Liquid Overfeed System Alternatives

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EXECUTIVE SUMMARY

Mechanically pumped liquid overfeed systems are the most prevalent evaporator liquid delivery method and have been used for decades. However, this design includes the following drawbacks.

1. Liquid refrigerant leaving an evaporator serves no useful function.
2. Special purpose pumps are necessary and additional recirculator liquid must be maintained to satisfy those pumps' NPSH (net positive suction head) requirements.
3. Excess refrigerant exists in the delivery (xTRL) and return (xTRS) lines.
    a. The evaporator does not require excess liquid supply to operate.
    b. Vertical return lines impose pressure drop from static head and/or reduced diameter required to increase vapor velocity for liquid entrainment.
    c. Horizontal return lines risk liquid being accelerated to vapor velocity with catastrophic hydraulic shock results.
4. This method supplies a fixed liquid feed rate from manually adjusted HEV (hand expansion valves) and is a feed forward control method. Since these valves cannot use feedback from variable system operation, they must be set for maximum load and are oversized for part load conditions.

A review of current and proposed evaporator liquid feed methods will support investigation of a system design which improves liquid feed control as well as suction riser performance.

INTRODUCTION

The discussion below is divided as follows:

- Evaporator liquid piping
    - Evaporator liquid requirements
        - Subcooling
        - Evaporation rate
    - Liquid feed controls
- Evaporator suction piping
    - Hydraulic shock and suction line velocity
    - Riser static penalty

EVAPORATOR LIQUID PIPING

Overfeed liquid has been widely used for decades as the default method of evaporator liquid delivery, whether by gas or mechanical means. Evaporator liquid is flashed down to suction pressure and temperature in a recirculator vessel, subcooled by external delivery pressure and sent across the plant at the desired overfeed rate. The design, by definition, supplies more liquid to an evaporator than it can evaporate. This goal of this effect is frequently described as “a fully wetted heat exchanger”, one in which liquid refrigerant is available for the maximum amount of evaporator primary surface. However, the overfed liquid interferes with this optimum by occupying space better used for evaporator vapor flow and by requiring a means of returning it to the delivery source without having served a useful purpose. In effect, the extra liquid is an insurance policy and as with all such protection, there are premiums to be paid. The external delivery requirement also adds cost in terms of equipment, additional controls and the amount of refrigerant necessary to protect mechanical pumps from operating below a level providing sufficient NPSH.

The key to an overfeed alternative is providing sufficient liquid to achieve optimal evaporation at varying evaporator load rates while minimizing excess liquid and the drawbacks listed above. Supply and control options might include the following.

<u>External PHE subcooler</u>

Subcooling supply liquid to near-suction temperatures minimizes flash gas volume in the evaporator and is vital to evaporator effectiveness. An alternative to the mechanically pumped method above begins with sending high pressure liquid (HPL) at system discharge pressure through a subcooling plate heat exchanger (PHE) with its refrigerating side operating at the appropriate suction temperature. Practical approach temperatures would provide HPL leaving at no more than 5°F above saturated suction temperature (SST) with a difference of <1% in flash gas generation between the recirculator shell and PHE methods. The PHE, however, offers several advantages:

1. The subcooled liquid remains at system discharge pressure and can be sent anywhere in the plant, regardless of distance or elevation.
2. The liquid pumps are no longer required.
3. The PHE can easily operate as a small flooded heat exchanger using the recirculator (now an accumulator) shell as its surge drum. This also allows any occasional liquid returning from the plant to be used to maintain that flooded operation.
4. The liquid refrigerant volume previously maintained in the recirculator served two functions, evaporator liquid supply and pump low-level protection. Evaporator liquid supply must be maintained, but is now done so in the HP receiver. The liquid protecting the pumps can be removed from the system.

A typical two-stage process plant would conventionally use two recirculators operating at high stage (HS) and low stage (LS) suction temperatures and the PHE approach would be used at each of these stages. The subcooled liquid feeding the plant could remain at or near system discharge pressure or it could be regulated as desired.

Modulating evaporator liquid feed

Reduction in overfeed ratio from traditional 4:1 or 3:1 rates has been practiced for decades and ratios of less than 2:1 are now actively being used. The goal is to reduce system charge, but the recent emphasis on hydraulic shock resulting from two-phase suction line overfeed liquid accelerated by suction line vapor adds another incentive. Since evaporator loads can vary for a variety of reasons, a modulating means of supplying liquid at or as near as possible to a 1:1 ratio is obviously superior to the customary fixed flow rate provided by a HEV. Such means have generally relied on control of suction line superheat, but this requires that a portion of the evaporator be used for sensible heat transfer and decreases its capacity. Two other methods may justify further exploration:

- Monitor the head of liquid in the evaporator by use of a differential pressure control connected to the lowest point of the suction header and a point above the evaporator which is reliably free from liquid. The control setpoint would initially be adjusted while the evaporator was under full load to establish the differential pressure corresponding to maximum required refrigerant inventory, but the same setpoint might also be used at partial load conditions (see Figure 1). This analog signal would allow full flow during evaporator post-cleanup and post-defrost refilling as well as lesser flow during processing.
- Sense temperature difference between air entering and leaving the evaporator coil. This becomes an energy balance by modulating refrigerant feed in response to that temperature differential, with a reset or safety function from the leaving air temperature for critical applications.

Each of these requires additional equipment and programming, but modulating evaporator liquid feed provides important evaporator suction line benefits described below.

Existing solutions

It is important to remember that existing system designs also solve many overfeed liquid problems and remain completely acceptable options.

1. Gravity drain systems. Many evaporators are located sufficiently high above the plant and machinery room floors to allow separating the overfeed liquid from the suction line before any risers and returning it to the recirculator by gravity or by means of a transfer vessel using gas or mechanical pumps.
2. Flooded systems. These are not always thought of in this light, but they accomplish many of the same goals by separating the evaporator overfeed flow pattern from the rest of the refrigeration system. The traditional machinery room recirculator pumps become unnecessary and liquid refrigerant is kept out of the suction line.

EVAPORATOR SUCTION PIPING

This portion of the piping system has already been discussed with respect to minimizing the possibility of hydraulic shock. It is frequently sized with respect to pressure drop or temperature drop, but the resulting vapor velocity is seldom mentioned and is an important aspect of hydraulic shock. The International Institute of Ammonia Refrigeration (IIAR) *Ammonia Refrigeration Piping Handbook* recommends a maximum velocity of 8,000 FPM, which is the equivalent of 133 FPS or 91 MPH (2004 edition, p 1-12). The following design scenarios may be useful in understanding this effect.

- -40°F SST; 8" sch 40 BW end cap; 2.0 ft^3 -40°F liquid NH_3 (86.2 lbf); 0.001 sec deceleration.
- Seamless A333 gr 6 pipe; yield strength = 35,000 psi; tensile strength = 60,000 psi.

Design criterion (ΔP/100')	Vapor velocity		Shock stress
0.10 psi per 100' of 8" sch 40 pipe	5,933 FPM	68 MPH	15,765 psi
0.25 psi per 100' of 8" sch 40 pipe	9,553 FPM	109 MPH	25,384 psi
0.35 psi per 100' of 8" sch 40 pipe	11,354 FPM	129 MPH	30,165 psi
0.50 psi per 100' of 8" sch 40 pipe	13,631 FPM	155 MPH	36,221 psi

Design criterion (ΔT/100')	Vapor velocity		Shock stress
0.25°F per 100' of 8" sch 40 pipe	5,190 FPM	59 MPH	13,791 psi
0.50°F per 100' of 8" sch 40 pipe	7,448 FPM	85 MPH	19,791 psi
0.75°F per 100' of 8" sch 40 pipe	9,184 FPM	104 MPH	24,404 psi
1.00°F per 100' of 8" sch 40 pipe	10,655 FPM	121 MPH	28,313 psi
2.00°F per 100' of 8" sch 40 pipe	15,203 FPM	173 MPH	40,398 psi

The figures show how easily high suction line velocities can impose stresses that exceed yield strength and approach tensile strength for pipe base metal. Defective welds provide lower metal strengths and only increase the risk of failure under these conditions. It is important to recognize these liabilities and select velocities under 8,000 FPM whenever possible (see Figure 2).

Another important advantage of a vapor-only suction riser is the elimination of static head penalty resulting from accumulated liquid. The line size compromise between dynamic pressure drop and liquid entrainment velocity thus also becomes unnecessary and the riser can be sized for velocity low enough to retain design diameter liquid droplets at return main levels of pressure drop. The following chart shows temperature penalties resulting from 1 foot of head at various suction temperatures.

Suction temperature	Psi/ft-hd	°F/ft-hd
○ -40°F SST	0.299 psig	0.9°F
○ -45°F SST	0.300 psig	1.0°F
○ -50°F SST	0.302 psig	1.2°F
○ -55°F SST	0.304 psig	1.4°F
○ -60°F SST	0.305 psig	1.6°F

If there is no alternative to a two-phase suction riser, the IIAR Riser© program is useful for selecting the best compromise between dynamic pressure drop from riser velocity and static pressure drop from liquid head (see Figure 3); https://iiarcondenser.org/foundation-research-projects-summary.

CONCLUSIONS

- Liquid refrigerant serves only one purpose in the evaporator – to absorb heat in an optimized evaporation process. More is NOT better.
- Alternate evaporator liquid feed solutions, proposed and existing, offer important advantages to a refrigeration system:
  - Charge reduction.
  - Simpler and more flexible operation with less equipment.
  - Improved evaporator effectiveness.
- Elimination of liquid refrigerant in suction lines provides:
  - Minimized chance of hydraulic shock.
  - Minimized suction riser static penalty.
  - Minimized riser dynamic pressure drop.

Figure 1. LTRS riser with lower & upper pressure transmitters (PT).

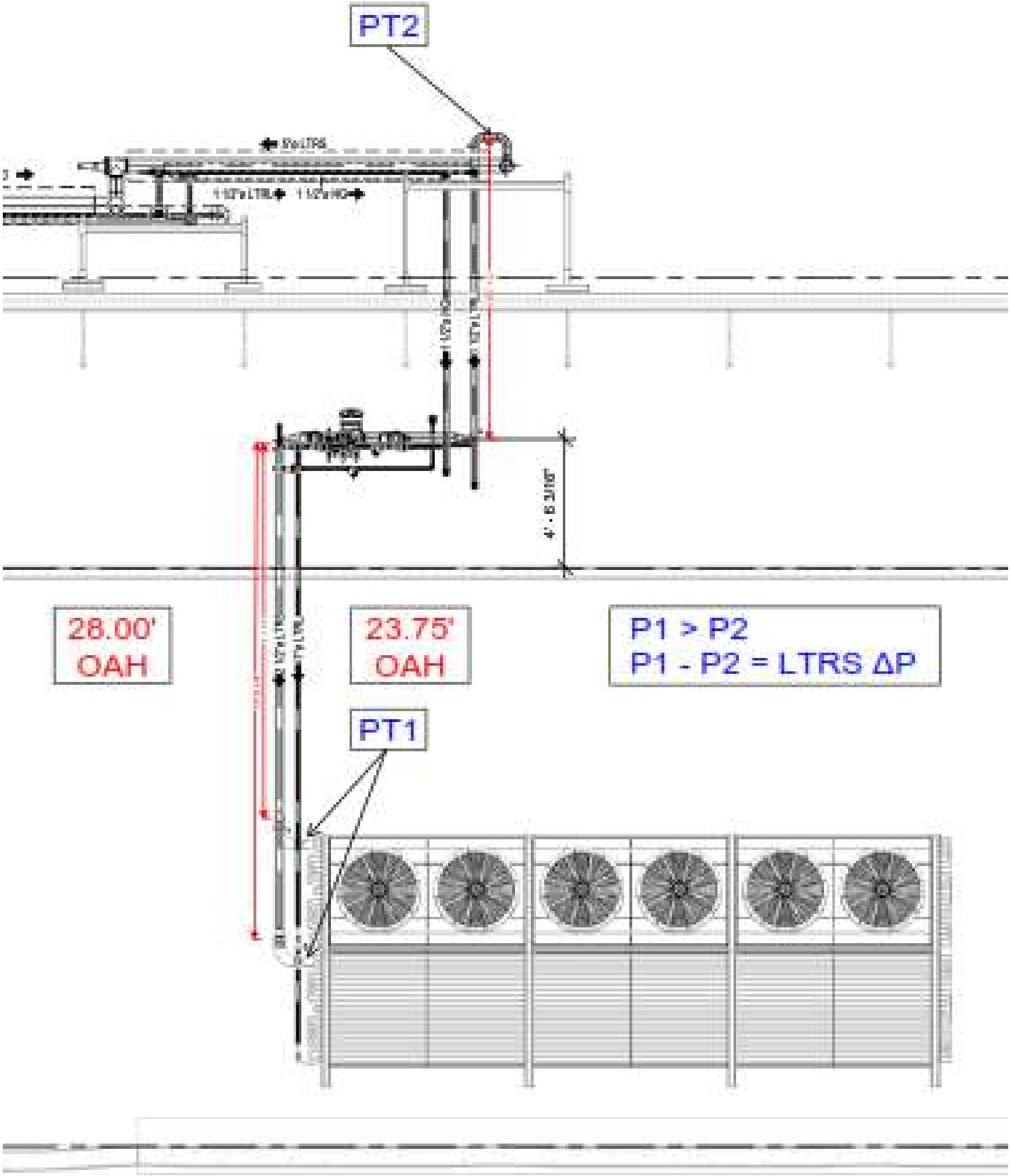

Figure 2. 12” LTRS line rupture; Millard - Mobile, AL (*CSB Safety Bulletin #2010-13-A-AL, Jan 2015*).

Figure 3. IIAR Riser© program calculations.