



The CONTACTOR™

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Heat Transfer in Quench Towers

Quench towers experience very rapid temperature changes along the flow direction. Temperature changes are induced by large mass fluxes of water vapor moving between the gas being cooled and the quench water (i.e., mass transfer of water). The bulk of the heat transfer is achieved by heat of vaporization being convected in the water vapor itself as it moves between the phases. Most of the heat is transferred by direct transport of water vapor; nevertheless, a significant amount of heat is also transferred by direct convection and conduction of heat, so sensible heat transfer plays a part.

Cooling towers are similar to quench columns but they don't show the same extremes of temperature change. Cooling towers are usually packed, too, but often with lumber fastened together to form what might be thought of as very large, coarse, structured packing arranged in slats and over which cooling water flows in films running down from slat to slat. Both are examples of so-called swamp cooling because cooling is primarily through the evaporation of water; nevertheless, sensible heat transfer contributes.

Why Heat Transfer Matters

ProTreat applies mass 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 they affected?

Absorbers consist of a stack of contacting trays or a bed of packing (random or structured) through which gas and liquid percolate 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 the vapor sees the highest acid gas concentrations. 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 strictly conductive and convective heat transfer.

If heat transfer is rapid and efficient, the gas temperature responds and 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 as it flows down the column. 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 help to determine the magnitude and location 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 H₂S or CO₂ 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. So, 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 between 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. 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. Examples are 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 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 chaotic froth between trays 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. If they do, it's accidental, so beware of suppliers of software tools who claim routine perfect agreement with plant measurements. There are error bars that are being ignored!!!

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, than 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 taken from *The Contactor*, Vol. 15, No. 04 showing the effect of varying phase HTCs on temperature profiles, the temperature bulge, and on the outlet gas and liquid temperatures. HTCs themselves have very little effect on treated gas and loaded solvent temperatures (these are a function mostly of inlet gas and liquid temperatures), but high HTCs produce hotter temperature bulges. Low HTCs result in quite different gas and liquid exit temperatures. So in some sense uncertainty in HTCs leads to uncertainty in simulation. See Vol. 15, No. 04 for further discussion.

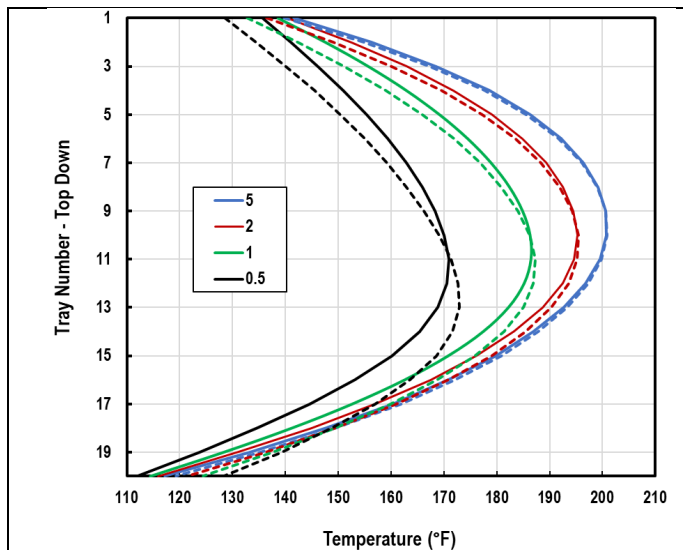


Figure 1 Sensitivity of Absorber Temperature Profiles to Large Changes in HTCs on Sieve Trays. Solid lines – Vapor, Dashed Lines – Liquid. Legend Shows Multiplying Factor on Heat Transfer Coefficient

The results in Figure 1 are for an absorber using piperazine-promoted MDEA solvent with the standard treated gas target of 50 ppmv CO₂. Low heat transfer resistance keeps the same vapor and liquid temperatures in adjacent positions and also produces the highest temperature bulge. Despite the relatively large effect on the size of the temperature bulge however, the treated gas and the loaded solvent temperatures are relatively independent of heat transfer. Instead, they depend more on the lean solvent and sour gas temperatures.

ProTreat uses the Billet-Schultes model as the default correlation for mass transfer coefficients (users are free to use the Onda correlation instead if they wish). Heat transfer coefficients are found by analogy; however, the actual values of the multiplying factors must be determined experimentally, by comparison between temperature profiles like the ones shown in Figure 1 and profiles measured on operating columns. This is what has been done for ProTreat’s mass transfer and heat transfer correlations. Thus, ProTreat’s simulated temperature profiles for absorbers and regenerators are as reliable and accurate as they can ever be. Unfortunately, the amount of quench tower data available is limited to two columns. ProTreat’s model for heat transfer in quench towers has been regressed to this data so although the model may not boast stellar accuracy, at least it agrees with what data exists.

In a previous issue of *The Contactor* (Vol.11, No. 7) it was pointed out that the cooled gas leaving a quench tower can be supersaturated with water vapor. Occasionally an engineer will express surprise at the spectre of a supersaturated vapor leaving such a vessel. Perhaps this is because we have become completely and uncritically acceptive of the ideal or equilibrium-stage concept. Or maybe a supersaturated vapor leaving a vessel after intimately contacting a boiling liquid is just an extreme example of a weakness of the ideal stage that we’d never thought about. The vapor is cooling so quickly (heat transfer) there isn’t time for it to drop out all the excess water it contains (mass transfer). So, it leaves in a supersaturated state. Similar observations have been made about the overhead vapor from a regenerator where the vapor can actually be supersaturated there, too, and the overhead vapor is quite wet.

Mass transfer rate-based models have numerous interesting little lessons to teach but, being able to explain the minutia, rate models are also able to perform astonishingly accurate tower designs and incisive troubleshoots. McCabe and Thiele have their place but there are circumstances where something better is needed—gas treating with amines is one of them.

To learn more about this and other aspects of gas treating, plan to attend one of our training seminars. For details visit ogtr.com/training.

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