Vapor Entrainment

Centrifugal pumps for refrigerant recirculation in liquid overfeed systems are very simple devices, they employ essentially one moving part. Consequently, problems from the pump's perspective (to anthropomorphize a piece of iron) are also simple. When too much flow is demanded of the pump by the system, cavitation will result. Conversely, insufficient flow through the pump may result in heating and boiling of the pumpage or in cavitation due to "recirculation." These are indicative of an improperly sized pump or an improperly adjusted system. A third simple characteristic of centrifugal pumps is that while they are very efficient liquid movers, they do a very poor job of pumping gasses or multiphase fluids. Vapor entrained in the liquid stream to the pump suction in large enough volume does not simply pass through the pump. A popular analogy is that of transporting helium filled balloons in your car. When you accelerate away from a stop, the balloons actually move forward toward the windshield. This is because the air surrounding the balloons is heavier than the helium; when you accelerate, the heavier air is forced toward the back of the car and displaces the lighter helium forward. In a similar fashion, the heavier liquid component of the pumpage is thrown outward by the centripetal action of the rotating impeller, and the lighter vapor is "centrifuged" toward the center of rotation. This creates a vapor blockage at the eye of the impeller, which reduces or prevents the passage of the liquid – the pump is "vapor bound." The phrase "vapor entrainment" implies that the vapor is carried into the pump from an external source. This is as distinct from cavitation where the vapor is actually generated within the pump. However, where the vapor content is not sufficient to stop the flow through the pump, it may actually result in noise, which sounds exactly like cavitation. Nevertheless, it is not directly related to or affected by the pump's Net Positive Suction Head Required (NPSHR) or the system's Net Positive Suction Head Available (NPSHA). How do you tell the difference? Diagnosis begins with an evaluation of how likely vapor is to be the problem.

A horizontal vessel is far more likely to contribute to vapor problems than a vertical. The distance between the operating level and outlet of the vessel (the mouth of the drop leg) is always smaller with a horizontal. This lack of submergence means that the pump suction line is closer to the vapor phase in the vessel so that vortexing is more likely. More important, the pump suction is closer to any surface boiling that occurs, and this increases the likelihood that vapor will be drawn into the suction line.

Where process loads predominate vs. cold storage loads, there are going to be more load variations and resulting pressure transients in the vessel. The "instabilities" will result in more boiling within the vessel and simply increase the likelihood that the pump will ingest vapor.

The preceding two system design/application characteristics individually or in unison make vapor entrainment a very likely cause of problems, and there are simple methods available to verify this. At the onset of a vapor entrainment event, the pump discharge pressure will begin to fall off very noticeably. When this begins to occur, it will be necessary to quickly start closing the pump discharge stop valve and observe the behavior of the pump. If the pump is suffering from cavitation due to too high a flow rate, the closing down of the stop valve will bring about almost immediate recovery. However, if the problem is due to vapor entrainment, the pump will stumble even more quickly and will likely lose prime. This is because the liquid velocities inside the pump impeller become inadequate to sweep vapor through, and more of the vapor becomes "stuck" in the impeller eye. Pump performance that is faltering due to low flow recirculation will also worsen as the stop valve is closed down. However, if the pump is connected to an adequately sized and adjusted bypass line and/or there are system loads on line (not all liquid solenoids closed), then recirculation is so unlikely as to be relegated to the end of the checklist. This simple test using the discharge stop valve will most likely reveal whether or not there is a vapor problem but not what its cause is. Unfortunately, the causes are numerous and often interrelated.

Vessel and piping design is always involved no matter what is deemed to be the greatest contributing factor. As previously mentioned, horizontal vessels always have less submergence available to separate the surface boiling from the mouth of the drop leg. Simple vortexing is not often a problem anymore as most vessel manufacturers have learned to include crossed plate vortex eliminators or similar devices in the mouth of the drop leg. However, vapor entrainment due simply to the proximity of the boiling layer to the mouth will still occur if the submergence is less than about 18 inches. If any pressure drop in the vessel is quicker than about 1 psi/min., boiling will occur about 3 feet below the liquid surface, and then obviously 18 inches of submergence will not prevent vapor from entering the drop leg. In a vertical vessel it would be unusual if there were not more than 3 feet of submergence. However, if the drop leg is properly sized, then the full liquid height from the operating level to the pump level can be used to protect against vapor entrainment rather than just the submergence above the mouth of the drop leg. If the drop leg is sized for a liquid velocity of about 25 ft./min., the bubbles will rise at a rate faster than the downward liquid velocity. In many cases a drop leg of larger diameter than the pump suction size is not used; rather, the pump suction pipe is simply connected directly to the vessel, and the horizontal to vertical transition is made with a long radius elbow. In such designs, the likelihood of vapor entrainment is greatly increased by the higher velocity in the smaller diameter line. Often the drop or pump leg is made reentrant to the vessel projecting through the vessel wall rather than flush with it. This is done to prevent oil entrance to the pump. However, if the projection is made too long, some of the submergence is lost.

Along with the vessel design, all but a few vapor entrainment problems are also directly related to the rate of pressure drop during any transient in the vessel. This leads to the discussion of *false loads*. The key to avoiding vapor entrainment in a vessel is to keep the rate of pressure drop as low as possible during any pressure reduction. Pressure reductions occur when a system is started up from ambient – the temperature and pressure must be brought down to their design values before they stabilize. Pressure reductions also occur when something upsets the system, such as an increased refrigeration demand caused by a new batch of warm product being brought to a freezer or increased shipping and receiving activity which allows more warm air into the refrigerated space. A false load is not directly related to an actual increase in refrigeration required but is due to the way the system functions. For example, when the liquid level in the LPR drops and the float switch causes the makeup solenoid to open, high pressure, high temperature refrigerant flashes into the LPR. This make-up refrigerant is as much as 30% vapor by weight, and this vapor is simply *flash gas*, it is not the result of any refrigeration load. In order to maintain the pressure in the LPR at saturation pressure the compressor(s) will load up to a higher percentage of capacity in order to remove the excess gas from the receiver. When the LPR liquid level is restored the float switch will close the solenoid, and the flash gas supply will be instantly removed. However, the compressor cannot unload instantly, so it will continue to operate for a time, fully loaded but drawing on a reduced gas supply. As a result the LPR pressure will drop until the compressor can unload. If this pressure drop is greater than about 1 psi/minute the liquid in the LPR will boil about 3 feet below the liquid surface, the pump will draw in the vapor and will lose prime until the vapor blockage "burps" through.

Another source of false load occurs as a result of hot gas defrosting practices. During hot gas defrost of an evaporator the liquid supply solenoid to that evaporator closes, the *defrost regulator* on the evaporator outlet closes, and a hot gas supply solenoid opens. Hot gas from the high side enters the evaporator and warms the coils. After a while the pressure inside the evaporator builds high enough that the defrost regulator opens, and now hot gas starts blowing down the wet return line to the LPR. This, again, is a false load, and the compressors respond just as with the make-up cycle. Sometimes there are ways to control false loads more closely, and sometimes compressors can be loaded more slowly, but false loading is a common source of pump grief. This grief is more from the standpoint of the operator than from the pump, because our pump will run vapor locked without a problem. If the vapor lock lasts too long, though, then the plant begins to have trouble maintaining temperature.

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