Refrigerant Transfer and Compressor Damage

While a piston or scroll compressor refrigeration system with a low-side oil sump is shut down, all is not at rest in the refrigerant circuit.

Cutaway views of two Danfoss compressors

Cutaway view of a piston compressor, the Danfoss Maneurop compressor

Cutaway view of a scroll compressor, the Danfoss Performer

The refrigerant charge can transfer from one location to another by the action of any of three mechanisms: by absorption of refrigerant vapour into the compressor oil; by temperature difference; and by gravity.

Ignoring these hidden phenomena can in some cases lead to system problems, and those problems can easily include compressor failure. Refrigerant in a system is obviously necessary. It must be managed properly both while the system is operating and during the off-cycle. Here we focus on refrigerant management during the off cycle, and problems that can arise both during the off cycle and as a result of transfer during the off cycle.

Migration

Currently our industry uses migration to describe refrigerant transfer due to three separate and distinct phenomena, and there is a danger of confusion and miscommunication.

The cause of refrigerant transfer in a system could be any of, or perhaps a combination of, the following:

1. Off cycle transfer of refrigerant caused by temperature differences within the system;
2. Off cycle transfer of refrigerant caused by absorption of refrigerant in the oil present in the compressor’s oil sump;
3. Flow of liquid refrigerant from a higher cool component to a warmer component lower in the circuit.

This article avoids the use of the term migration.
Some of these refrigerant management issues that can cause compressor damage are:

- Refrigerant absorption into the compressor’s oil
- Oil dilution
- Oil pump-out
- Transfer due to temperature difference
- Refrigerant drain-back
- Slugging

A specific refrigerant charge is required for proper operation of any given refrigeration system. This charge amount may be above or below the maximum recommended for the compressor by its manufacturer. Systems that typically require less than the maximum amount recommended for the compressor are: self-contained systems such as domestic refrigerators, window AC units, self-contained ice machines, vending machines, and the like. Those that can require more include residential split air conditioners, ice machines with remote condensers and walk-in coolers. Even self-contained commercial air conditioners may require more refrigerant that is recommended for the compressor.

When dealing with systems built up in the field (split residential and commercial systems), the amount of refrigerant required must also take into account the system elements added in the field, particularly the liquid and suction lines. Additional oil may be required to ensure proper lubrication of the compressor. When the amount of refrigerant needed for proper operation of the system exceeds the maximum amount recommended for the compressor, steps must be taken to protect the compressor from the effects of refrigerant transfer during the off cycle.

**Refrigerant absorption**

Absorption (the transfer of refrigerant by diffusion from system zones rich in refrigerant to system zones rich in oil) takes place without measurable pressure differentials in the system because the vapor pressure of the system refrigerant is slightly lower at the oil surface than it is in the rest of the interior of the refrigeration system.

*What causes absorption?*

A compressor's lubricant should be miscible with the system refrigerant. Miscibility ensures that the lubricant sent into the refrigeration system from the compressor is reliably returned to it, because the lubricant is physically combined with the refrigerant.

At any normal temperature, the vapor pressure of the oil in a refrigeration system is much lower than the vapor pressure of the refrigerant, and during shut down periods, as a result of the miscibility of refrigerant in oil, refrigerant in contact with the surface of an oil pool is absorbed into the oil. This reduces the system pressure at the surface of the oil pool, causing diffusion of refrigerant vapor from refrigerant-rich zones in the system. This is the same as the effect that occurs when we open the bathroom door after taking a hot shower and humidity from the bathroom very quickly diffuses throughout our house. In the refrigeration system, though, absorption occurs even when all parts of the system are at the same temperature. As refrigerant diffuses and is absorbed into the compressor oil, the oil level rises. This is to be expected in all systems. When the amount of refrigerant available for migration is below the compressor’s limit, the sudden reduction in crankcase pressure when the compressor starts will produce some foaming due to refrigerant leaving the oil; this is a normal and tolerable effect, visible as foam in a compressor sight
glass. Refrigerant-oil foam consists of bubbles of refrigerant gas enclosed by an oil film. When the amount of refrigerant in the system exceeds the compressor’s limit, though, and shutdown is long enough, the oil level can be higher than tolerable. Much more foam will be produced, rising higher and persisting longer in the sight glass.

Champagne, warm and shaken, provides an excellent demonstration of foaming after you pop the cork and a column of white foam violently exits the bottle. Here the gas is carbon dioxide and the liquid is champagne, and clearly there is too much foam.

When the system refrigerant charge is at or below the compressor's recommended maximum, foam generation can cause small amounts of foam to reach the compressor’s internal suction passage. The compression process can withstand small amounts of oil without harm, but when liquid content of the foam is high enough, the attempt to force the liquid component of the foam through the compressor can create a pressure that is high enough to break the compressor.

A compressor able to avoid damage while moving large amounts of oil as a result of refrigerant migration during the off cycle may be damaged by other means. Consider two additional effects of having too much refrigerant in a compressor’s crankcase at start, oil dilution and oil pump out.

**Oil dilution**

Excessive refrigerant will reduce the lubricating ability of the oil in a compressor’s crankcase. The viscosity of the oil in a crankcase with high refrigerant content is reduced by the presence of the dissolved refrigerant. As a result, metal to metal contact of bearing surfaces can occur during start-up and for some time later, until the excess refrigerant is driven out of the oil as suction pressure drops and the build up of heat from compressor operation drives the excess refrigerant from the oil. As a result a compressor’s bearings may be damaged.

*Image: Bearing damage due to oil dilution. Note transfer of aluminium from bearing to shaft*
**Oil pump-out**

Oil pump-out can occur when sufficient foam is delivered into the system by the compressor at start-up so as to reduce the oil content in the sump to a level too low for effective supply to the compressor’s oil pump. It is correct to observe that the oil delivered to the system will be returned to the compressor as refrigerant circulates through the system but, while the sump is starved for oil, running will threaten bearing life. If bearings survive the first cycle of oil pump out they are at increasing risk during each subsequent run cycle unless the conditions permitting excess migration are addressed.

![Bearing damage, lack of oil. Metal removed from shaft surface](image)

**Crankcase heaters**

It is prudent to use a crankcase heater in any system containing a charge of refrigerant exceeding the compressor’s recommended maximum. By keeping the oil in the compressor at a temperature of 18°F (approx. 10°C) higher than the temperature in the rest of the system, the amount of refrigerant that transfers to the compressor's oil sump can be kept to a tolerable level. The heat provided by a crankcase heater requires some time to become effective. Follow the compressor or system manufacturer’s recommendations for heater size and for the amount of time to energize the crankcase heater before start-up.

**Pump-down**

Another protective technique for preventing refrigerant transfer during off cycles is to apply a pump-down system so that the refrigerant can be isolated from the compressor during shutdown periods. This is accomplished by placing a solenoid valve ahead of the TXV. A system thermostat is used to open the solenoid valve when cooling is required. When the thermostat is satisfied, the solenoid valve closes shutting off the supply of refrigerant to the evaporator. The suction pressure drops quickly, and the system is shut down by a pressure switch in the suction side of the system. In this scheme, the refrigerant charge is isolated from the compressor’s oil sump by the closed solenoid valve and the compressor discharge valve during shutdown. As this pump-down system relies on the compressor for charge isolation, it is prudent to keep power applied to the system so that if sufficient refrigerant leaks back through the compressor to threaten compressor survival, the pressure switch will act on the rise in suction pressure and the compressor will start, transferring the surplus refrigerant to the high pressure side of the system.

Pump-down controls should be applied whenever evaporators in field assembled systems are equipped with electric defrost heaters and when the required system charge is so large that it overcomes the ability of a crankcase heater to protect the compressor from refrigerant transfer during the off cycle.
Refrigerant transfer due to temperature difference

Aside from refrigerant transfer by absorption into the system’s oil, transfer can also occur as a result of temperature differences in different sections of the system. These differences, and the transfers that result from them, are due to the heat pipe effect. Simple heat pipes are heat transfer systems without compressors that operate according to the principals of fluid transfer by the pressure difference caused by condensation and flow due to gravity. All refrigeration systems behave as heat pipes in their shut down mode.

Imagine two sealed tubes: one tube has been evacuated, and the other has been charged with a small amount of a liquid such as water or a refrigerant with the remainder of the tube’s internal volume being filled with the liquid’s vapor (steam, in the case of water). When the bottoms of both tubes are dipped in a bowl of warm water, the tube containing liquid and vapor will rapidly become warm over its entire length, while the evacuated tube, having no liquid inside, will take much more time to warm up. The liquid refrigerant at the bottom of the charged tube vaporizes at the warm (bottom) end and condenses in the cooler upper zone, aiding the transfer of heat that is also taking place through the walls of both tubes by conduction. In the tube charged with refrigerant, gravity has effect as the condensed refrigerant flows back to the bottom of the tube. The vaporization-condensation cycle in a heat pipe continues as long as there is a temperature difference.

Refrigerant drain-back

In a stopped refrigeration system, the delivery by gravity of refrigerant to the compressor is called refrigerant drain-back. Drain-back will occur if three conditions are met: (1) condenser higher than compressor; (2) condenser at a lower temperature than the rest of the system; and (3) there is no trap in the discharge connection to the condenser.

![Oldham coupling seize](image-url)  

*Oldham coupling seize – A damaged Oldham coupling bearing in a scroll compressor, possibly caused by refrigerant drain-back.*

When liquid refrigerant drains back to the compressor and acts as a solvent, it may threaten compressor life by washing away lubricant from bearing surfaces, leaving the bearings unlubricated when the compressor starts. Another threat due to drain-back is a substantial rise in discharge pressure as liquid accumulated in the compressor discharge line is cleared during the compressor start-up. The rise in discharge pressure needed to clear a refrigerant filled discharge muffler or discharge line can be high enough to cause compressor failure.
A connecting rod big end is seized and broken due to a lack of lubrication.

To avoid liquid drain-back when a condenser is above a compressor discharge connection, route the system discharge tubing above the highest element of the condenser to ensure that liquid is trapped within the condenser when the compressor is not running, and therefore can not drain back to the compressor.

Damaged Oldham coupling bearing in scroll compressor, possibly caused by refrigerant drain-back.
Slugging and Suction Line Accumulator

A slug is a quantity of liquid delivered to the compressor inlet during start-up or while operating that is large enough to overcome the compressor’s ability to separate liquid from refrigerant vapor before the excess liquid reaches the compressor mechanism.

![Broken spirals in scroll set, possibly due to liquid slugging](image)

If, during the off cycle, sufficient liquid can accumulate anywhere between the evaporator refrigerant metering device and the compressor suction so as to lead to compressor slugging, a suction line accumulator is required, large enough to prevent compressor damage from slugging. Evidence of slugging shows up as excessive vibration and noise from the compressor as well as in substantial foaming in the compressor sight glass. Ultimately, slugging will lead to compressor failure.

A suction line accumulator is a device capable of separating liquid from vapor and metering the flow of liquid to the compressor at a tolerable rate.

Being able to recognize the symptoms of refrigerant transfer during the off cycle is a valuable part of any technician’s knowledge. By correctly diagnosing the kind of refrigerant off cycle transfer affecting the system, we will know what corrective actions are needed to protect the compressor.