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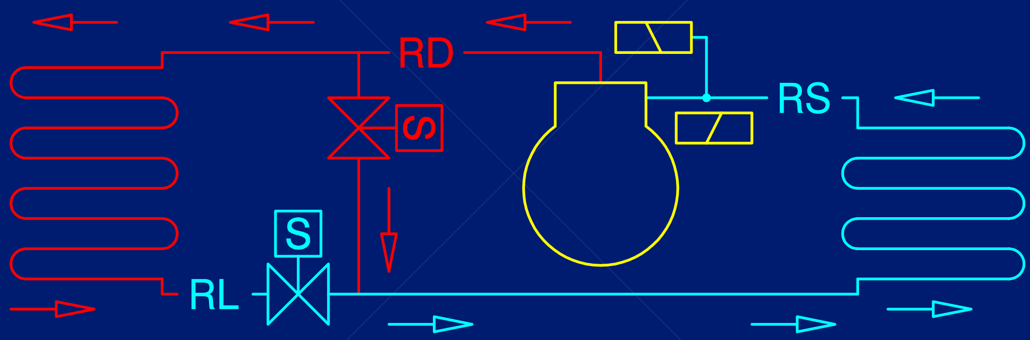
ReFreeX Refrigeration Method



ReFreeX

ReFreeX™ Refrigeration Method

1. Content

2. Introduction

2.1. What is ReFreeX™?
It is a new and improved refrigeration method.

2.2. What is new?
- expansion performed through the piping – no thermostatic valve – no capillary
- evaporator liquid feeding limited by a pulsing solenoid
- hot gas defrost through the evaporator distributor without additional piping

2.3. Main advantages
- 80% reduction of 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 traditional refrigeration plant with thermostatic expansion valve can be used

3. The traditional refrigeration plant

3.1. The traditional refrigeration circuit

Typically, a dry-expansion refrigeration system includes a compressor, a condenser coil, and an evaporator coil. Refrigerant vapour is compressed to high pressure by the compressor and is directed into the condenser where the high pressure refrigerant vapour is condensed to a high pressure liquid. An expansion valve is provided between the condenser and the evaporator so that liquid refrigerant from the condenser may be adiabatically expanded before it enters the evaporator. In the evaporator, the low pressure refrigerant absorbs heat from the surroundings and is transformed into a vapour which is returned via a suction line to the inlet of the compressor.

3.2. The mechanical expansion valve

In many conventional refrigeration plants, the expansion valve is a so-called thermostatic expansion valve. The common mechanical thermostatic expansion valve, like the Danfoss TE2 model, has an expansion port therein with a metering orifice and a valve member for regulating the flow of refrigerant through the expansion port. A spring biases the valve member toward its closed position. A diaphragm actuator is provided. One side of the diaphragm is exposed to suction gas pressure while the other side is connected via a capillary tube to a thermostatic bulb in heat transfer relation with the refrigerant vapour (referred to as the suction gas) exhausted from the evaporator. The bulb is charged with a suitable volatile fluid (e.g., a refrigerant) and thus exerts a pressure force on the valve member via the diaphragm actuator counteracting the force of the spring and the suction gas pressure. When the thermostatic bulb senses an increase in temperature of the suction gas with respect to its pressure, the net pressure force exerted on the diaphragm actuator is correspondingly increased thereby to further open the valve and to permit more refrigerant to flow through the evaporator thus resulting in a lowering of the suction gas temperature. Upon sensing a decrease in suction gas temperature, the thermostatic bulb will decrease the pressure force exerted on the diaphragm actuator and thus will permit the spring to at least partially close the valve thus lowering the flow of refrigerant into the evaporator and, in turn, raising the temperature of the suction gas. In this sense, the expansion valve regulates the overheating at the evaporator outlet, the overheating being defined as the refrigerant vapour temperature above the temperature of a saturated vapour of the same refrigerant at the same pressure.

3.3. Limits of the mechanical expansion valve

The common expansion valve has usually following limitations.

A. To get the maximum capacity from the evaporator, a near to zero overheating at the evaporator outlet would be desirable. However the common expansion valve is not usually able to regulate safely under about 4° to 6° C of overheating, leading to a 5 to 10% evaporator capacity loss.

B. When the refrigerant flow through the valve is under about 50% of the valve maximum capacity, the valve begins to swing between excessive opening and excessive closure, leading to reduced efficiency of the refrigeration system and to dangerous refrigerant liquid feeding to the compressor inlet. Usually the valve maximum capacity is reduced as to avoid this swing, but doing so the refrigeration system can not perform at its maximum capacity and efficiency in every operating condition.

C. In the common refrigeration systems with air cooled condenser, during winter operation the pressure at the condenser drops, so reducing the valve flow capacity under acceptable limits. The common solution is to limit air flow to the condenser, switching off some of the condenser fans as to ensure the refrigerant pressure at the condenser outlet being not less than 8 to 12 bars. At a lower condenser pressure the refrigeration system would have a bigger capacity and a reduced energetic consumption, but this condition is not allowed by the thermostatic valve limitation.

D. Gaseous phase in the refrigerant entering the expansion valve limits the flow through the metering orifice that is usually calculated for fully liquid phase refrigerant. To avoid this limitation, the connection to the valve is generously sized and the refrigerant quantity in the system is bigger than would be otherwise necessary. Often a liquid receiver is also installed between the condenser and the expansion valve. The additional refrigerant in the receiver compensates variations in the operating condition of the refrigeration system. The receiver compensation leads to a further increase of the total refrigerant quantity. Moreover the presence of a liquid receiver over a certain capacity is subjected to regulations such as the 97/23/EC (also known as PED) of the European Union.

E. During winter operation, a lower pressure at the condenser requires usually a bigger quantity of refrigerant in the system, to avoid gaseous phase refrigerant being delivered to the valve. So condenser pressure has to be kept over a certain value or a bigger quantity of refrigerant has to be provided.

3.4. The electronic expansion valve

Thermostatic expansion valves with electronic control have been proposed.

In the US patent nr. 4,459,819 a simple solenoid with an included <u>metering orifice</u> “for restricting the flow of refrigerant” is claimed and described. The solenoid is periodically pulsed on and off to control the refrigerant flow in response to the overheating of the refrigerant at the evaporator outlet.

The Danfoss AKV expansion valve has a concept similar to the US patent nr. 4,459,819. A solenoid valve with an included metering orifice is pulsed-on each 6 seconds and then pulsed-off after a suitable time calculated by a proportional-integral-differential electronic controller.

3.5. Limits of the electronic expansion valve

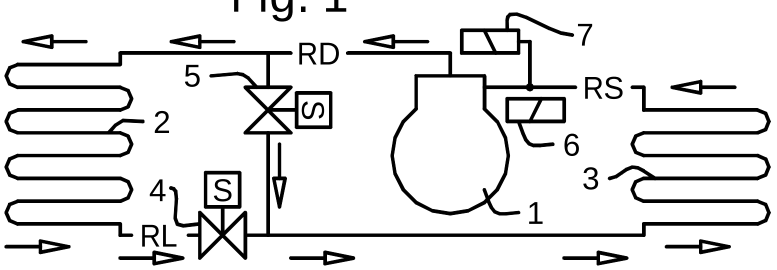
In all of those valves liquid refrigerant arrives at the valve inlet and then expands as it flows through the valve. So those electronically controlled valves replicate the function of the traditional expansion valve, improving the precision of overheating regulation and widening the range of flow capacity over the traditional expansion valve. Those electronically controlled expansion valve solve limitations previously listed as A, B and C, but do not solve D and E limitations.
There is a strong pressure to reduce the quantity of refrigerant, because the common HFC refrigerants cause greenhouse effect, moreover the elimination or reduction of the liquid receiver is often desired to avoid 97/23/EC regulation and similar ones. Nonetheless the common refrigeration systems still do not satisfactorily solve those concerns. So far the necessity to feed fully liquid refrigerant to the expansion valve, combined with the pressure drop trough said valve, leads to wide connections from the condenser to the valve, big quantity of refrigerant and often to liquid receiver needing. From another perspective, the contemporary function of expansion and flow control in the same valve has prevented solution of the limitations above listed as D and E.

4. The ReFreeX™ refrigeration method

4.1. The circuit

Referring now to fig. 1, a ReFreeX™ refrigeration system to be used for a cold room is indicated in schematic form. The

Fig. 1



1. Compressor
2. Condenser
3. Evaporator
4. Regulating solenoid
5. Hot gas solenoid
6. Temperature probe
7. Pressure probe

refrigerant is preferably an HFC like the R134a.
An electronic controller with a microprocessor uses the information from the probes to calculate the refrigerant overheating at the compressor suction inlet.
The pressure probe is connected to the low pressure plug on the compressor and the temperature probe is located on the suction piping near to the compressor.
The regulating solenoid valve is a plain on-off solenoid valve like the Danfoss EVR model.

4.2. The refrigeration

During cooling the hot gas solenoid valve is kept closed and the wanted overheating is controlled by switching on and off the regulating solenoid valve.
The regulating valve is fully opened regularly at a freely settable interval of about 10 seconds and kept on for a variable time (on time) from 0 to 10 seconds, to get the wanted overheating. When the refrigeration system is started for the first time, the on time is at a freely settable interval of about 2 seconds, then the on time is gradually increased or decreased to control the overheating, preferably by a proportional, integral and differential control method.

4.3. The defrost

During defrost, the regulating valve is closed, the hot gas valve is open, and the compressor is on, delivering hot gas to the evaporator without by-passing the evaporator distributor.
During defrost, not being installed a liquid receiver, the liquid refrigerant is accumulated in the condenser that is partially flooded, this flooding helping to rise the condenser pressure and so helping the refrigerant flow to win the natural pressure drop of the circuit.

4.4. The ideal test

At first sight, expecially for people with a long experience in refrigeration plants with thermostatic valves, it is not clear whether the system could efficiently refrigerate and there is confusion about how to size the components.
Following thought test performed in ideal (imaginary) condition could help to clarify the matter.
Imagine to build a refrigeration plant for a cold room and to size the components as follow

- regulating valve: oversized to get a negligible pressure drop
- liquid line from condenser to evaporator: with size chosen at random
- every other component: accordingly to traditional methods

Imagine to fix (ideally) the condenser pressure and the cold room temperature at the wanted operating conditions. Suppose moreover to require a value *ohw* for the refrigerant overheating - named here as *oh* - at the compressor inlet. Imagine now to fill gradually the system with refrigerant, keeping the regulating valve open until oh drops to ohw. Three cases are possible:

L- The liquid line is so small that fully liquid refrigerant begins to exit from condenser but the liquid line pressure drop is so high that oh is still higher than ohw. Further refrigerant filling simply flood the condenser with small overheating improvement.

L0 The liquid line is exactly sized, so, when fully liquid refrigerant begins to exit from condenser, oh is exactly ohw. The refrigeration system capacity and efficiency is as required.

L+ The liquid line is so big that, before fully liquid refrigerant begins to exit from condenser, oh is already equal to ohw. Then part of the refrigerant from the condenser outlet is gaseous, so the capacity and the efficiency of the refrigeration system is reduced, because part of the gas does not undergo evaporation during the refrigeration cycle. If efficiency is the main concern, the refrigerant quantity can be increased until fully liquid refrigerant begins to exit from the condenser, letting the regulating valve to pulse on and off to reduce the flow and to maintain wanted overheating. However in common refrigeration systems the refrigerant gaseous phase density is so small compared to the liquid phase that a relevant volume of gas can be tolerated at the condenser outlet.

Known piping pressure drop calculation can be used to size the liquid line in the L0 case. This calculation is however impossible where the connection length is not known in advance, like in a cold room installation where the location of compressor, condenser and evaporator are decided during installation on site. To overcome this difficulty the liquid line can be oversized by a safety margin as in the L+ case.

During real operation of the refrigeration system, the piping pressure drop between the condenser and the evaporator can be lower than required, if the regulating valve would be completely open, this would result in too much refrigerant being supplied to the evaporator and in a too low overheating. For this reason the regulating valve is then pulsed on and off to limit the refrigerant flow and to get the required overheating. A bigger regulating valve has a smaller pressure drop when it is fully open and allows for a bigger pressure drop in the liquid line, reducing then the refrigerant quantity. So regulating valve sizing is limited by cost and practical reasons. The common on-off solenoid valve without metering orifice (like Danfoss EVR), used as regulating valve, has simplicity, reliability and cost advantage over more sophisticated valves.
The valve main function is to regulate the refrigerant flow as to get the desired working condition of the refrigeration system. However the valve can be sized to perform a relevant part of the expansion, but this is not desirable because it leads to a pressure drop through the valve, so reducing the acceptable pressure drop through liquid line, then increasing the quantity of refrigerant required.

4.5. Application examples

External measures			Room insulation			External	Goods	Room	Outdoor	Plants	**Refrigerant**	
Width	Length	Height	Walls	Ceiling	Floor	volume		temp	temp	total	**type**	**total**
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	60	**R404A**	**7,0**
16,04	10,00	3,58	8	8	-	574	dairy product	2	35	10	**R134a**	**2,5**

Above examples show common cold room applications and the total quantity of refrigerant necessary to operate them.

5. The ReFreeX™ advantages

5.1. The environment

- 80% reduction of refrigerant charge and then greenhouse effect
- less lubricating oil thanks to refrigerant reduction
- reduced metal thickness in piping thanks to no PED (97/23/EC) applicability

- reduced winter consumption

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

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

5.4. Flexibility
- easy refrigerant migration
- same plant usage in a wide range of indoor and outdoor temperatures

6. Patents and contacts

6.1. Patents
European patent is pending with number 04425426.6.
USA patent is pending with number US10/956,297.

6.2. Contacts
Please contact

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