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Vapor lock in refrigeration systems

Vapor lock in refrigerant liquid lines is one of the most common causes of malfunction in refrigeration systems used for comfort cooling. Design manuals, such as the *ASHRAE Handbook of Fundamentals* and most relevant textbooks, give little information for the system designer to follow regarding the liquid line design.

As part of an integrated two-phase system, the design procedure for the liquid line cannot be segregated from the physical design of the condenser, receiver, subcooler, and general geometry regarding the relative location of these components.

The vapor lock phenomenon is similar to vapor locking or air binding in a hydronic system. It occurs when the liquid line rises, possibly runs horizontally, and then drops again to the throttling device (expansion valve). In addressing this problem, the first characteristic that must be recognized is that the receiver contains a mixture of liquid and vapor. Thus, the fluid in the receiver is *always* saturated. Neglecting velocity conversion losses ($\rho v^2/2$) and friction losses, if the liquid line leaves the receiver and rises upward, a pressure loss equal to the product of the specific weight (w) and height (h) results. Thus, as the refrigerant rises, evaporation occurs. This phenomenon results in vapor bubbles forming in the higher section of piping.

Pressure differential needed

With the relatively low velocities existent in most liquid lines, the vapor will not continue down the subsequent drop to the expansion valve but will collect in the higher horizontal piping until the line has essentially become totally vapor bound. Subsequently, a significant pressure differential is required to free the line of vapor and reestablish liquid flow to the expansion valve (and evaporator).

As an example, again disregarding velocity conversion and friction losses, if Refrigerant 22 at 110 F (43.3 C) condensing temperature leaves a receiver and rises 13 ft (4 m) vertically, at the top of the riser approximately 13 percent of the available piping volume will initially be occupied by vapor, and to remove this vapor through a subsequent 13-ft vertical drop will require a pressure motivation of approximately 6 psi (41,368.56 N/m^2). But since the vertical column represents a gain of approximately 6 psi (wh), the net motivating force must equal 12 psi (82,737.1 N/m^2). With the net loss of 6 psi, the vapor cannot be recondensed, and thus, the fluid entering the expansion valve will be a liquid/vapor mixture.

Manifestations of this phenomenon in refrigeration systems include:

- *Unstable operation of thermostatic expansion valve*—The valve, sensing excessive superheat resulting from lack of adequate refrigerant, opens full. Following sufficient pressure differential buildup to purge the line, the high-liquid content mixture reaches the valve and the evaporator, subsequently decreasing the superheat and closing the valve. This cyclical action causes surging or instability in the valve operation.
- *Extreme head pressure sensitivity*—Often, with the sight glass (properly placed) immediately ahead of the expansion valve, the only way the glass can be "cleared" of vapor is by overcharging the system until the receiver is

completely flooded, and some of the condenser surface is used as a subcooler. This "correction" results in decreasing the condenser heat transfer surface. In addition to limiting the full load capacity, this makes the system head pressure overly sensitive to changes in ambient temperature for air-cooled units or water temperature for water-cooled units.

- *Significant reductions in system capacity*—A further capacity reduction occurs if the sight glass is located at the receiver outlet rather than immediately ahead of the expansion valve; it will not reveal the liquid vapor mixture existing at the valve location. Thus, although there may be a clear liquid at that point, the fluid entering the expansion valve, being a mixture of liquid and vapor, will significantly reduce the full load capacity of the system.
- *Occasional liquid slugging of compressor*—Generally, the most costly result of liquid line vapor lock is the loss of a compressor due to liquid slugging at reduced-load conditions. With low load on the evaporator, the superheat sensor, as explained previously, positions the valve full open, and following the ensuing vapor purge of the liquid line, the low-quality mixture moves liquid refrigerant through the evaporator and to the compressor before the thermal element can respond.

Useful design guidelines

The most basic approach to follow to prevent vapor lock in liquid line design is to perform a pressure/temperature/quality analysis of the system being designed. Short of this, the following may prove useful design guidelines:

- Remember, if a receiver is employed, the fluid in the receiver is at saturated condition.
- Any useful subcooling must be accomplished after the fluid leaves the receiver.
- Subcooling must be adequate to offset all pressure decreases in all segments of the liquid system (not just, for example, a *net head* difference between receiver liquid level and expansion valve inlet).
- Avoid high points (rise and ensuing drop) in the liquid line whenever possible. Without a high point, flashing can occur, but vapor lock will not result.
- If there are necessary rises in the liquid line, all devices that cause dynamic pressure drop (filter/dryer, solenoid valve, etc.) should be located immediately ahead of the expansion valve.
- Locate a liquid line sight glass immediately ahead of the expansion valve.
- Do not overlook pressure losses resulting from conversion of static pressure in the receiver to flow velocity ($\rho v^2/2$) in the liquid piping.

In summary, this often overlooked phenomenon of the design of the liquid system in a vapor compression refrigeration cycle can either plague designers or be an interesting challenge.