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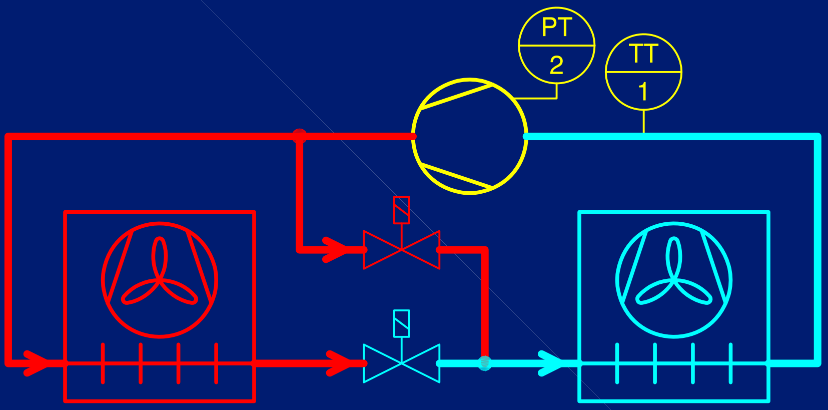
ReFreeX Refrigerating System



ReFreeX

ReFreeX™ Refrigerating System

1. Content

2. Introduction

2.1. What is ReFreeX™

It is a new and improved refrigeration method.

2.2. What is new

- lack of thermostatic valve and capillary
- liquid feeding regulation by a plain on-off solenoid
- hot gas defrost through the evaporator distributor without additional piping

2.3. Main advantages

- 80 percent reduction of the refrigerant charge
- no liquid receiver and no PED (97/23/EC) applicability
- reduced winter consumption
- fully digital control

2.4. Where to use it?

- for cold rooms
- for water chillers
- for heat pumps
- wherever a refrigerating system with thermostatic valve may be used

3. The typical refrigerating system

3.1. The vapour-compression refrigeration

A typical vapour-compression refrigerating system includes a compressor, a condenser coil, a metering device, and an evaporator coil, interconnected by piping. The compressor pumps the refrigerant vapour through the discharge piping into the condenser, where the vapour rejects heat and is liquefied. A metering device—often said expansion device—regulates the liquid refrigerant flow from the condenser outlet towards the evaporator inlet. The refrigerant pressure drop through the device causes a partial adiabatic evaporation—the so-called expansion—into a liquid-vapour mixture, which enters the evaporator, where it absorbs heat from the coil and is fully evaporated, before returning to the compressor inlet through the suction piping.

3.2. The mechanical thermostatic valve

The mechanical thermostatic valve—also said thermostatic expansion valve—is a common metering device in vapour-compression refrigerating systems. The valve regulates the refrigerant vapour overheating at the evaporator outlet; the overheating is defined as the temperature excess with respect to the saturated vapour at the same pressure.

A popular design of thermostatic valve has a metering orifice in series with a circular passage, in which a conical tip moves in and out, to regulate the refrigerant flow, from maximum opening to closure.

A diaphragm moves the conical tip, according to the refrigerant overheating at the evaporator outlet. The face of the diaphragm towards the closure position is kept at the evaporator outlet pressure; the other face is kept at the saturation pressure corresponding to the refrigerant outlet temperature, by a capillary tube connected to a bulb, which is charged with the same refrigerant of the system and is kept in thermal contact with the evaporator outlet.

The refrigerant overheating at the evaporator outlet provokes an overpressure between the diaphragm faces, which pushes the conical tip towards the opening position and is counterbalanced by a regulation spring, to determine the desired overpressure and, indirectly, the refrigerant overheating.

At the evaporator outlet, an overheating rise moves the diaphragm towards the opening position; hence it increases the refrigerant flow through the valve and leads to a subsequent overheating drop, which in turn has the opposite effect: an equilibrium position is eventually reached.

3.3. Limitations of the mechanical thermostatic valve

A mechanical thermostatic valve has following limitations.

A. To get the maximum evaporator capacity, a near-to-zero overheating at the outlet is desired; the mechanical thermostatic valve is unable to regulate under 4 K overheating: the capacity is reduced by 5 percent or more.

B. When the refrigerant flow is less than half of the valve capacity, the valve typically swings between excessive opening and excessive closure, reducing the system capacity and inducing liquid slug to the compressor inlet. The valve orifice is thus sized proportionally to the lowest design flow, but that limits the system performance.

C. During winter operation, the condenser pressure drop lessens the valve flow capacity under acceptable limits. The solution is to reduce the air flow at the condenser, by switching off some of the condenser fans; sometimes the pressure of systems charged with R404A is kept at not less than 17 bars; yielding a much lower energy efficiency.

D. At the thermostatic valve inlet, eventual vapour bubbles hinder the flow through the metering orifice, which is calculated for fully liquid refrigerant; to avoid bubbles, the piping from the condenser outlet to the valve is generously sized; the system refrigerant charge is thus more than would be otherwise necessary. To compensate the operation fluctuations, a liquid receiver is often installed between the condenser and the valve, further augmenting the refrigerant charge. Moreover, liquid receivers involve strict safety measures; in the European Union, for instance, they are regulated by the 97/23/EC directive, also known as PED, and by the EN 378 family of standards.

E. During winter operation, when the condenser pressure drops, the refrigerating system needs more refrigerant, to avoid bubbles at the valve inlet; condenser pressure is thus kept over a minimum threshold or more refrigerant is charged.

3.4. The electronic thermostatic valve

Thermostatic valves with electronic control have been proposed since the ’70s. The US patent nr. 4459819, filed in 1982, claims a refrigerating system with a device made by a simple solenoid valve with an included metering orifice “for restricting the flow of refrigerant.” The solenoid is periodically pulsed on and off to control the refrigerant flow in response to the overheating at the evaporator outlet.

The Danfoss AKV valve has a similar concept: it is a solenoid with an included metering orifice, pulsed-on each six seconds, and then pulsed-off after a suitable time, by a proportional-integral-differential method.

3.5. Limitations of the electronic thermostatic valve

The electronic thermostatic valve replicates the function of the mechanical one, improving the precision of overheating regulation and widening the range of flow capacity; thus it solves limitations previously listed as A, B, and C, but does not solve D and E.

4. The ReFreeX™ refrigerating system

4.1. The circuit

The cover figure, shows a minimal ReFreeX™ refrigerating system. The ReFreeX electronic controller, not depicted, drives every system component. The overheating is calculated by combining the signal of a pressure probe and a temperature probe, both located near the compressor inlet, to facilitate the maintenance. The valves for liquid, in blue, and hot gas, in red, are plain on-off solenoids, as the Danfoss EVR model.

4.2. The refrigeration

During cooling, the hot gas valve is kept closed; the liquid valve is opened regularly, each eight seconds, and kept open for a variable on-time, from near-zero to eight seconds. When the refrigerating system is started for the first time, the initial on-time is set at five seconds; later, it is gradually increased or decreased, according to the ReFreeX algorithm, to get the desired overheating.

4.3. The defrost

During defrost, the liquid valve is closed; the hot gas valve is fully open; the compressor pumps the hot gas into the evaporator, through its distributor. Most of the refrigerant mass is liquid and at rest inside the condenser, which is partially flooded.

4.4. A thought experiment

Following thought experiment clarifies the underlying physics and a method to size the components.
Build a minimal refrigerating system for a cold room, by following criteria.

- liquid solenoid valve: oversized to get a negligible pressure drop
- liquid line diameter from condenser to evaporator: three different sizes, described below as L-, L0, and L+
- every other component: according to traditional methods

Fix the air temperature around the condenser and the evaporator. Write *oh* for the effective overheating at the compressor inlet; write *ohw* for its desired value. Charge gradually the system with refrigerant; keep the liquid valve fully open, until oh drops to ohw. Following three cases are possible.

L-. The liquid line diameter is too small: fully-liquid refrigerant begins to exit from the condenser, but the liquid-line pressure-drop is so high, that oh is still higher than ohw. Further refrigerant charge just floods the condenser; the overheating improvement is small.

L0. The liquid line diameter is precisely sized: at the same time, fully-liquid refrigerant begins to exit from the condenser and oh is equal to ohw; the refrigerating system efficiency is optimal.

L+ The liquid line diameter is too big: before fully-liquid refrigerant begins to exit from the condenser, the oh attains ohw. A liquid-vapour mixture flows out the condenser; hence the refrigerating system efficiency is reduced, because part of the refrigerant mass does not undergo evaporation in the cycle. The refrigerant charge may be completed, until fully-liquid refrigerant begins to exit from the condenser; the liquid valve has to pulse on and off, to reduce the flow and to maintain the desired overheating. In practice, a 10 percent volume of vapour refrigerant may be tolerated at the condenser outlet, since it makes a much smaller mass percentage, which is what matters.

To size exactly the liquid line as in the L0 case is impractical when the liquid piping length is not known in advance, as in a cold room installation, in which the location of compressor, condenser and evaporator are eventually varied during the on-site installation. The liquid line is thus oversized by a safety margin, as in the L+ case.

4.5. Application examples

External sizes			Room insulation			External	Goods	Room	Outdoor	System	**Refrigerant**	
Width	Length	Height	Walls	Ceiling	Floor	volume		temp	temp	mc	**type**	**charge**
m	m	m	cm	cm	cm	m3		°C	°C	hp		**kg**
23.90	10.36	7.76	20	20	12	1˙921	frozen food	- 25	35	2 x 30	**R404A**	**7.0**
16.04	10.00	3.58	8	8	-	574	dairy product	2	35	1 x 10	**R134a**	**2.5**

The examples above show common cold room applications and their ReFreeX refrigerant charge.

5. Why it has not been done before

5.1. The expansion bias

Several experts in the field of refrigeration believe that the *expansion* is essential in the refrigeration cycle.

At the time of writing, in 2016, a Google search for *expansion refrigeration* returns half a million results; among them there is Wikipedia about the thermostatic expansion valve[1], where the device is correctly described as a “component ... that controls the amount of refrigerant flow into the evaporator.”

The term *metering device* or *regulating device* makes the concept clear; the term *expansion*, instead, leads many to believe that regulation and pressure drop have to occur in the same device; that an orifice or a capillary are required; it is neglected that what matters is just the amount of refrigerant fed to the evaporator.

The expansion bias has prevented an earlier adoption of the ReFreeX method; the rest of this section is devoted to disentangle the refrigeration from the expansion, for someone used to it.

5.2. Why it works

In the arrangement L0 of previous thought experiment, liquid refrigerant flows out of the condenser while vapour refrigerant comes back at the compressor inlet. The vapour energy is higher than the liquid one; that energy difference is absorbed from the rest of the universe, by the law of conservation of energy; since the only significant heat exchange is inside the evaporator, the energy difference amounts to the cooling effect of the refrigerating system.

Every other system in the same conditions—of refrigerant flow at condenser outlet and compressor inlet—has the same cooling effect. In particular, a refrigerating system with a thermostatic valve and a ReFreeX system in the arrangement L+ of previous thought experiment have the same cooling capacity, as long as they work in the same conditions.

A more detailed analysis involves the refrigerant enthalpy—instead of energy—and the refrigerant speeds at condenser outlet and compressor inlet, to take into account flow work and kinetic energy; the final result is the same: the cooling effect depends from the conditions at condenser outlet and compressor inlet, only.

5.3. Fine, but where is the expansion?

The law of conservation of energy asserts that the energy difference between the returning vapour and the departing liquid has been absorbed elsewhere, independently from where and whether expansion happened.

That is the law essence: the intermediate steps are not relevant. In other words, the path taken from the initial to the final state is not important: the refrigerant energy is a state function.

5.4. So, what is the orifice for?

Not for expansion is the short answer.

In the mechanical thermostatic valve, the pin that regulates the refrigerant flow is perfectly able to *expand* the refrigerant, by limiting the passage, until eventually closing it—as it does when needed, indeed. The orifice mitigates the immediate valve opening upon sensing a high overheating at the evaporator outlet.

Without orifice, the valve would eventually open completely the flow, flooding the compressor with liquid refrigerant, much before sensing an overheating drop and closing abruptly: permanent valve swinging might result.

5.5. Refrigeration without expansion

To make a traditional refrigerating system operate without expansion, put a liquid subcooler at the condenser outlet, as to cool the liquid down to the evaporation temperature. If the system condensates at 45 °C and evaporates at +5 °C, for instance, then cool down the liquid to 5 °C or colder.

The subcooler must be an external device, but its details are not important; imagine a coil immersed inside water and melting ice, between the condenser outlet and the thermostatic valve inlet.

The liquid refrigerant enters the valve no warmer than 5 °C and exits at the saturation pressure corresponding to 5 °C: there is no expansion passing through the valve; there is just evaporation inside the evaporator.

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[1] https://en.wikipedia.org/wiki/Thermal_expansion_valve

The system cooling capacity is thus what is in the same conditions, without subcooler, plus the subcooler capacity itself. The thermostatic valve works perfectly, even when no expansion is involved.

5.6. A by-product rather than a feature

The warm high-pressure liquid out of the condenser is necessarily transformed into a cold low-pressure liquid-vapour-mixture at the evaporator inlet. Along the path, there is no significant heat exchange; hence part of the refrigerant has to be evaporated, to cool down itself: that is the so-called expansion.

The expanded part of the refrigerant is sacrificed just to bring the refrigerant down to the evaporation temperature; the rest is evaporated inside the evaporator, to produce the cooling effect. The expansion is thus a pressure-drop by-product rather than a feature; it is a necessary loss rather than a useful cooling effect.

5.7. The future of expansion

In the EU, the EN 378 family of standards relegates the term expansion, mainly, to a volume increase, without phase change, due a temperature rise. Hopes of an early expansion demise are chilled, however, by the new EU regulation 2015/1095, regarding ecodesign requirements for some kind of refrigeration equipment, where it mentions “an expansion device” with the meaning of a regulating device or metering device.

The term expansion will be hard to eradicate.

6. The ReFreeX™ advantages

6.1. The environment

- 80 percent reduction of refrigerant charge
- less lubricating oil
- reduced metal thickness in piping thanks to no PED (97/23/EC) applicability
- reduced winter consumption

6.2. Reliability

- minimal number of components
- safe hot gas defrost
- low charge of refrigerant and oil

6.3. Maintainability

- fully digital control
- extensive alarm system
- monitoring from local or remote PC
- setting from local or remote PC

6.4. Flexibility

- easy refrigerant migration
- usage in a wide range of indoor and outdoor temperatures

7. Patents and contacts

7.1. Patents

The ReFreeX technology is covered by European patent nr. EP 1607699 A1, filed in 2004.

7.2. Contacts

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