The CONTACTOR™

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Sensible Heat Transfer in Amine Towers

Heat transfer between the phases flowing through columns containing trays and packing in distillation and absorption service has rarely been a subject of much interest to practitioners. It's always been assumed to occur so quickly that the phases have been taken to be of equal temperature. However, amine treating units often show very hot absorber peak temperatures whose size and location may have just as much to do with sensible heat transfer as with absorption.

TGU Quench towers, too, experience very rapid temperature changes where, although the bulk of the heat transfer is achieved through huge mass fluxes of water between the gas being cooled and the quench water (i.e., mass transfer of water), sensible heat transfer also plays a significant role. Cooling towers are similar to quench columns but they don't show the same extremes of temperature change. Both are examples of so-called swamp cooling because cooling is primarily through the evaporation of water; nevertheless, sensible heat transfer is still important to both.

Why Heat Transfer Matters

ProTreat® applies *transfer rate* concepts to virtually every aspect of gas treating. Heat transfer is no exception. Interphase heat transfer rates between gas and froth or gas and film flow are tightly integrated into every simulation of absorber and regenerator performance. What do heat transfer rates affect and, mechanistically, how are these things affected?

Absorbers consist of a stack of contacting trays or a bed of packing (random or structured) through which gas and liquid flow vertically upwards and downwards. Absorption of acid gases is exothermic and generates heat in the liquid, raising its temperature, especially towards the bottom of a tower where acid gas concentrations are highest in the vapor. Some of this heat is transferred into the gas by evaporating water (swamp cooling), but not all of it. The rest is transferred as sensible heat by classical conductive and convective heat transfer.

If heat transfer is rapid and efficient, the gas temperature responds and the gas heats quickly. Meanwhile the liquid cools. As the gas moves up past the temperature bulge it starts to meet cooler liquid, heat transfer reverses direction, and the gas starts to cool while the liquid becomes warmer. The gas shuttles heat up the column and the liquid shuttles it down—heat becomes trapped inside the column and the more efficient the heat transfer the more heat gets trapped and the hotter the temperature bulge. The heat transfer rates are determined by the heat transfer coefficients (HTC) for the two phases, and they in turn determine the magnitude of the temperature bulge. Why does this matter?

If the temperature bulge inside an absorber is broad enough and hot enough it can affect the simulated treating level. This can make the difference between successful and failed designs in that the treated gas may or may not meet H_2S or CO_2 specifications for the unit. In addition to overall treating performance, if the design results in a tower with peak temperatures that are too high, corrosion of the tower shell and internals can become very serious issues. Solvent suppliers are well aware of the danger and try to limit the bulge temperatures to a specific value. Of course, one must be able to predict internal temperatures. In a heat transfer rate model this depends on gas- and liquid-side heat transfer coefficients.

Heat Transfer Coefficients

There is a wealth of published information concerning heat transfer in two phase flows, e.g., nucleate boiling, condensation in systems containing noncondensables, but the heat transfer is invariably to or from solid surfaces such as tube walls or nucleation sites. Apart from a single work, work of we are unaware of measured data on heat transfer between the moving phases themselves, and this is what's pertinent to heat transfer in mass separation columns. However, all is not lost because there are numerous mass and heat transfer analogies that can be applied. Analogies such as the Reynolds analogy and Chilton-Colburn j-factor analogy using various dimensionless groups. Mass transfer has been well-studied in absorption systems using all kinds of tower internals; heat transfer has not. So the only real path to estimating HTCs in mass separation columns is by analogy with mass transfer—by necessity, this is the route taken in ProTreat.

Mass transfer measurements are not exact so any analogy replicates the mass transfer measuring error into heat transfer, i.e., there are similar random errors in mass (MTCs) and their analogous HTCs. As may be remembered from undergraduate studies, the "error bars" on semi-empirical Nusselt number correlations for shell and tube exchangers, for example, are significant in and of themselves. If heat transfer in an exchanger has sizable error bars, how much more would we expect error bars for heat transfer between two phases flowing in the highly chaotic froth of a tray in a column? Therefore, it is completely unrealistic to expect simulation to be 100% accurate and for it to exactly reproduce measured plant performance.

Error bars on measured fundamental parameters mean simulation and field measurements will never coincide. There are error bars!!!

Heat Transfer Coefficients Affect Amine Unit Simulation

As already pointed out, if heat generated in the solvent can be rapidly transmitted into the gas, a lot more heat will be carried up the column, then downwards by the liquid and ultimately become trapped somewhere between the tower ends. On the other hand, if HTCs are low, heat of reaction cannot as readily get into the gas so more of it remains trapped in the liquid and is carried out the bottom. The temperature bulge will be less pronounced.

Figure 1 is an example showing the effect of varying HTCs on temperature profiles and on the difference between simulated gas and liquid temperatures. The default (ProTreat recommended) HTC correlation is represented by the value 1 in the figure (green line). Other numerical values represent multiples of those calculated from ProTreat® correlation. Large HTCs produce gas and liquid streams exiting a tray that are pretty much identical. Lower HTCs result in quite different gas and liquid exit temperatures. The purpose of this plot is to show the sensitivity of simulation to uncertainty in HTCs. There is no right or wrong answer here, just a range into which the results should probably fall. However, there's also an issue of credibility—it seems unreasonable to expect the gas and liquid leaving a tray to show a 5°F temperature difference when the temperature rise across the tray itself is only 5°F. ProTreat's internal correlation has been found to represent best measured tower performance and temperature profiles obtained by thermocouple and infrared scanning methods.

It is interesting to note that under conditions of humidification and dehumidification, 98% of the resistance to heat transfer is contributed by the gas phase. Since the liquid phase is mostly water, perhaps it is unsurprising that gas phase resistance dominates.

The ProTreat simulation results in Figure 1 are for a piperazine-promoted MDEA solvent used in LNG production. The standard treated gas target is 50 ppmv CO_2. All the cases shown here meet this specification. The smallest temperature bulge case meets the specification by the widest margin and the highest bulge temperature with very little room to spare. Furthermore, the highest temperature bulge exceeds the usually recommended maximum (85°C or 185°F) putting the design at increased risk for corrosion. Thus, it's safer to assume higher heat transfer rates and mitigate the risk. Sensitivity of tower performance to uncertainty in heat transfer can be assessed by adjusting the multiplier on a given correlation for the heat transfer coefficient in much the same way that one can adjust mass transfer coefficients. A factor of two or even three seems quite reasonable given the very complex nature of heat transfer in multiphase systems.

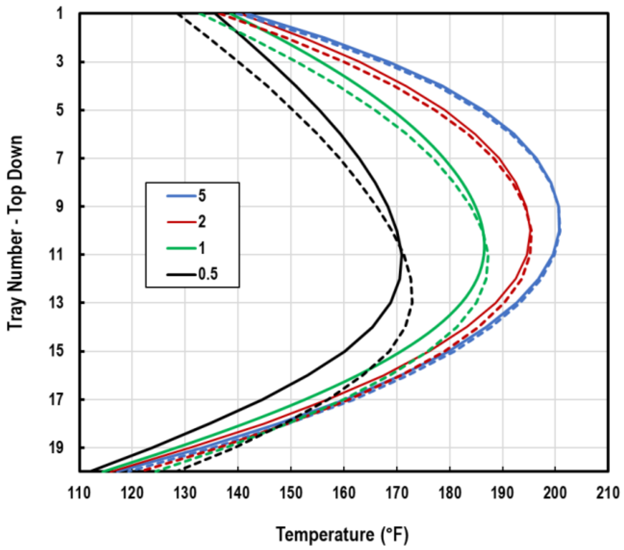

Figure 1 Sensitivity of Absorber Temperature Profiles to Large Changes in HTCs on Sieve Trays. Solid lines – Vapor, Dashed Lines – Liquid. Legend Shows Multiplying Factor on Heat Transfer Coefficient

Heat transfer is an important part of mass transfer rate-based column simulation and it cannot be ignored. ProTreat's heat transfer correlations are directionally what one would expect. For example, fast thermal diffusion is consistent with fast mass diffusion, and tray hydraulics affects mass and heat transfer in similar ways. The absolute values of heat transfer coefficients must be obtained from column operating data. We have regressed the correlations to achieve agreement with *measured* temperature profiles in amine absorbers where the highly exothermic reactions cause column behavior that is a severe test of one's ability to model heat transfer.

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