Blends, Glide and Flooded Evaporators

Systems with a flooded evaporator pose a unique challenge when it comes to retrofitting, but one alternative appears to have a low enough glide to make a retrofit simple enough for the equipment owner.

BY GUS ROLOTTI

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Owners of equipment using R-22 are aware of the refrigerant’s current phaseout. Many have taken measures to mitigate supply shortages and equipment downtime by saving R-22 for service by reclaiming it, replacing some of their equipment with systems using HFCs or by using alternatives to R-22. A combination of these measures makes the basis for a well-thought-out refrigerant-management plan, which equipment owners should have in place. However, owners of equipment that use flooded evaporators have seen that their options for alternatives are very limited. This article explores some of the issues affecting flooded evaporators, in particular those dealing with blends and glide.

Definitions

Let’s start by defining the terminology to ensure we are all speaking the same language.

**Flooded evaporators:** Typically used in large applications, they come in several types and technologies but essentially, a flooded evaporator is a container for liquid refrigerant. It becomes cold because of evaporation of the refrigerant as it boils off and exits. Bundles of tubes containing water, brine or other solutions of secondary coolants are submerged in this pool of liquid and get cold as a result. The refrigerant and secondary coolant exchange heat, causing a phase change (refrigerant) or temperature change (secondary coolant), but never really come in contact with each other. Figure 1 shows a schematic of a flooded evaporator. Please note that only the refrigerant and secondary fluid paths are shown for simplicity without controls, oil return lines, etc.

**Blends:** When two or more single-component refrigerants (those made up of the same molecules) are mixed together, the refrigerants do not chemically react to form a new refrigerant, but rather behave as an average of how the components would behave. Each individual refrigerant will retain its pressure-temperature relationship, boiling point, etc. Depending on how close the different components behave, the blend will more or less closely resemble a single-component refrigerant. The type of single component refrigerants used and their quantity in the composition will determine the final behavior. For example, when creating a blend to replace R-22, manufacturers will look for components that on average have similar pressure-temperature relationships, add a particular component to reduce the flammability of another or to improve oil miscibility. Of course, there are many ways to do this, which explains why there are so many replacements for R-22.

**Glide:** Since the components of a blend do not chemically react with each other, but rather remain more or less independent, when a blended refrigerant goes through a phase change at one of the heat exchangers, the composition of the vapor and liquid portions will be different from each other, not only at a particular point, but also all along the length of the exchanger. In practical terms, the refrigerant will not boil off at a single temperature, as a single-component refrigerant would, but over a range of temperatures. This range is called “glide.” The higher the glide in a blend, the higher the differences will be in composition between the vapor and liquid for a given temperature and pressure. Glide plays a significant role on what applications are suitable for a blend and its behavior on different types of evaporators.
Incidentally, while the glide of a blend depends on temperature, pressure and composition, the HVACR industry has not settled on a standard condition to report it. This leads to misinformation and incorrect comparisons. When comparing the glide of different refrigerants, be sure to compare them at similar conditions, especially in the case of higher-glide blends.

**Fractionation:** Just as the components of a blend can be put together, they can also separate or “fractionate.” The higher the glide of a blend, the greater its tendency to fractionate. The amount of fractionation depends on the pressures of each component for a given temperature, available volume for vapor and liquid in a tank or system, relative quantities of each phase, turbulence (whether the system is running or at rest) and many other factors.

### Blends, glide and fractionation

In order to visualize the complex phenomena taking place when blends evaporate, we will use a simpler two-component blend made of refrigerants A and B. Adding a third (or a fourth, fifth, etc.) component will simply increase the number of interactions, but in essence will be similar to what is covered in the following paragraphs.

In Figure 2, the saturation temperature of the blend has been plotted against the composition for a constant pressure. The x axis shows the amount of component A, therefore at x=0, pure B is at its boiling point, and at x=1, pure A is at its boiling point.

The first thing to notice is that there are two lines. The area above the top line, called the “dew-point curve,” represents an area of all vapor. The area below the bottom line, called the “bubble-point curve,” represents an area of all liquid. The area between the two lines is the glide area and represents the transition of the components from liquid to vapor. If we follow a vertical straight line up (increasing temperature at a constant composition for the given pressure), the refrigerant will be all liquid until we reach the bottom line. At that point, the first bubble will form as the refrigerant begins to evaporate. This will continue until the last drop of liquid evaporates when the top line is reached. Beyond that point, temperature of the vapor begins increasing. Keep in mind that when referring to a constant composition, it is the total amounts of components A and B and not how much of each component there is in the vapor or liquid phases.

It should be pointed out that for the illustration, a blend was chosen with two separate lines that do not cross each other, which is typical of many refrigerant combinations. However, many other configurations are possible. In one...
possible configuration the two lines could actually cross each other. The crossing point denotes an azeotropic blend for that particular pressure, temperature and composition, and the blend will behave as a single-component refrigerant.

The vertical distance between the bubble-point and dew-point lines is in fact the glide of the blend at that particular condition. Notice how much the glide can vary as the constant composition line is moved horizontally.

### Blends and the evaporator

Now that the behavior of blends and the construction of a flooded evaporator have been explained, it is time to look at how blends behave in them.

When refrigerant passes through a direct-expansion evaporator, all of it will change from liquid to vapor. The composition of the blend at the inlet of the evaporator is the same as the composition at the exit. In other words, if you were to follow a discrete amount of refrigerant, it would enter, evaporate and exit in its totality. While the individual compositions of vapor and liquid might be different from each other along the evaporator path, all the refrigerant will evaporate upon exit.

While this would cause evaporator glide, the circulating composition in the system is the intended composition of the refrigerant. In the case of a flooded evaporator, that is not necessarily the case. The mass of liquid refrigerant entering the evaporator is the same as the mass of vapor leaving (otherwise the evaporator would be filling up with refrigerant) but their compositions are not the same. The reason for this is fractionation. The vapor phase inside the evaporator will be different from the liquid phase and richer in the higher-pressure components. As the suction of the compressor removes vapor from the evaporator, more and more of the higher-pressure components are removed from the liquid and evaporated. This will continue until a balance for the specific conditions of the running system are reached and equilibrium is established. This means that more of the higher-pressure components will be in circulation, and more of the lower-pressure ones will stay behind in the evaporator. If we were to follow a discrete mass of refrigerant, we would see that it would enter the evaporator and separate. A portion of all the components would evaporate, but the portion of the higher-pressure component evaporating would be larger.

Figure 3 shows the changes in composition for both the liquid and vapor phases of the refrigerants from the nominal. While the compositions are those at static equilibrium, which is not what would be happening inside the flooded evaporator, they illustrate to some degree the changes that could be expected. Notice also that while some components only change a small amount, others have a more significant change as in R-134a reducing by 12% in R-407C.

The problem in this case is that the composition of the circulating refrigerant is not that of the nominal refrigerant itself. This will cause the system to behave differently since
pressures will be higher, especially at the condenser and the system will typically lose capacity and efficiency or experience other performance issues.

Solutions

Owners of systems with flooded evaporators have few options if they want to retrofit their R-22 equipment. Mechanical changes may offer some improvement. In general, when high-glide blends are used, depending on the application and running conditions, they have typically limited success. The best approach is to use a refrigerant with low glide that will minimize the issues described above. Figure 4 shows a comparison of the glide of some of the different R-22 alternatives in the market today.

Out of the long list of R-22 alternative refrigerants, only one has a glide that appears low enough to be used in flooded evaporator systems, R-434A. It has been used successfully in many flooded evaporator retrofits in Europe. While it is difficult to predict exactly what glide is low enough to operate properly, it is clear that the lower the glide, the better the chances are in avoiding these problems and achieving optimal performance. R-434A has a glide of 3°F, while the closest refrigerant in the list is at almost double that. The most common and best-performing R-22 alternative refrigerants (R-407A and R-407C) have a glide about three times that value, making them clearly unsuitable for the application. There are other low-glide refrigerants that could be used, such as R-404A or R-507A, but their use would require significant and costly system changes due to their operating conditions.

Summary

Systems with a flooded evaporator pose a unique challenge when it comes to retrofitting, due to the potential for fractionation. One alternative, R-434A, appears to have a low enough glide to make a retrofit simple enough for the equipment owner.

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