LIQUID OVERFEED SYSTEMS

Ramesh Paranjpey
Fellow ASHRAE, Consultant
Pune: 411038
Email: pramesh@vsnl.com

ABSTRACT:

The liquid overfeed systems are normally used for low temperature applications, where there are multiple evaporators operating at the same temperature or at different temperatures. Of late, liquid overfeed or liquid recirculation systems are becoming more and more popular. Basically, these are flooded evaporator operation with higher than required liquid feed to the evaporator. Not much of information or case studies are available. There is lack of clarity to certain terminologies like how much should be pump circulation rate, surge volume capacity for low pressure vessel, what is exactly the meaning of over feed rate etc. The information regarding what should be the correct rate of liquid circulation, whether to use hand expansion valves or flow control valves, use of pressure regulator, use of orifices in each refrigeration circuit and its size, what is the ideal pump discharge pressure, what is the allowable inlet and outlet temperature difference and many other design criteria are not available. Similarly information on installation practices for pumps, piping sizes selection and installation practices, adjustment of optimum flow, is not readily available At the time of designing and selecting the equipment author had to struggle to get satisfactory design guidelines. The plants installed so far are on the basis of some sketchy ideas, thumb rules and when author contacted the contractors/designers as why they are doing so no satisfactory answer was available except saying that this is what they have been doing so long. The author therefore thought that it is necessary to present a paper clarifying many such doubts, which will serve as guideline for the people who wish to design pump recirculation systems based on required information. This paper is based on the design of actual system already commissioned and working satisfactorily.

***Key words**: L.P. receiver, surge volume, re- circulation flow rate, pump pressure*

1. Introduction

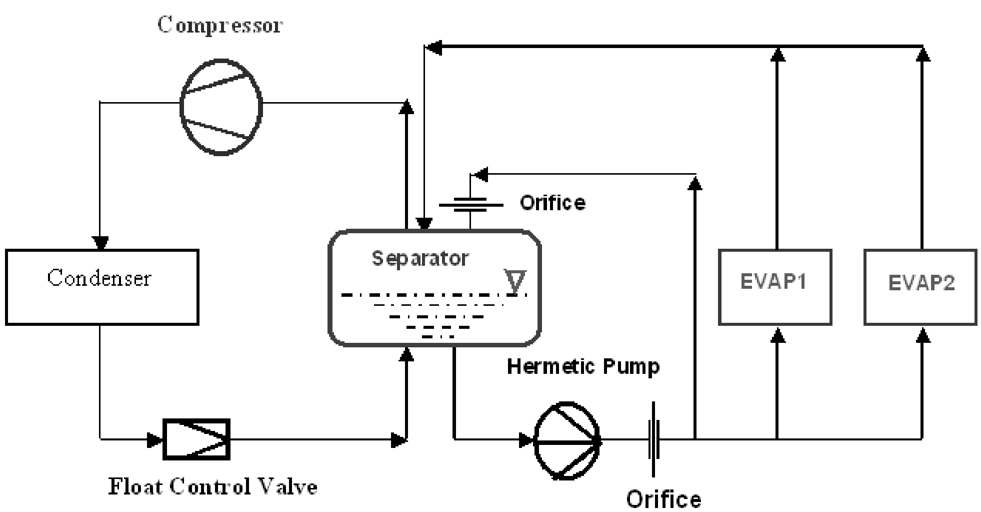
The liquid overfeed or also known as pump recirculation system designs are widely used, especially in low temperature multi-evaporator systems, more popular with ammonia refrigerant. One of the reasons for use in ammonia refrigerant system is the smaller mass flow rate required to be handled with ammonia system as compared with R-22 refrigerant systems. A 100 ton plant with -25^0 C /+40^{0}C requires about 1193kg/hr of saturated liquid ammonia to provide desired refrigeration effect. If for same application R-22 is used then the liquid flow rate would be about 8317 kg/hr. This means a pump having circulation rate in ratio 4:1 would require 10 kW pump motor for R-22, whereas for ammonia it would be only 3 kW. Since these pumps are running continuously so long as plant is in operation, it contributes substantial additional operating cost.

The terminologies used in recirculation systems are different and need to be understood clearly. Also not much information is available to the designer as to what should be optimum flow rate, pump discharge pressure to be maintained, what is the correct meaning of surge volume in L.P. vessel, correct installation practices, and how to adjust flow rates etc.

2. Liquid Recirculation or Overfeed Systems

Refrigeration engineers know that refrigeration is a utility, which is different than other utilities like water, steam or air. The refrigeration system performance is interlinked with load pattern and this utility is not available instantaneously as water or steam. In pump circulation system design, the advantage is one effectively decouples refrigeration system with load allowing more efficient operation and lot of flexibility for design and operation. The fault finding and trouble shooting is also easier as one can be sure of refrigeration system design is OK so long as enough liquid is available in low pressure receiver at the required temperature to meet the demands of all the evaporators. It is then easier to concentrate on performance analysis of low/evaporator side independently in case proper results are not being achieved. This is not so easy where system is directly responding to load.

The overfeed means much more liquid is fed to evaporator than the liquid actually vaporizes. Excess liquid is called overfeed, which returns to low pressure side accumulator or L.P. receiver. By over feeding the evaporator, the inner surface is kept thoroughly wetted and thus achieves optimum heat transfer.



Overfeeding also ensures that the vapours coming out of the evaporator are at close to saturated condition without any superheat thus lowering compressor inlet gas temperature, which also means corresponding lower discharge gas temperatures, which are critical factor for ammonia systems working at low temperature applications. Higher discharge temperatures pose many problems for compressor.

In liquid overfeed systems the refrigerant liquid coming out of receiver is expanded to the required pressure/temperature and this liquid is stored in low pressure receiver. It is then pumped in the various operating evaporators, like product coolers, blast freezers or plate freezers. The rate of circulation through the coolers is more than 1 as explained above and excess un-evaporated liquid together with the vapours generated due to heat load are again returned to low pressure receiver. It thus forms an independent low side circuit. The compressor sucks the vapours from this low pressure receiver and the cycle continues.
In the normal flooded system similar pattern also exists, except that the refrigerant mass flow circulation rate in the evaporator and the compressor is the same.

3. When to use liquid overfeed or other designs?

1. For moderate temperature evaporators with HFC/HCFC refrigerants, direct expansion design is preferred.
2. For small number of low temperature evaporators, flooded coil evaporators is best option.
3. As the number of evaporators increases and as the temperature requirement gets lower and lower, liquid recirculation/overfeed systems are the choice systems. Normally for more than 3 to 5 evaporators, liquid recirculation is the best option. At low temperatures, achieving good heat transfer in the evaporator is crucial since the plant operates with high compression ratios, where quantities of flash gas are appreciable affecting proper wetting of the surface. The fundamentally liquid overfeed system causes more wetting of tubes associated with high velocity of refrigerant results in higher heat transfer rate.
4. When machine room is far away from production area where coolers/freezers are located.

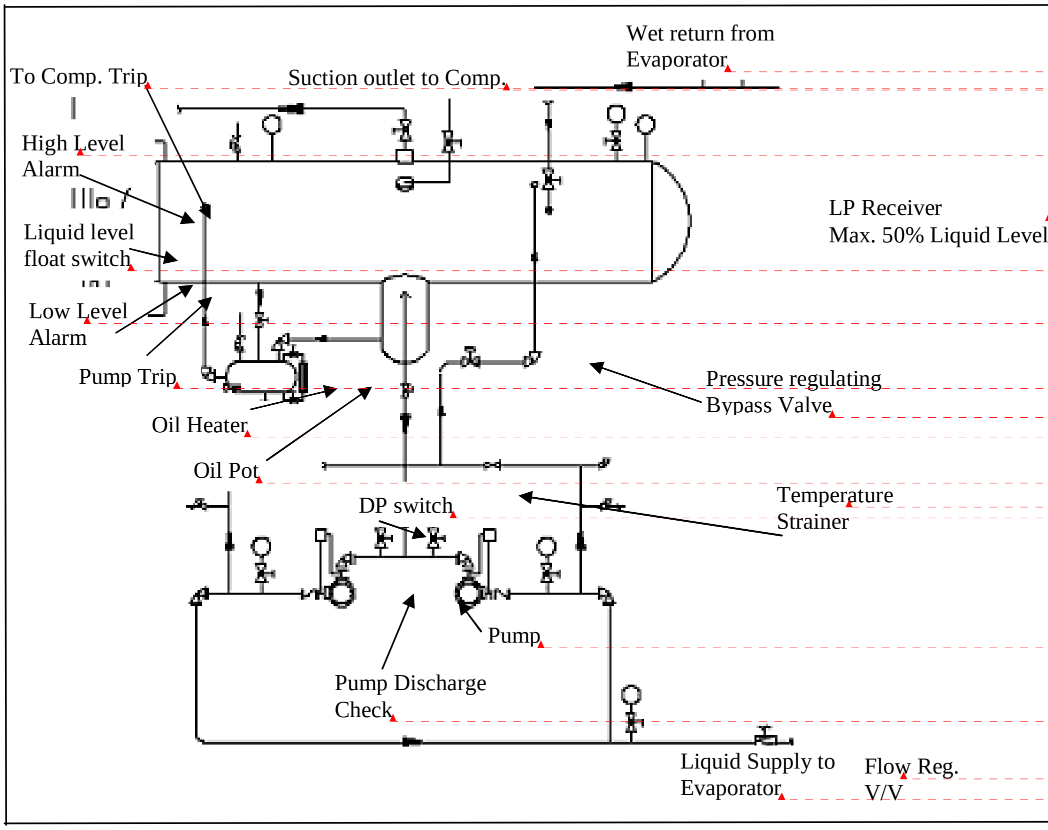
The distinguishing components in the overfeed system design over and above the normal gravity flooded systems are low pressure receiver, circulation pumps and refrigerant liquid and wet return pipe line. The required additional controls and installation of this vessel, a pump also needs special attention.

4. Low Pressure Receiver

It performs two major roles in the system

1. Liquid vapour separation to ensure only vapour is sucked by the compressor.
2. Liquid refrigerant storage at a required temperature so that it is available as a utility to meet the requirement of either one or more operating evaporators.

Since low pressure receiver has large quantity of refrigerant stored at a low temperature and it may not be possible to pump down this liquid to high pressure receiver every time when the plant is shut down, it is suggested that the vessel should be designed for maximum standing pressure corresponding the maximum surrounding plant room temperature. Although the literature mentions design pressure as 150 psig, it is highly recommended that this vessel should therefore be designed for 300 psig pressure similar to high pressure receiver. The second important point is, since it is storing low temperature liquid; whose temperature in most cases would be lower than minus 20^0C, the material of construction used should be low temperature steel like SA516/517 grade 60/70.



4.1 Liquid Refrigerant Level

The important liquid refrigerant levels to be considered while designing the vessel are as under

1. **Working liquid level :(Recommended level is 50%)** A float switch regulates solenoid valve in liquid line. When liquid level falls and solenoid valve opens, liquid refrigerant is admitted to the vessel and when level reaches desired value, the solenoid valves closes. This operation is similar to standard gravity flooded systems. The major difference is in many cases the high side may be a two stage plant using open inter-stage cooler and in which case the pressure drop available across the hand operated expansion valve is very low and the valve should be accordingly sized. Similarly the height at which interstage liquid cooler is installed is important & should be equal though not more than liquid level in the low pressure receiver. If the inter-stage cooler is at a lower level than LP vessel then due to elevation difference the liquid line pressure drop takes place. If this pressure drop is more or equal to the pressure difference needed from inter-stage to LP vessel then it becomes very difficult to admit liquid in the L.P. vessel or the rate of liquid filling becomes

abnormally slow. Thus location of various vessels and the sizing of expansion device are critical issues.

The quantity of liquid required to be stored in the L.P. vessel can be calculated based on the internal volume of all working evaporators and the associated pipe lines. The rate of circulation and the quantity required to be stored are two separate issues and should be treated independently.

2. **Surge volume:** the volume above working liquid level provided in the vessel is known as surge volume and serves the purpose of accommodating liquid that might be forced out of evaporators during defrosting of one or more evaporators. Another aspect needs to be considered is the liquid in the wet return line from evaporators to L.P. vessel, which may drain in the L.P. vessel if power shut down takes place and the liquid refrigerant pump becomes inoperative. In normal circumstances the amount of liquid + vapour returning is same as pump circulation feed to evaporators, but when pump is not taking out liquid from vessel due to reasons mentioned, the extra liquid quantity gets added to vessel from the wet suction line and vessel design needs to take this point in to account in addition to defrost quantity. This level can be provided with alarm indication making the operator aware that liquid level is likely to reach dangerous levels and something is wrong with the plant needing investigation.

3. **Ballast Volume**: The other important level on the lower side of the operating liquid level is the liquid required either during start up after a pump down cycle or if additional evaporators are taken on line for operation. During this period the liquid drawn from the vessel is at higher rate than it is returning to L.P. vessel. The alarm indication for this minimum level should be provided making the operator aware about the falling liquid level. It does not mean that pump stops at this alarm indication and it continues to run. The ballast volume is generally calculated for 5 minutes period meaning pump flow rate multiplied by 5.

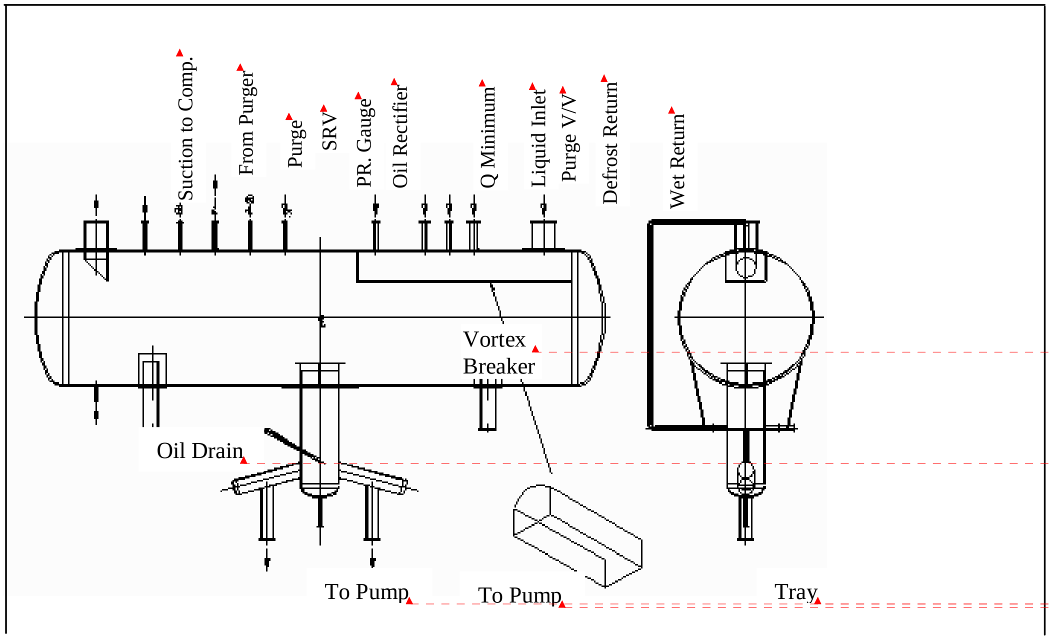
4. **Low level trip:** Pump always needs liquid refrigerant at the inlet or on the suction side hence further drop in liquid level should be set to trip the pump before the vessel empties. Getting vapour or the bubbles at the entry of the pump due to any reason should be avoided for trouble free operation of pump and overall system.

5. **High level trip**: High level cut out set at a higher level than surge volume level will trip the compressor for its protection from liquid entry.

The high level and low level cut outs are actuated by independent float switches thus requiring in all three float switches the third one is for maintaining normal working liquid level whereas alarms can be actuated by 4-20 mA output signal from sensors.

4.2 Construction and Nozzles for Low Pressure Receiver

The sizing of low pressure receiver, both for vertical and horizontal design is given in ASHRAE Refrigeration volume 2006 chapter 1 and many manufacturers also give ready selections based on tonnage, refrigerant used and operating temperatures.



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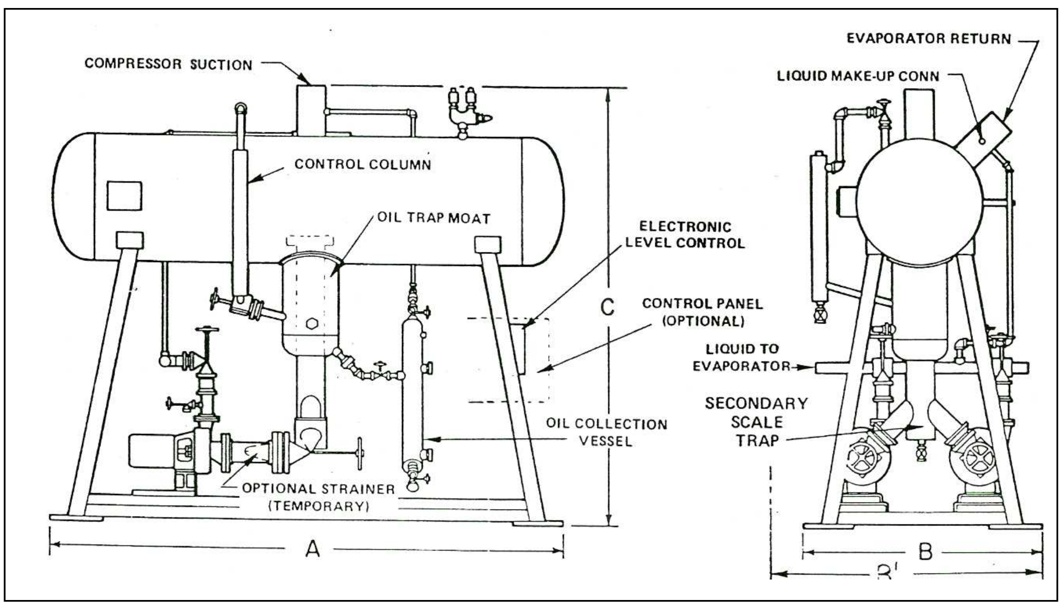
The industrial refrigeration Hand book by W.F. Stoecker also gives design guidelines for sizing. Horizontal type vessel is preferred to provide sufficient surface for the settlement of the oil in the drum and to enable stable suction head conditions.



Besides selecting the diameter and length of the LP vessel, various nozzles fitted on the vessel need some special considerations. It is suggested that a channel/trough on one end of the vessel may be internally created in which all the wet liquid return lines from evaporators, main liquid entry to vessel from HP or intermediate pressure vessel through expansion valve as well as other pipes which are likely to carry liquid enter. These pipes would also be defrost return, minimum flow return from refrigerant circulation pump/ and pump bypass. The liquid falling from all these nozzles first enters the trough and then flows in to the vessel, thus eliminating chances of short circuiting directly to compressor suction. The compressor suction connection is provided at the other end keeping maximum distance between wet return and compressor suction. The suction pipe is also provided with pipe extending in the vessel with 45 deg cut or 'U' bend on the opposite direction of liquid entry for obvious reason of avoiding liquid droplet entering in the compressor suction line.

The main liquid out let connection is at the bottom of the vessel from where the liquid refrigerant pump inlet connection is taken. This pipe is to be sized adequately in diameter and length so that pump suction does not receive gas bubbles as well as liquid flow to pump suction is laminar (3fps). The entry point has to be provided with vortex breaker plate and pipe should protrude in the vessel by about 2" to prevent oil accumulated in the vessel from entering the pumps. Normally two pumps are provided; one working and other as standby and hence two outlets from this vertical leg at 15 deg inclination feeding to pump suction are provided. Independent connection to each pump from the vessel is the best option in case more than one pump is working. The oil drain at the bottom of the liquid leg is essential from which oil can be drained in a pot or directly to outside depending on which refrigerant is used. In case the drop leg is protruding in the vessel then oil drain pot should be connected directly to vessel drain. The drain pot should not be insulated and can have a 60W electric heater element as well. These are some of the special requirements of LP vessel construction.

6. Circulation Ratio

As discussed earlier, in the overfeed systems, deciding the pump circulation rate is an important factor and needs consideration. Firstly, it is essential to understand the difference in recirculation rate and overfeed rate. The circulation rate is the ratio of actual flow rate supplied to the evaporator by pump to the flow rate at which refrigerant evaporates. The amount of liquid evaporating depends on the heat load and the circulation rate could more by 3 to 4 times depending on the type of evaporator design. The circulation rate of 4 means if the quantity of liquid entering the evaporator is 4 kg then out of which 1 kg liquid evaporates and 3 kg of liquid along with 1 kg of vapour returns to the L .P. receiver.

The overfeed rate is the ratio of liquid mass upon the vapour mass existing from evaporator. In the case mentioned above it would be 3. If all the liquid entering is vapourized then overfeed rate would be zero and the recirculation rate would be 1, which happens in case with normal flooded systems where pumps are not used.

These excess or overfeed quantities of liquid may seem wasteful and unnecessary, but as mentioned earlier they perform the important function of totally wetting the inside of evaporator coil surface with liquid refrigerant from the beginning to the end of the coil which gives very high heat transfer coefficient and optimizes coil surface.

6. Selection of Recirculation Pump and Installation Precautions

It is suggested that semi-hermetic pump be used as it has several advantages including avoidance of shaft seal and leakage possibilities, higher speeds, increased swept volume and pumping head.

The cavitation, vapour entrainment and internal recirculation have an effect on pump's capacity and can cause considerable damage to pump seals, impellers, motors and casing.

The lower density of refrigerants such as ammonia (0.75 sp.gr. at -40deg c) and propane are more sensitive to cavitation. Also, the dilution of the refrigerant by oil and foaming tendencies of oil in halocarbons will contribute to cavitation.

Cavitation

Preventing cavitation means preventing vapour generation in the pump impeller. The LP receiver has both liquid and vapour, hence even if vapour generation with in pump is prevented; it is possible for vapour to flow with the liquid in the impeller from LP receiver.

Operating conditions, which may lead to vapour entry could be

1. Low liquid level in LP vessel. A vortex can form similar to the whirlpool seen when draining the bath tub. The vapour gets pulled into the pump in such cases. Vortex breakers are therefore necessary at the exit point from vessel to pump.
2. Refrigeration load fluctuations can result in pressure transients within the receiver. A rapid pressure drop can cause boiling to occur below the liquid surface.
3. During hot gas defrost the hot gas enters the LP vessel making this superheated gas to boil the liquid.

Since the refrigerant in the pump is in boiling condition, for refrigerant pump's the Net Positive Suction Head (NPSH) is not so much relevant as it is understood in non volatile liquids. NPSH therefore is misleading as the liquid head in the surge drum can be reduced to zero by the effect of the mass of bubbles in the boiling refrigerant. The only true head of liquid is in the liquid down leg from the bottom of the surge drum to the center line of the refrigerant pump. The liberal sizing of this drop leg is therefore essential to ensure velocity of liquid flowing is kept below 3fps, above which the gas bubbles are likely to change direction and flow downward towards drop leg instead going upwards towards compressor suction.

The discharge head of the pump should also be adequate to overcome the required height lift, the pressure drop in liquid lines, the drop in coolers and valves or orifices at the evaporators.

Hermetic pumps are normally provided with constant flow regulators to ensure that maximum permissible flow is not exceeded. It is used instead Qmax-orifice. Some pump manufacturer provides Qmax and Qmin orifices to be connected as shown in the diagram. The minimum flow is required for sufficient cooling of canned motor, prevention of vaporizing inside the pump (dry running of slide bearings) and avoidance of cavitation in the low range of the pump operation.

The pumps have built in filters to avoid damage to slide bearings, hence an additional filter is not advisable to be permanently connected in the suction side as it would cause excessive pressure drop. If necessary, a suitable strainer can be installed only during start up period till the refrigerant lines are cleaned. It is recommended to install ball valves with free passage in the suction line to keep pressure drop minimum.

Pressure gauges in the suction and discharge lines should be installed. Pumps must be primed and vented through Q min. connection by fully opening the pump suction and bypass line shut off valves. Additionally a differential pressure control can also be incorporated for safety of the pump as it shuts down the pump when discharge head becomes lower than the minimum permissible discharge head. The shut of valves in the by pass lines must always remain open (remove hand wheels). A pressure regulator in the bypass line opens if the pump discharge pressure rises too high, and the flow is routed directly back to the receiver.Provide non return valve in pump discharge line in addition to isolation ball valve.

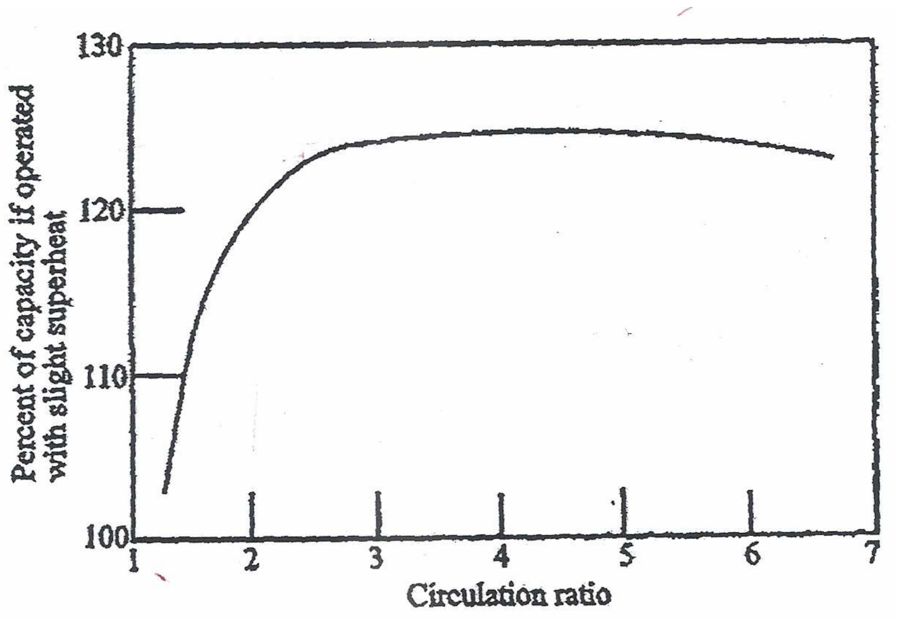
Line Sizing

ASHRAE page 1.7 (Refrigeration volume) gives line sizing methods. The simplest being if the circulation rate is 4 and if the refrigeration tons are 100, then design the lines for 400 ton sizing and for wet return line from evaporator to LP vessel, use one pipe size higher than calculated for suction lines to accommodate extra liquid.

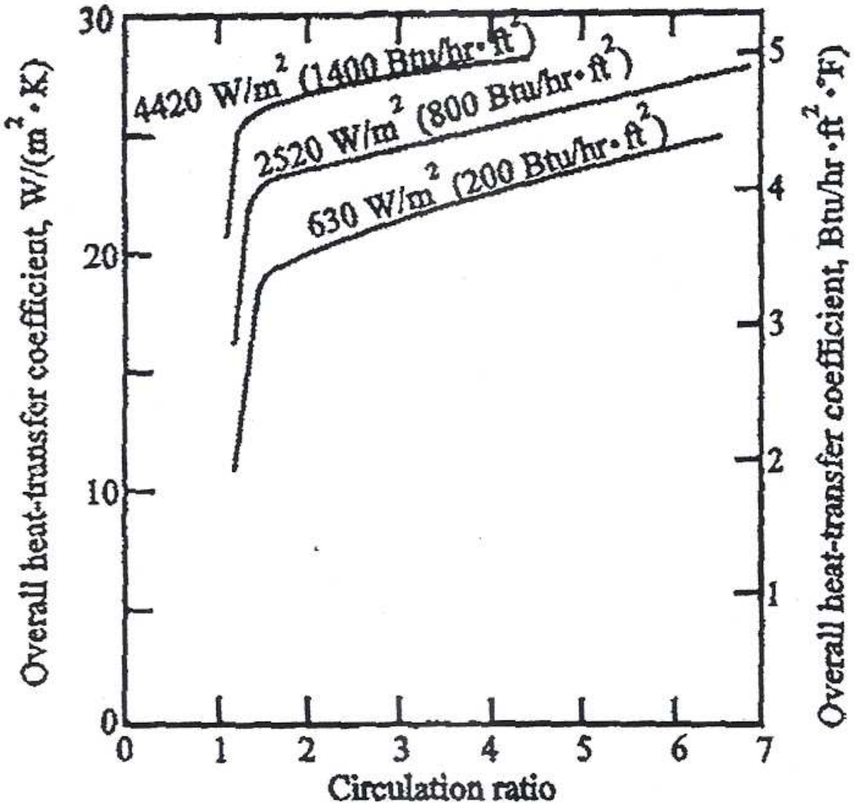
7. What should be optimum rate?

If the circulation rate is more than one, then it surely increases heat transfer coefficient, but on the other hand increases cost of pumping by way of larger pump and power cost. It also increases the pressure drop through the evaporator means higher evaporating. It also means if the inlet temperature to evaporator is to be controlled as per design requirements then the outlet pressure would be lower than inlet pressure equivalent to pressure drop and this means the compressor suction pressure would be lower leading to higher power consumption, reduced compressor capacity and higher discharge gas temperatures at the compressor outlet.

Many experiments have been tried to find optimum flow. No doubt the heat transfer coefficient increases as the circulation rate is increased, but the largest gain in heat transfer is when the entire evaporator inside area completely remains wet from inlet to outlet as it is latent heat transfer or phase change process which absorbs maximum heat from fluid or product. This rate of circulation could therefore be any where from 1 to 2 and then further increase in circulation rate beyond 2 leads to marginal increase in heat transfer coefficient



Percent of capacity if operated
with slight superheat
130
120
110
100
1
2
3
4
5
6
7
Circulation ratio



8. Whether to use top feed or bottom feed

When feed rate increases, the velocity increases. For ammonia refrigerant where the ratio of gas volume to liquid is high, the turbulence at higher velocities causes lot of splashing and geysering effect. Even with steady state and annular velocities of 4000-5000 feet/minute, it is possible to see un-wetted surfaces out of total evaporation area. This effect is less in bottom feed evaporators since gravity and pressure drops will equalize the flow of remaining liquid in the tubes or plate cavities. Liquid separation is unlikely to occur in bottom feed evaporators since liquid is being pushed upwards violently by gas molecules vibrating at their sonic velocity.

In top feed evaporators, observations tend to confirm stratification of liquid and gas with liquid tending to cover the lower surfaces leaving some of the upper surfaces dry. The gravity influences the liquid; the dominant forces on the liquid and gas are friction, separation characteristics and eventually the dispersion of droplets when the liquid becomes entrained in the gas.

The re-circulation rates specified are therefore different for top and bottom feed evaporators. High recirculation ratios of 10 or more are specified for brine configurations. When this type of design is used pressure drop is normally not a factor as only the sensible heat of liquid is used without boiling and vapours formation.

This explains why different recirculation ratios are specified for different types and for different configurations.

ASHRAE recommends circulation rate for Top feed evaporators using larger diameter tubes as 6 to 7. For bottom feed evaporator using smaller tubes as 2 to 4 and for R-22 refrigerant -3.

Experiments have been also tried with circulation rates as high as 20 to 40 using R-12 refrigerant with plate freezers.

This leads to another area of discussions as to whether top feed is better or bottom feed. Both the directions have been used successfully. Each has some advantages associated with some draw backs. Normally the evaporators are provided with orifices at the inlet, with smaller diameter orifice in the lower circuit than higher circuit. This ensures proper distribution of liquid in each circuit.

The advantages of top feed are

1. Smaller refrigerant quantity circulating in the system requiring smaller low pressure receiver.
2. Natural gravity-draining of evaporator coil before defrost cycle and coil can be emptied before defrost.
3. No chance of oil accumulating at the lower portion of coil.
4. Better with air water or electric defrost as external heat is preferred due to orifice restriction for defrosted liquid drain. Some manufacturers provide larger orifices on the bottom circuits to make sure enough hot gas condensate can pass through the lower circuit to complete the defrost. Except for some lower circuits that are kept oversized for defrost conditions, most manufacturers vary orifice size as a function of elevation

The advantages of bottom feed are

1. Better heat transfer coefficient for the same circulation rate or lower circulation rate for same heat transfer coefficient.
2. More uniform distribution of refrigerant through the various coil circuits.
3. Hot gas defrost is better since flow of hot gas is opposite to normal refrigeration flow
4. Energy saving due to hot gas defrost arrangement.

9. How to adjust optimum flow rate?

Normally in flooded systems it is a practice to use combination of solenoid valve and hand expansion valve. In case of pump circulation systems using multiple evaporators it may not be easy to adjust hand expansion valves of each cooler accurately as adjustment of one cooler hand expansion valve would require re adjustment of hand valves of other coolers. The flow regulating valves (FRV) installed at the inlet of each cooler are therefore recommended instead of hand expansion valves. The automatic flow regulating valves serve two functions. It maintains a constant, but adjustable liquid ammonia refrigerant flow rate to evaporator and also acts as a check valve during hot gas defrost. In the normal flooded systems the liquid entry to hand expansion valve is high pressure and warm liquid whereas in pump circulation systems the liquid entry is moderately pressurized cold liquid.

Install temperature probes at the inlet and outlet of each evaporator. When plant operation stabilizes for say after 30 to 45 minutes, then notes the position of FRV and then gradually turn the valve more and more towards close position until the gas outlet side temperature gets a lot higher all of a sudden than the inlet liquid temperature. For example if the inlet temperature is say -32^{0}C the outlet temperature could rise to -20^{0}C. This indicates that at this point the amount of liquid supplied is equal to amount of liquid evaporated. This also means that all the liquid supplied has evaporated and at gas outlet point we are having approx. 10 to 12 degree superheated gas.

Measure how many rounds you are now from having totally closed position. This position is equal to re-circulation rate of 1:1 same as we get in normal flooded systems. Please then open the FRV three times more from this position to get recirculation rate of four. As mentioned earlier higher circulation rate is of no benefit what so ever.

10. What should be inlet pressure to evaporator?

Most of the designers/users feel that higher the pressure better is the pump flow to coolers and better is the performance. This thinking is incorrect. The inlet pressure to evaporator should be just enough to overcome pressure drop inside the cooler and the wet refrigerant return line up to L.P. vessel. For example, if the plant has been designed for evaporating temperature of -32^{0}C,saturation pressure corresponding to -32^{0}C is 1 bar absolute. If the pressure at the inlet is higher than this say 2.0 bar, the corresponding saturated evaporating temperature is -18^{0}C. This means although the liquid supply temperature is -32^{0}C, it will not be evaporated till the pressure inside the evaporator drops to 1.0 bar and till such height the heat transfer is only sensible in compensating the sub cooling. It means using part of the evaporator area for sensible cooling instead evaporating and thus loosing valuable surface area from being effective. To put it simply part of the area of evaporator will be used to overcome 12 deg of sub-cooling of liquid from -32 to -20 deg c and there would be no boiling, just a temperature increase. As the refrigerant rises, it will decrease in pressure, reducing sub cooling. These two simultaneous effects of –increasing temperature and decreasing pressure-mean that after a while boiling point is reached and refrigerant starts to boil albeit at a higher temperature than at the exit.

In most of the installations it has been observed that it takes mush longer time to cool if the valve flow and inlet pressure is not properly adjusted. With higher flow rates and pressures, the cooling which should be achieved by evaporating the liquid inside the evaporators and not by heating the cold pressurized liquid without actual evaporation taking place. In abnormal circumstances evaporation may actually take place in suction line or even in L.P. vessel if the circulation rate is too high.

The temperature difference between inlet and outlet should finally stabilize for less than 1^{0}C when the flow rates are adjusted between 3 to 4.

11 Conclusion

Having discussed various aspects of unique requirements of ammonia pump recirculation systems I shall now summarize some other installation and other precautions to be taken which are normally overlooked.

1. L.P. vessel should be designed for 300 psi since long/accidental shut down may lead to increase in pressure.
2. High level alarm should be set at 50 % level and shut down at 55 % level
3. Suction pipe to pump should be sized for 3 fps velocity. Ball valves are best in pump suction to give full flow.
4. Pump should be at least 6 pipe diameters away from elbow and eccentric reducers at the pump flange are recommended, when direct vertical inlet to pump is not possible. Preferred piping is always vertical direct inlet to pump suction.
5. Pump mounting plates should be supported on flexible mounts to accommodate piping length variation due to temperature variation.
6. Oil drain pot should not be insulated and a pressure relief valve must be provided for the drain pot.
7. The mouth of drop leg should protrude about 2inch into LP receiver to prevent any oil collecting from being ingested by pump.
8. Minimum 8' distance between vessel bottom to pump inlet to ensure NPSH requirements.
9. Vortex breaker in the inlet line of liquid to pump in the LP receiver should be provided.
10. Pumps should be selected for low NPSH (1.5 to 2.5 ft head). The liquid level from center line of pump suction to ammonia operating level should be twice the pump NPSH.
11. Provide independent suction pipe to each pump and not from common drop leg if possible to ensure that vapour bubbles caused by heat transfer from standby idle pump into suction of operating pump are avoided.

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