The CONTACTOR™

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Can Contactor Overhead Gas Be Supersaturated with Water?

From the standpoint of simulation, if you're using an ideal stage model even with efficiencies, i.e., not a true rate-based simulator, the answer to the title question is "absolutely not", unless you apply an efficiency to the interphase transport of water. All streams leaving a tray are in perfect equilibrium and that means with respect to water saturation, too. But if you're using a real mass transfer rate-based simulator (ProTreat®) then the gas exiting an absorber or a quench column certainly can be supersaturated. In fact it normally is, although usually (but not always) the degree of supersaturation is very small. How is this possible? After all, water vapor condenses very easily into liquid.

We're going to take a little different approach to discussing this topic by replacing a discourse with a dialog between our technical support team and an unnamed user of ProTreat®. The context of the problem is a TGU Quench column.

User: In reference to the attached simulation (see Figure 1 for schematic), it seems the overhead vapor (Stream 3) is carrying more water than it should be, considering its temperature. Is this an error in the program? I am very confused why the overhead stream is carrying more water than it should be…quite a bit more!

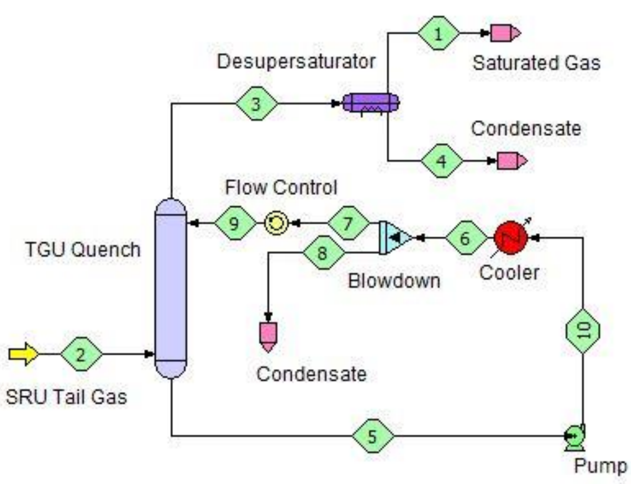

Figure 1 **TGU Quench System**

Support: If the gas and liquid phases were pure water, supersaturation would be an impossibility. However, Stream 3 contains mostly non-condensables which offer resistance to the diffusion of water vapor through the gas phase towards and from the liquid phase. This mass transfer resistance allows the gas to be supersaturated or subsaturated depending on whether the gas is in contact with liquid that is hotter or colder than itself.

The following figure shows typical water vapor partial pressure profiles, equilibrium and actual, simulated for a quench column. At the top of the column the vapor is being cooled and its temperature and vapor phase water content are not at equilibrium because of mass transfer resistance. Even water condensation is a mass-transfer rate-controlled process and it requires a difference between actual and equilibrium to drive it.

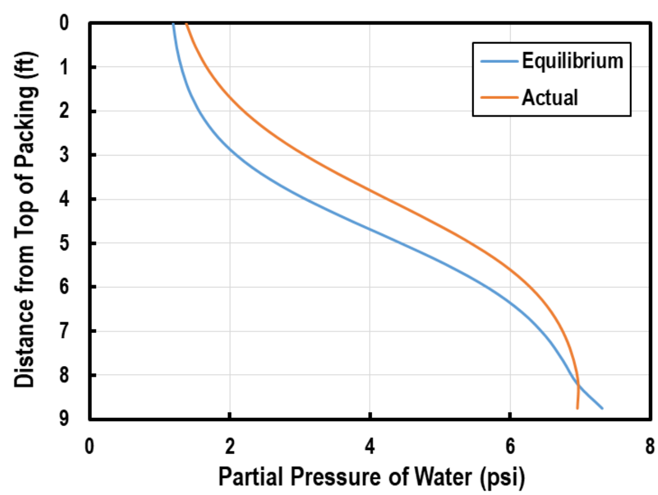

Figure 2 **Actual and Equilibrium Partial Pressures of Water Vapor**

User: It just doesn't make sense to me that water in the vapor phase would have so much resistance to moving into the liquid phase. Of all the components, I would assume that water condensing into water would be very fast. Do you have any real-world sampling data to support the prediction of an overhead vapor stream that is supersaturated?

Support: It would be extremely hard to collect such samples. In addition, it would be even harder still to determine with any certainty that the liquid content of the flow through the overhead vapor line was not from entrainment rather than supersaturation.

Actually pure steam condenses into liquid water extremely rapidly; however, in most gas treating applications we're dealing with water vapor diffusing through much non-condensable gas and the fact that there is a non-transferring gas is what's responsible for resistance to diffusion of water from the bulk vapor phase to the interface. (Incidentally, this is also what's responsible for the very poor heat transfer characteristics of condensers handling non-condensables in the feed vapor, and why it's important to release the non-condensables periodically from condensers.) *Once at the interface*, water condenses into the liquid instantly (but only to the extent consistent with water's vapor pressure in equilibrium the liquid phase). All of this is especially evident in cooling and quench towers where cooling is actually limited by the resistance to mass transport of water through the gas or air phase.

So cooling tower performance is actually limited by vapor phase diffusion of water, i.e., the rate limitation is mass transfer, even though cooling towers and quench towers are used specifically as heat transfer devices. In the case of regenerators and even absorbers, the effect isn't nearly as pronounced, but it's still present, especially if there is a steep temperature change at one end or the other.

User: It makes pure sense to me that the water in the vapor phase has resistance to condensing into the liquid phase because the interface is "crowded" with other species that are non-condensable. But in a pure steam case… no resistance. Thanks for explaining that. Makes sense.

Now my only problem is figuring out what happens to the column's overhead stream (Stream 3 in the simulation I sent) that is carrying way more water than saturation. What happens to that stream? Does it just stay supersaturated until it hits the next unit operation? Or until it cools down in the overhead piping? Does the water "mist out" of the supersaturated condition?... thus resulting in a saturated vapor now carrying liquid droplets? That is what is confusing me.

Support: Supersaturation is an unstable state and is impossible to maintain it in flow through a pipe. Undoubtedly the excess water vapor condenses into tiny droplets (mist) which then loses its droplet content to the pipe wall. Although we don't have quantitative measurements of the degree of supersaturation, there is certainly anecdotal evidence of almost pure water running down the overhead piping and collecting at low spots. In an amine system if this were entrainment it would contain a similar amine concentration as the lean amine entering onto the feed tray. The fact that it contains little of no amine lends credence to the assertion that the liquid is condensed supersaturation.

User: So how much supersaturation can one expect?

Support: In a TGU Quench tower under typical operating conditions, ProTreat would calculate around 130% relative humidity (Figure 3). In another recent case (Figure 4), you were looking at stripping ammonia from water using hot atmospheric air. There we calculated *225% relative humidity* of the air leaving the stripping column! In stripping 6.6 gpm of 18 wt% aqua ammonia, removing the supersaturation generated 0.12 gpm of condensate.

Figure 3 shows for a Quench column how supersaturation and the temperature elevation of the outlet gas relative to the cooling water temperature depended on Quench Water Rate in a particular application (40 MMSCFD of tail gas quenched with 160°F cooling water in a packed column).

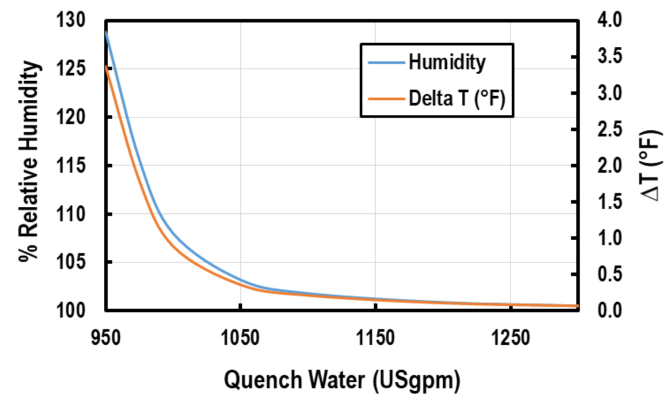

Figure 3 **Relative Humidity and Outlet Gas Relative to Cooling Water in a TGU Quench**

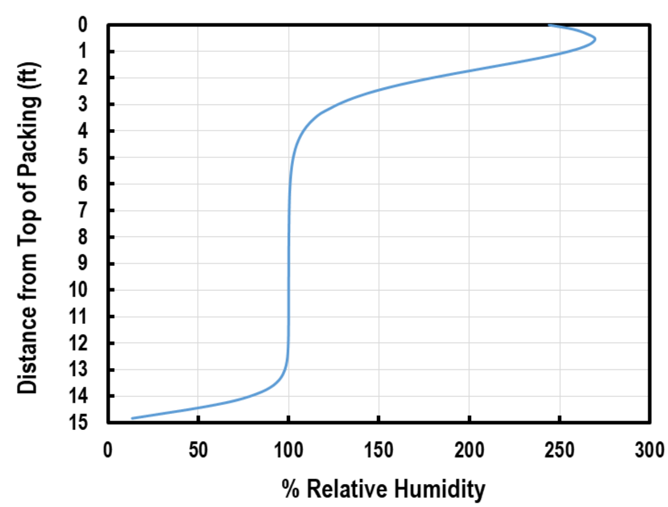

Figure 4 **Relative Humidity and Outlet Gas Relative to Cooling Water in a TGU Quench**

Gases leaving towers in certain applications can be amazingly supersaturated with water vapor. This effect will be completely missed by any simulator that is not fully mass transfer rate based. The result is underestimating the downstream water flow rate.

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