unit performance, depending on the circumstances.

Satisfactory absorber operation often depends critically on achieving the right solvent lean loading. Because it is hard to measure on-line, temperature is the usual proxy for lean loading. Part 1 of this article discussed where the best places are to measure temperature in a regenerator; this article has discussed several ways to control lean loading by controlling temperature. But probably the most beneficial tool one can use for analysing and monitoring an amine unit is a truly mass transfer rate-based simulator.