Freeze Protection

Freeze protection is a very important subject when designing a refrigerant system. The problem of freezing often concerns the evaporator, because it normally cools water with a refrigerant evaporating at low temperatures. It becomes a problem when the system is poorly designed and/or when external factors have a negative influence.

The protection against freezing can be provided on the secondary fluid side and/or the refrigerant side of the heat exchanger. The actual cause of freezing is a low evaporation temperature. If this temperature can be kept above the freezing temperature of the secondary fluid in all operating conditions, there will be no risk of freezing. In this section, situations where there is a potential risk of freezing are described, and methods to protect a system against freezing are discussed.

Situations with a Potential Freezing Risk

In some evaporator applications, there is a risk of freezing of the secondary fluid channels. A low evaporation temperature with low secondary fluid temperatures and a low total or local water flow rate increases the risk of freezing. In normal, steady operation, freezing is very seldom a problem. However, there are other situations where there is an increased risk of freezing.

Start-up at low ambient temperatures (systems with an air-cooled condenser)
At low ambient temperatures, the condensing pressure is low during the start-up of the compressor. This also results in a low evaporation temperature. Figure 1 shows how the suction temperature varies in such a system during the start-up.

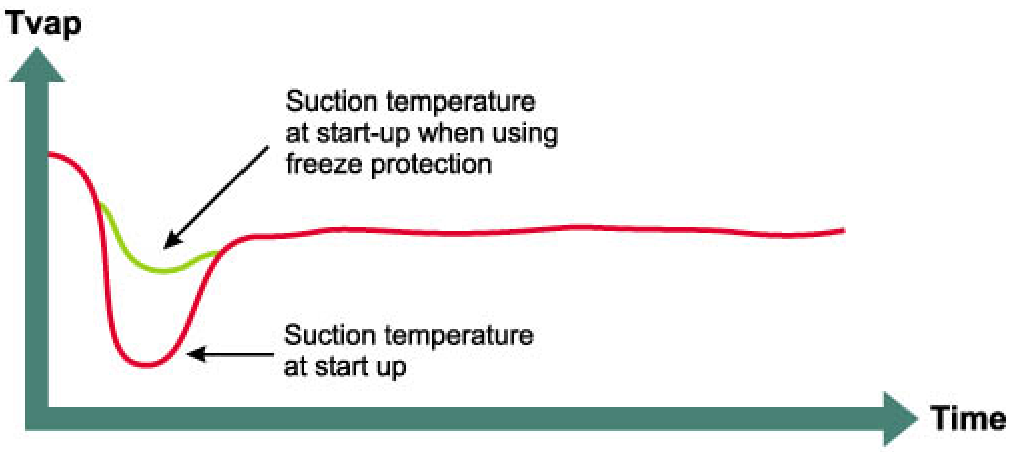

Figure 1. Suction temperature at start up, with and without protection against freezing

The various methods for increasing the evaporation temperature during the start-up include:

- Hot gas by-pass valve
- Suction pressure control valve
- Condensing pressure control valve
- Compressors with variable capacity

Reversed cycle defrosting (heat pumps)
For heat pumps with outdoor air-to-refrigerant evaporators, it is sometimes necessary to defrost the coil. This can be achieved by reversing the refrigerant flow. The evaporator is then run as a condenser for a short time, allowing the ice on the outside of the coil to melt. Because the coil is very cold when defrosting starts, the condensing pressure will be very low. The situation during defrosting is therefore the same as when starting up an air-

cooled system at low ambient temperatures, i.e. the evaporation will be relatively low. During the defrosting cycle, the heat exchanger that normally operates as a condenser will be operating as an evaporator. Due to the low evaporation temperature, there may be a risk of freezing in this heat exchanger.

Some examples of system adjustments to minimize the risk at reversible mode are:

- Stop coil fan to increase condensing pressure
- Activate electrical heaters on the condenser
- Don’t start defrost with too low inlet water temperature to condenser

Pump down stop

In a traditional pump down stop of a system, the liquid line solenoid valve is first closed. The compressor continues to run, and the refrigerant is pumped from the evaporator to the high-pressure side of the system. The evaporation temperature will fall to relatively low temperatures. Eventually, when the evaporation temperature reaches a pre-set level, the low-pressure control will stop the compressor. Due to the low evaporation temperature during the pump down, there is a risk of freezing the evaporator. With BPHE evaporators, the hold-up volume of the evaporator is so small that no pump down is necessary.

If pump down is used, make sure the following is applied

- Secondary side pump is maintaining a high flow in the evaporator
- Add a pressure cut out value in suction line to avoid too low temperature

Simultaneous compressor and water pump stop at low suction temperatures

If the compressor is stopped at evaporation temperatures below 0°C, and the water pump is stopped at the same time for some reason, there is an obvious risk of freezing in the secondary fluid channels. Simultaneous stop should always be avoided.

Outdoor units during off periods at ambient temperatures below 0°C

If the heat exchanger (evaporator or condenser) is installed outdoors, there is a risk of freezing when the ambient temperature is below 0°C. Insulation and electrical heater are ways to protect against freezing. Emptying secondary side fluid could be required if very low ambient is expected.

Disrupted water flow rate

The water flow can be disrupted locally inside the evaporator, or the total flow can be disturbed. A local disturbance can be caused by the blocking of a channel, or part of a channel, by fouling or particles. The flow is then reduced or stopped, and the risk of freezing increases dramatically. The total flow can be disrupted by a closed valve, pump failure or initial cavitation when starting the pump, which also increases the risk of freezing. Installing and maintaining a filter on the secondary side is the easiest way to avoid this problem.

Protection Methods Against Freezing on the Secondary Fluid (Water) Side

Freezing protection on the secondary fluid (water) side uses indirect methods to avoid or minimize situations with a risk of freezing. Figure 2 shows a refrigerant system that can be protected from freezing by controlling the water side of the system. Some of the protection methods are described below.

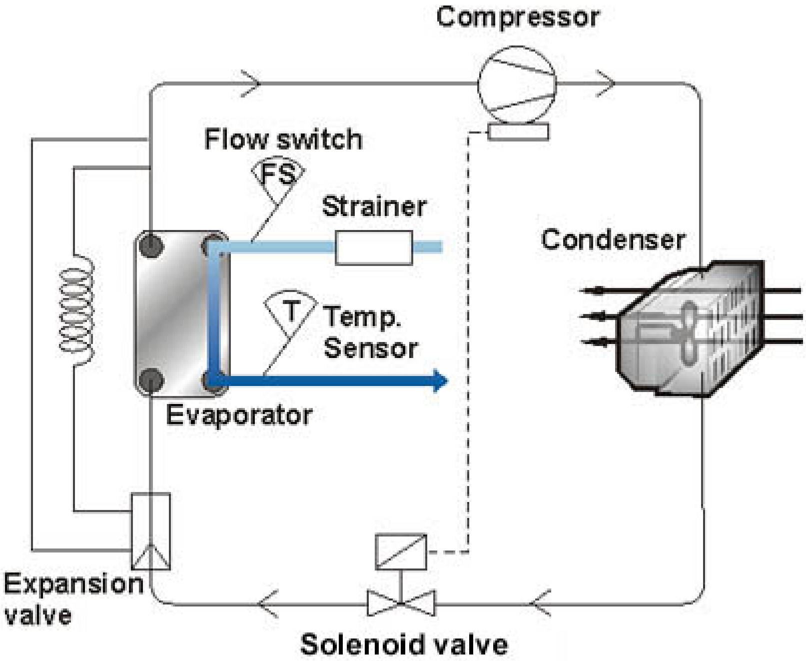

Figure 2. Refrigerant system that can be prevented from freezing by controlling the water side.

Flow switch in the water circuit of each evaporator.
The flow switch stops the compressor if the water flow falls below a certain level. This level should be as high as possible to secure a maximal water flow rate.

As an alternative to a flow switch, a differential pressure sensor in the water circuit can be used. When there is a water flow, the sensor detects a pressure difference between the evaporator inlet and outlet. If there is no flow, there will be no pressure difference and the compressor will be stopped. A second alternative to a traditional flow switch is a pressure sensor mounted in the water inlet pipe. When the water pump is running, there is increased water pressure, which is detected by the sensor. If the pump (and thus the flow) is shut off, the pressure will decrease, and the sensor will tell the compressor to stop.

Strainer to prevent locally low flow inside the evaporator.
The flow switch protects only against a low total water flow. A strainer is required to prevent particles from entering the evaporator and disturbing the flow locally inside the heat exchanger. The strainer should stop particles larger than 1 mm. This corresponds to a mesh size of 16-20 mesh, depending on the wire diameter. The strainer should be installed before the BPHE inlet.

Temperature sensor in the water flow leaving the evaporator.
The temperature sensor protects against low water temperatures. When the leaving water temperature falls below a certain level, the compressor is stopped. This level should be as high as possible without disturbing the operation of the system. Due to stratification of the water in the pipe it might be difficult to measure the lowest water temperature. Measuring

inside the water port is therefore also a possibility. Optimal placement of the sensor can be dependent on operating conditions. This should be evaluated during system verification.

Delayed water pump stop when stopping the compressor.
The pump can be allowed to run for some minutes after the compressor is stopped. This gives the evaporation temperature time to increase to a level high enough to avoid freezing.

Electric heater and insulation applied to the outside of the heat exchanger.
An electric heater and insulation can prevent the freezing of outdoor units during off periods. Electrical heater is also a possible freeze protection in special operating conditions e.g. start up at low ambient and coil defrost

Avoid reversed cycle defrosting when the condenser entering water temperature is low.
To minimize the risk for freezing, defrosting should not be allowed when the temperature of the secondary fluid entering the condenser is below 20°C. During defrost the evaporating temperature is normally very low. Maintaining a high water temperature is important.

Start the water pump before starting the compressor.
The pump should be started before the compressor to allow the water flow to stabilize. This avoids possible disturbance of the water flow due to initial pump cavitation.

Protection Methods Against Freezing on the Refrigerant Side

Protection on the refrigerant side aims to keep the evaporation temperature above the freezing temperature of the secondary fluid. Some methods of freezing protection on the refrigerant side are described below.

Low-pressure (LP) control.
LP control stops the compressor when the evaporation temperature falls below a certain level. This could therefore provide ideal freeze protection. However, it should be noted that for practical reasons, this device is often bypassed and not working during the most critical situation, i.e. during the start-up. This bypass of LP control should be minimized. It is also important that is it differentiated from the LP-control that is intended to safe guard the compressor. The cut out value for the compressor is often much lower and will not protect the BPHE.

Hot gas bypass valve
When the evaporation temperature falls below a set level, this valve leads gas from the high-pressure side of the system to the evaporator inlet (see figure 3). This will prevent the evaporation temperature from decreasing, and thereby protect from freezing. This function can be realized using either a modulating valve (continuous regulating) or a controller combined with a solenoid valve.

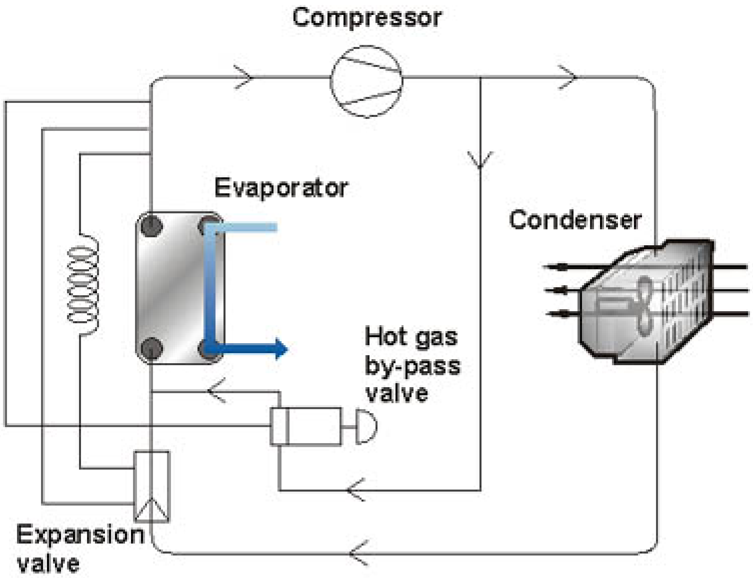

Figure 3. Refrigerant system with freezing control using a hot gas bypass valve on the refrigerant side.

Suction pressure control valve
This valve is positioned in the suction line (see Figure 4). When the evaporation temperature falls below the set level, the valve starts to throttle. The evaporation temperature is thereby prevented from decreasing any further. This valve provides good freeze protection. The disadvantage is that there is also a pressure drop through the valve when it is fully opened. The pressure drop will have a negative impact on the system efficiency (COP).

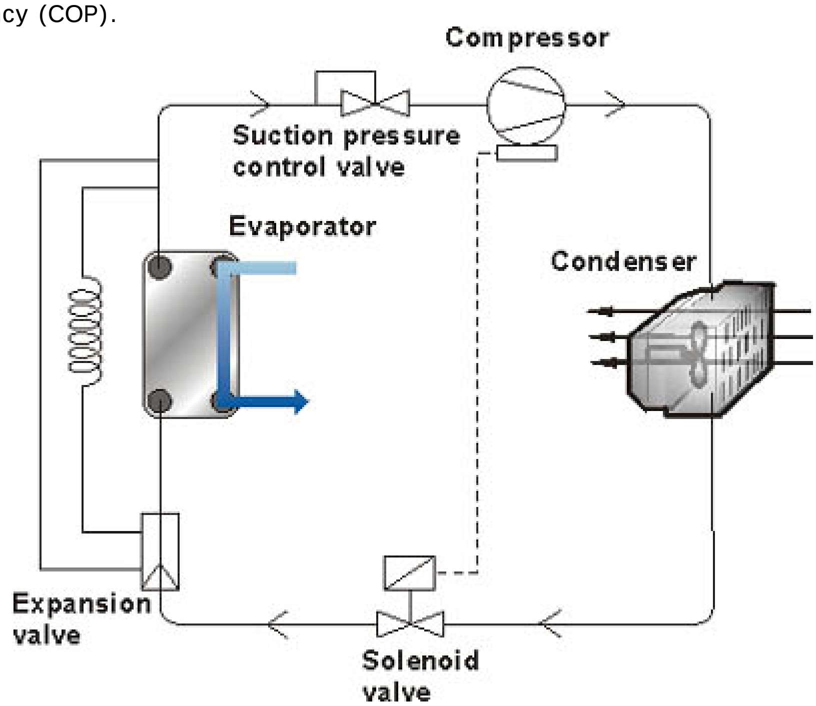

Figure 4. Refrigerant system with freezing control using a suction pressure control valve on the refrigerant side.

Condensing pressure control valve
This valve is positioned in the liquid line between the air-cooled condenser and the receiver (see Figure 5). During the winter, when the low ambient temperature results in a low condensing pressure, the valve starts to throttle. Liquid is then backed up into the condenser, which decreases the heat transfer surface available for condensing. The condensing pressure hence increases, and the fall in evaporation temperature will be prevented.

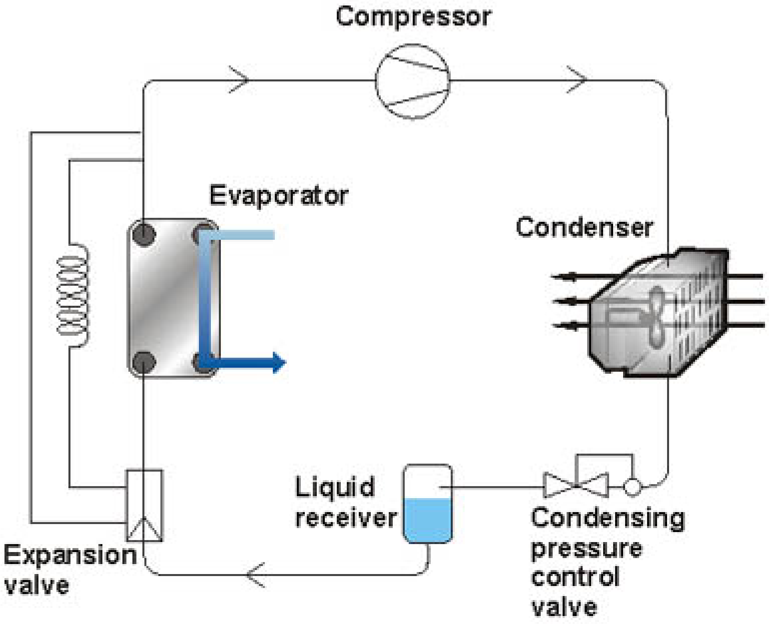

Figure 5. Refrigerant system with freezing control using a condensing compressor control valve on the refrigerant side.

Temperature sensor in the suction line or refrigerant liquid inlet line.
Measuring the refrigerant temperature in and out of the evaporator is not resulting in an optimal freeze protection. First of all it doesn't measure the lowest temperature, which is more relevant. Secondly, how to interpret the measurement depends on operating condition. If outlet gas temperature is measured to be at nominal value the superheat can still be very high which lead to very low evaporation temperature and thereby risk of freezing. For inlet measurement, this is impacted by the distributor pressure drop. Operation at high capacity will induce high pressure drop and a high inlet temperature. Due to higher capacity the evaporation temperature will however decrease and in worse case freezing will occur.

A better solution would be to monitor the actual evaporation temperature and that can be done by measuring saturation pressure out of the evaporator and then recalculate to corresponding saturation temperature.

Avoiding low condensing pressure at start-up.
Delayed condenser fan start can be used to minimize the problem of a low condensing pressure. The compressor is allowed to start before the fan is started. The condensing pressure increases more quickly, and the fall in evaporation temperature will not be as great. There are indications that a delayed condenser fan start could increase the evaporation temperature by approximately 5°C. When the pressure increases, the fan is started. If possible, the fan speed should be increased gradually to avoid a steep fall in condensing pressure.

Variable compressor capacity.
If a compressor with variable capacity is installed, it can be used to avoid low evaporation temperatures. The compressor is started at as low a capacity as possible. This will minimize the fall in evaporation temperature during the start-up.

No pump down.
In systems using BPHE evaporators, the refrigerant volume is very small and there is no need to use a pump down system. Instead, the liquid line solenoid valve is closed at the same time as the compressor switches off. Switching the system off like this avoids the low evaporation temperature occurring during a traditional pump down.