

COPELAND SCROLL™ COMPRESSORS USING VAPOUR INJECTION FOR REFRIGERATION

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1 Introduction

The vapour injected scroll compressor makes use of an economizer with the vapour compression cycle. This cycle offers the advantages of more cooling capacity and a better COP than with a conventional cycle. Both the capacity and the COP improvement are proportional to the temperature lift and this technology offers best results at low evaporating temperatures where capacity and efficiency are most needed. It is usually possible to specify a smaller displacement compressor for a given cooling load. Additionally the cooling provided by the interstage injection allows the compressor to operate over a similar envelope to a conventional liquid injected model, and so the vapour-injected scroll can operate at all the normal low temperature application conditions.

2 Principle of operation

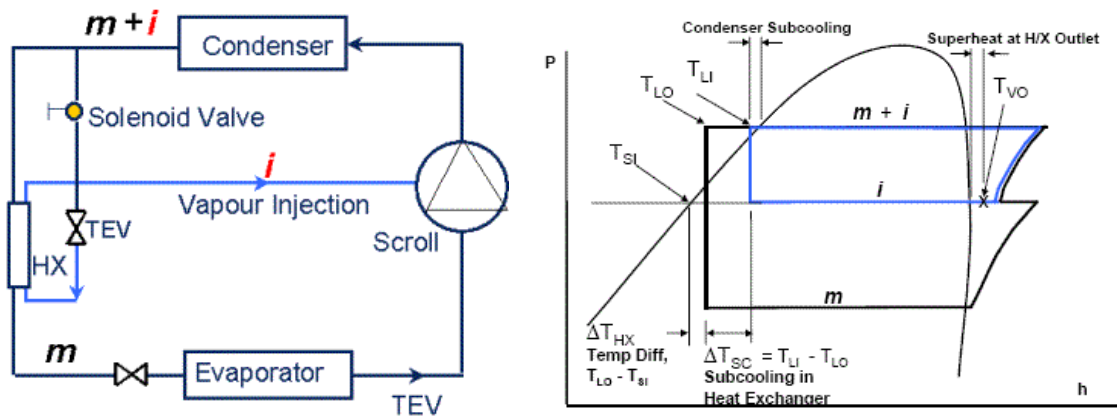


Figure 1: Circuit diagrams showing the main circuit, mass flow rate m , the economizer circuit and the mass flow rate i

As shown in **Figure 1**, a portion of the condensed liquid i is expanded through an expansion valve into a counterflow brazed-plate heat exchanger (HX), which acts as a subcooler. The superheated vapour is then injected into an intermediate vapour injection port in the scroll compressor. The additional subcooling increases the evaporator capacity by reducing the temperature of the liquid from T_{Li} to T_{Lo} , thus reducing its enthalpy. The additional condenser mass flow, i gives a corresponding increase in the heat rejection at the condenser.

The vapour-injected scroll compressor cycle efficiency is higher than that with a conventional single-stage scroll delivering the same capacity because the added capacity from subcooling is achieved with less power. The incremental vapour created in the subcooling process is compressed only from the higher interstage pressure rather than from the lower suction pressure.

The cooling effect is achieved by the addition of vapour to the compression process at the intermediate pressure and at temperature T_{Vo} which is controlled by the HX expansion device.

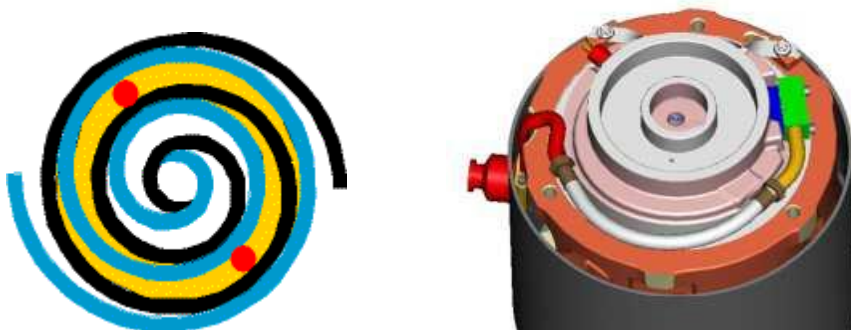


Figure 2: Position of the injection ports in the scroll set and the internal tubing connecting the injection inlet with the scroll set

The vapour is injected into the scroll set at an intermediate point in the compression process via two symmetrically positioned ports as shown on the left in **Figure 2**. The size and position of these ports have been optimised to ensure maximum COP and capacity benefit at typical operating conditions. A single inlet connection on the shell communicates with the injection ports via a flexible tube as shown on the right, and drillings in the fixed scroll. The flexibility ensures that axial compliance is maintained.

3 Capacity effect

With the vapour-injected (VI) scroll there is much less change in capacity as condensing pressure changes than with conventional compressors.

The blue line in **Figure 3** representing the VI scroll characteristic has a lower slope than that of the conventional compressor. Less capacity is delivered when the condensing temperature falls, and this results in less cycling and better COP because the condenser is less heavily loaded during the run period.

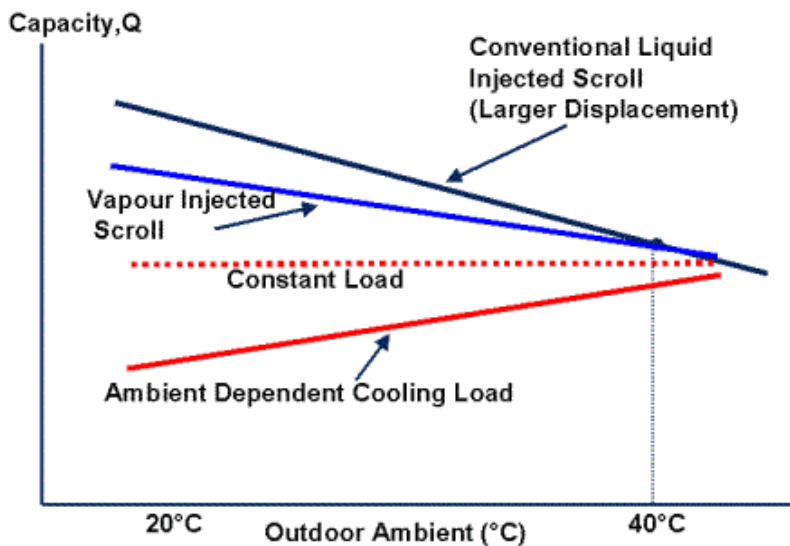


Figure 3: Capacity variation and cooling load characteristics

For a design point capacity of 4kW a reciprocating compressor will deliver typically 6 to 7kW when the condensing temperature falls to 20°C, as shown in **Figure 4**. For a constant load this represents 50-75% over capacity. By contrast a VI scroll having equal design point capacity would deliver 4.5kW or just 12.5% over capacity.

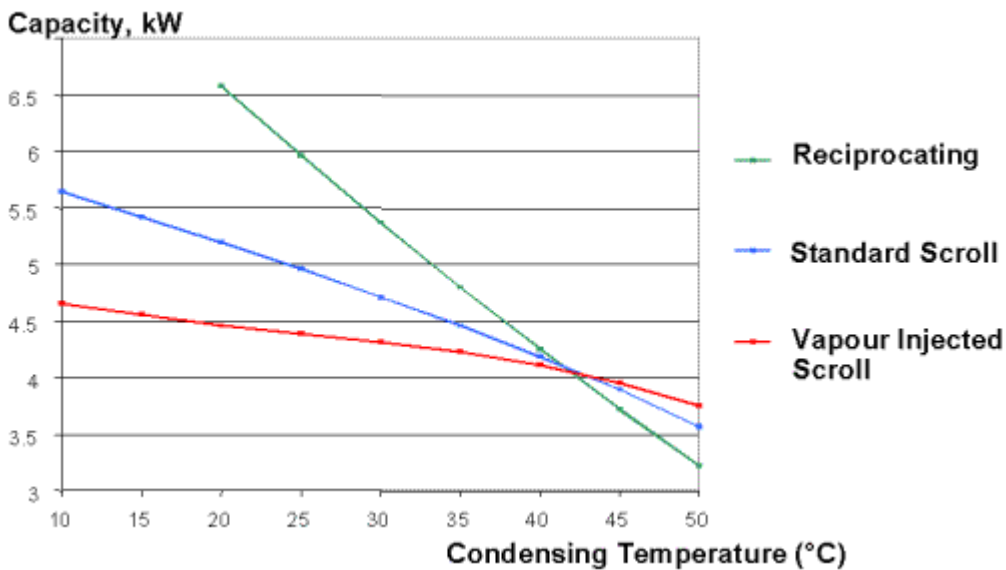


Figure 4: Capacity variation with condensing temperature, R404A

4 Operating envelope

Figure 5 shows the wide operating envelope for the VI scrolls and illustrates the marginal effect of high suction gas return temperatures.

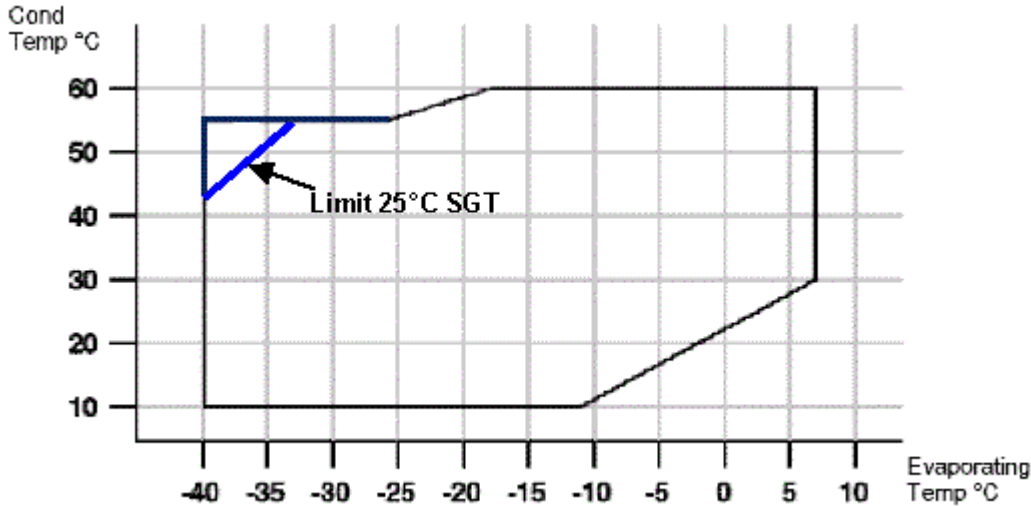


Figure 5: Operating envelope for VI Scroll with suction gas temperature 0°C showing cut off for 25°C, R404A

5 Multiple compressor systems

Multiple VI compressors can share one subcooler (HX) and Electronic Expansion Valve (EXV) as shown in Figure 6. Solenoid valves must be fitted to the individual vapour injection lines to close when the compressor is switched off. This is to avoid excessive quantities of liquid entering the compressor during standstill.

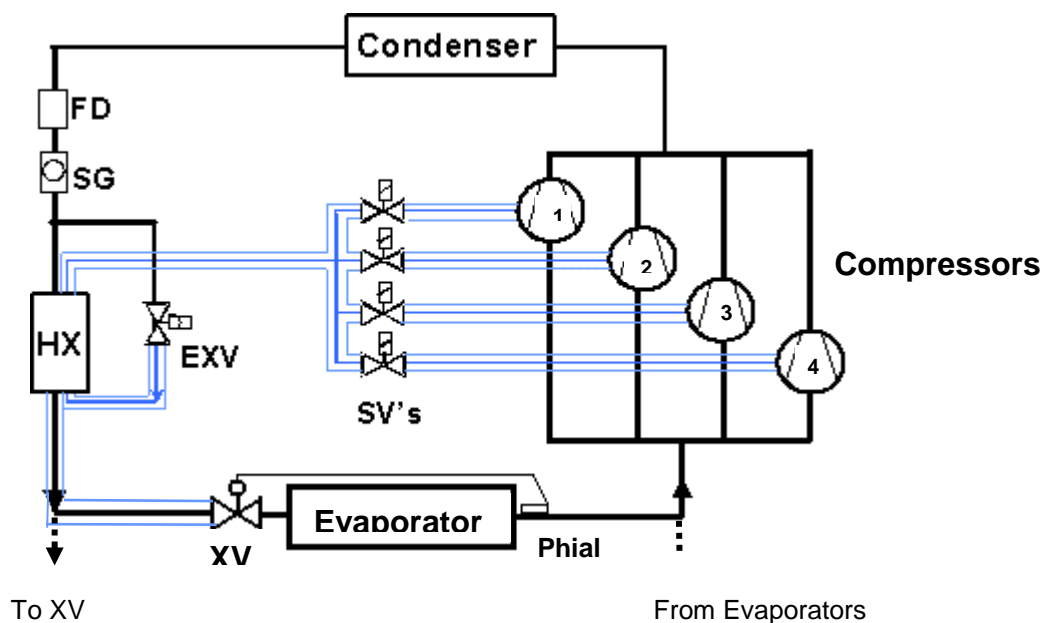


Figure 6: Arrangement for multiple compressors using one heat exchanger (HX)

6 Subcooler selection and application

The SWEP or Alfa Laval HX selection for up to 6 VI scrolls of each size is shown in tables below. This selection is based on R404A for standard conditions, -35/40°C with R404A and will be applicable to most low temperature applications.

Total number of compressors	Heat Exchanger model (SWEP)					
	ZF13KVE	ZF18KVE	ZF24KVE	ZF33KVE	ZF40KVE	ZF48KVE
1	B8T-14	B8T-14	B8T-14	B8T-20	B8T-20	B16-20
2	B8T-14	B8T-20	B16-20	B16-20	B16-30	B16-30
3	B16-20	B16-20	B16-20	B16-30	B16-30	B16-30
4	B16-20	B16-20	B16-30	B16-30	B16-40	B16-40
5	B16-20	B16-20	B16-30	B16-40	B16-40	B120T-30
6	B16-20	B16-20	B16-40	B16-40	B120T-30	B120T-30

Table 1

Total number of compressors	Heat Exchanger model (Alfa Laval)					
	ZF13 KVE	ZF18 KVE	ZF24 KVE	ZF33 KVE	ZF40 KVE	ZF48 KVE
1	AC30 - 10 EQ	AC30 - 10 EQ	AC30 - 14 EQ	AC30 - 20 EQ	AC30 - 24 EQ	AC30 - 24 EQ
2	AC30 - 14 EQ	AC30 - 20 EQ	AC30 - 24 EQ	AC30 - 34 EQ	AC30 - 40 EQ	AC30 - 40 EQ
3	AC30 - 24 EQ	AC30 - 24 EQ	AC30 - 40 EQ	AC30 - 50 EQ	AC30 - 60 EQ	AC30 - 60 EQ
4	AC30 - 30 EQ	AC30 - 34 EQ	AC30 - 50 EQ	AC30 - 60 EQ	AC70 - 30 HX	AC70 - 30 HX
5	AC30 - 34 EQ	AC30 - 40 EQ	AC30 - 60 EQ	AC70 - 34 HX	AC70 - 40 HX	AC70 - 40 HX
6	AC30 - 40 EQ	AC30 - 50 EQ	AC70 - 30 HX	AC70 - 40 HX	AC70 - 50 HX	AC70 - 50 HX

Table 2

For sizing alternative HXs or for different conditions the first step is to establish the load. This can be found using the Copeland® brand products Selection Software (see below). The liquid outlet temperature T_{LO} and saturated intermediate temperature T_{SI} can also be found from the software. The heat balance across the HX may then be used to establish the load. Please refer to **Figure 7**. For optimum performance it is best to choose 5K heat exchanger ΔT and 5K heat exchanger superheat as shown.

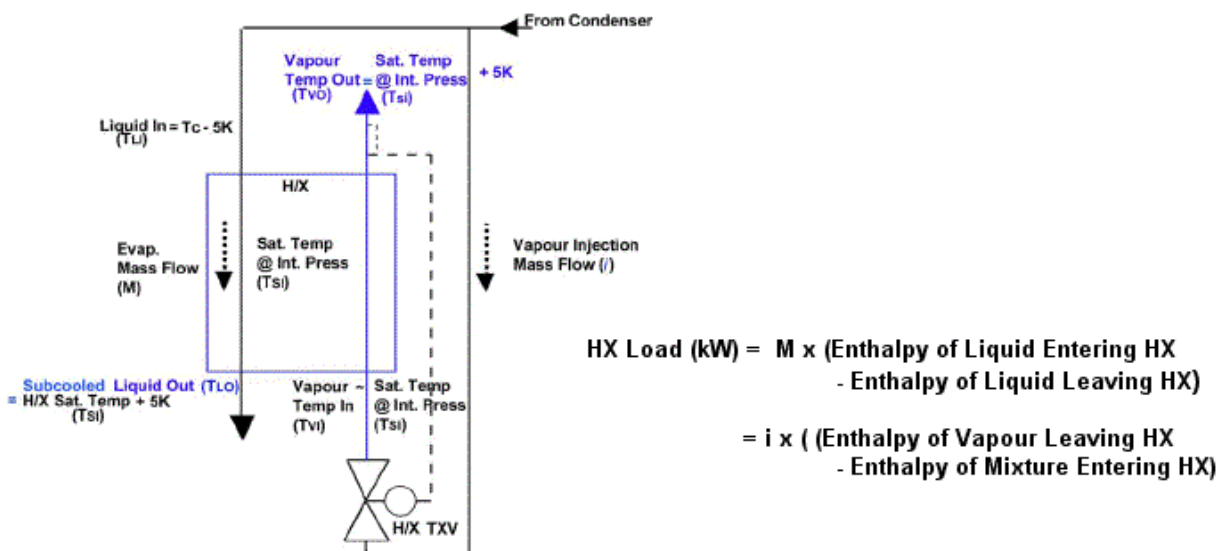


Figure 7: Heat balance method for calculating the HX load and injection mass flow rate

It should be noted that the benefit of natural subcooling, ie, condenser subcooling is limited to a maximum of approximately 5K. Further natural subcooling leads to little further reduction in liquid temperature T_{LO} . The subcooler performance is based on a temperature difference ΔT_{HX} of 5K.

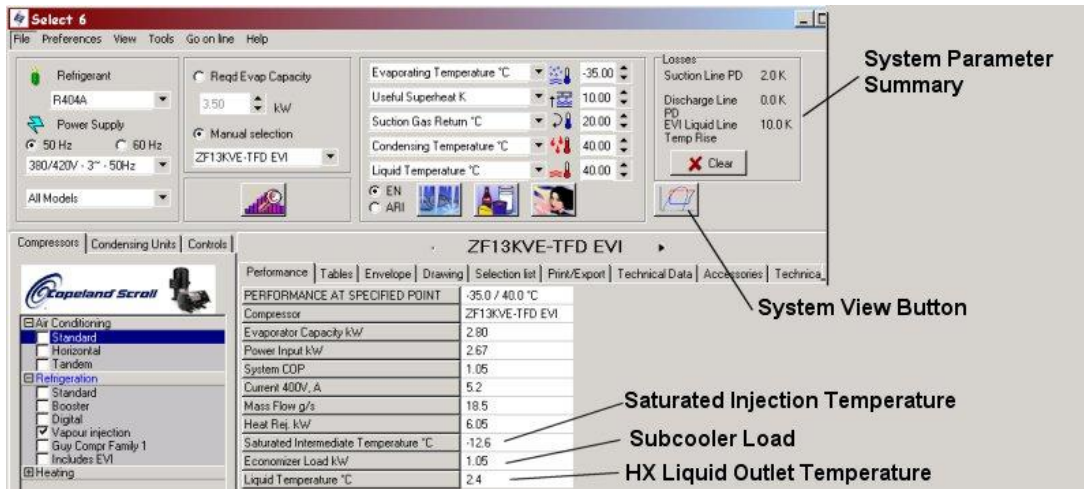


Figure 8: Selection Software screen showing HX capacity and system parameters

In the Selection Software the value of the liquid temperature T_{LO} is provided along with the subcooler load and saturated injection temperature T_{SI} . Additional system parameters are shown at the top right of the screen and these may be input and adjusted by activating the system view button. Ensure that when the system view screen appears, the “Show Vapour Injection” option is activated:

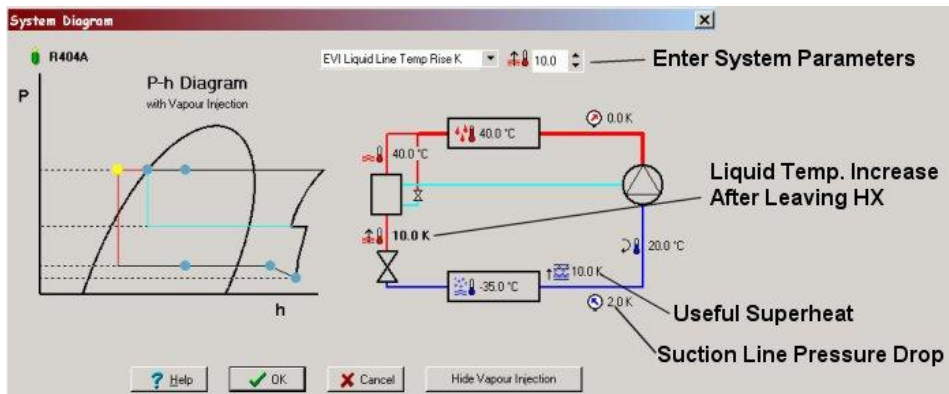


Figure 9: Selection Software screen showing HX capacity and system parameters

It is quite often necessary to make an allowance for liquid heat gain between the heat exchanger and the expansion valve. If the liquid line is routed through regions where the surrounding temperature is above the liquid outlet temperature T_{LO} there will be a rise in temperature with a corresponding small loss of system capacity. This liquid temperature increase after leaving HX (also called EVI liquid line temperature rise) can be adjusted on this screen.

Downstream extraction shown in **Figure 10(b)** refers to taking the liquid for the HX expansion device from the HX liquid exit as shown. This method is sometimes proposed to ensure good subcooling at the TXV inlet. Whilst there is no overall heat gain or loss compared to the usual upstream extraction it does mean that the injected mass flow \dot{m}_i is passing through the HX twice and incurring extra pressure drop on the liquid cooling side. This may result in the need for a larger HX. Also downstream extraction requires more connections and tubing on the subcooled liquid side all of which need to be insulated to ensure minimal heat gain. For these reasons downstream extraction is less preferable than upstream shown in **Figure 10(a)**.

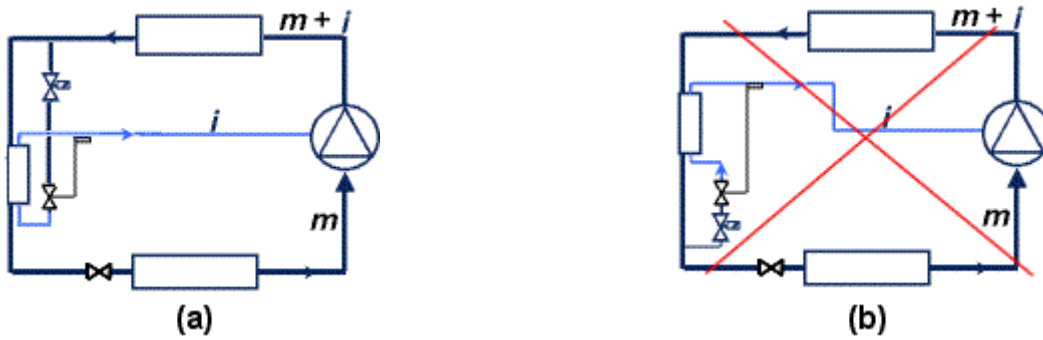


Figure 10: Liquid extraction (a) Upstream (recommended) (b) Downstream (not recommended)

The Subcooler HX must be installed vertically with the vapour entry at the bottom. The expansion valve should be connected at a distance between 150 mm and 200 mm from the vapour entry and at a position not lower than inlet connection.

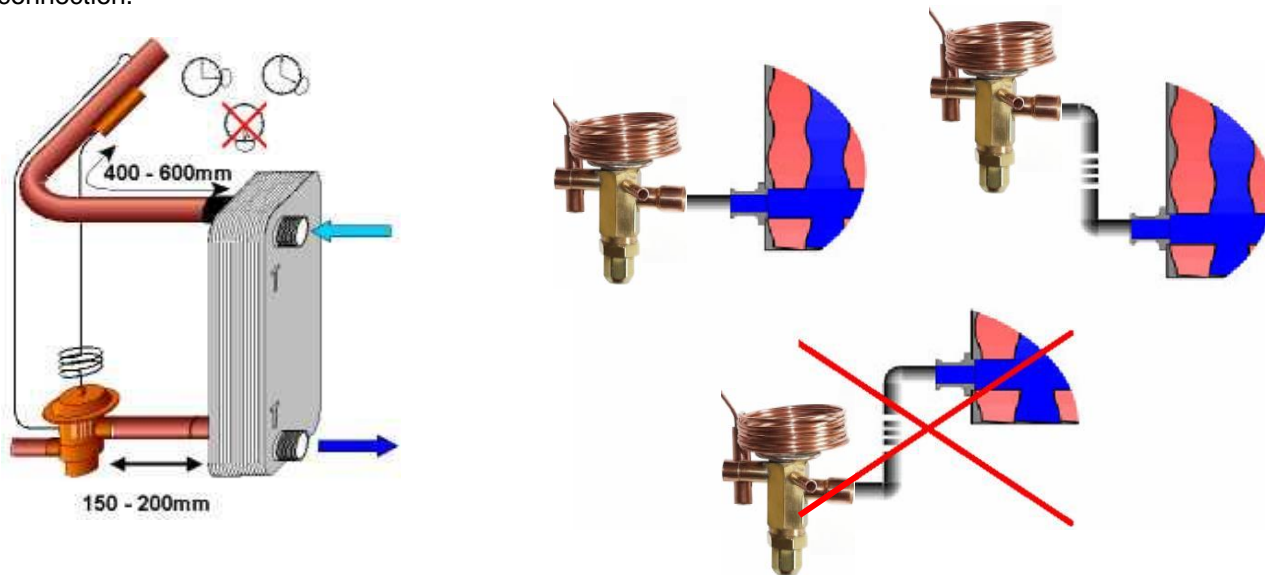


Figure 11: Position of the expansion valve and bulb when using a plate heat exchanger

Where a thermostatic valve is used the bulb of the expansion valve should be positioned 400 – 600 mm from the vapour outlet preferably after a bend and on the inside as shown on the left in **Figure 11**. The position of the bulb relative to the section of the tube is illustrated. It should not be attached underneath the tube. External equalisation is not essential. The tubing between the expansion valve and the HX entry may either be straight or include a bend as shown on the right in **Figure 11**.

For multiple compressor systems an electronic expansion valve is recommended (see below).

It is most important that the connection diameter at the entry to the HX is small enough to induce the turbulence required for uniform distribution and evaporation. **Table 3** below may be used as a guide:

Model	Vapour inlet	Vapour outlet	Liquid inlet	Liquid outlet
B8T-14	1/4"	1/2"	1/2"	1/2"
B8T-20	1/4"	1/2"	1/2"	1/2"
B16-20	1/2"	7/8"	1/2"	1/2"
B16-30	1/2"	7/8"	1/2"	1/2"
B16-40	5/8"	1 3/8"	5/8"	5/8"
B120T-30	7/8"	1 3/8"	1 3/8"	1 3/8"

Table 3

7 Liquid receiver

A liquid receiver may be necessary to accommodate charge variations over the operating condition range. It should always be fitted in the condenser outlet liquid line and not in the heat exchanger outlet liquid line. This is because vapour phase may be present in a receiver and this is only possible with saturated liquid.

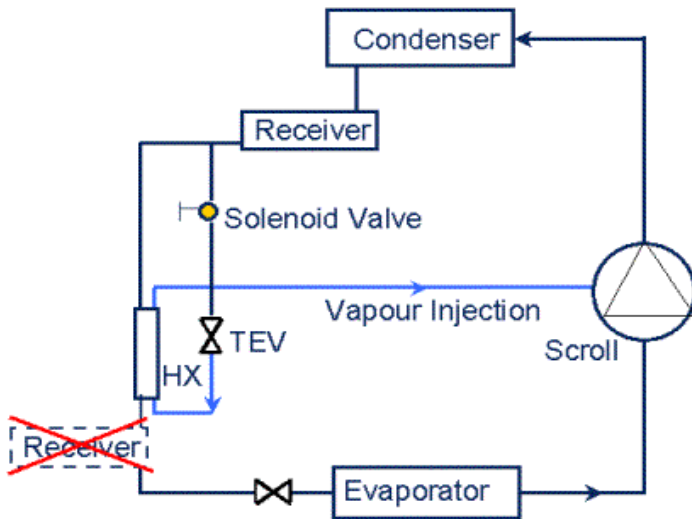


Figure 12: Where not to place the liquid receiver

8 Subcooler expansion valve and solenoid valve selection

The expansion device used in conjunction with the subcooler HX may be a TXV or an electronic expansion valve (EXV). A solenoid valve should be added if the expansion device does not completely close. This is to avoid liquid migration to the compressor during the off cycle. The solenoid valve may be in the liquid line or the vapour line. A liquid line position is usually preferred because the valve is smaller but a vapour line installation will be necessary if multiple compressors are used in parallel as shown in **Figure 6**.

Table 4 below may be used as a guide for selection of the EXV:

Total number of compressors	Electronic stepper motor valve					
	ZF13KVE	ZF18KVE	ZF24KVE	ZF33KVE	ZF40KVE	ZF48KVE
1	EX4	EX4	EX4	EX4	EX4	EX4
2	EX4	EX4	EX4	EX4	EX4	EX5
3	EX4	EX4	EX4	EX4	EX5	EX5
4	EX4	EX4	EX4	EX5	EX5	EX5
5	EX4	EX4	EX5	EX5	EX5	EX5
6	EX4	EX5	EX5	EX5	EX5	EX5

Table 4

If an EXV is used it should be a variable orifice type. Pulse modulating types are unsuitable because the internal volume of the HX is low and they will give rise to unstable operating conditions which may result in an unacceptable quantity of liquid overfeed.

TXV's can be used with multiple compressors. The recommended expansion valves together with solenoid valves appropriate for vapour lines (up to 2 compressors) are shown in **Table 5** below:

Number of compressors	Components	Thermostatic expansion valves and solenoid valves					
		ZF13KVE	ZF18KVE	ZF24KVE	ZF33KVE	ZF40KVE	ZF48KVE
1	TXV	TX3-S22	TX3-S23	TX3-S24	TX3-S24	TX3-S25	TX3-S25
	SV1	110 RB2	110 RB2	110 RB2	200 RB3	200 RB3	200 RB3
2	TXV	TX3-S24	TX3-S25	TX3-S25	TX3-S26	TX3-S27	TX3-S28
	SV1	110 RB2	110 RB2	110 RB2	200 RB3	200 RB3	200 RB3
	SV2		200 RB3	200 RB3	200 RB4	200 RB4	200 RB4

Table 5: Components

Number of running compressors	Components	Thermostatic expansion valves and solenoid valves					
		ZF13KVE	ZF18KVE	ZF24KVE	ZF33KVE	ZF40KVE	ZF48KVE
1 On 2 Off	TXV	TX3-S24	TX3-S25	TX3-S25	TX3-S26	TX3-S27	TX3-S28
	SV1	110 RB2	110 RB2	110 RB2	200 RB3	200 RB3	200 RB3
	SV2	Off	Off	Off	Off	Off	Off
1 On 2 On	TXV	TX3-S24	TX3-S25	TX3-S25	TX3-S26	TX3-S27	TX3-S28
	SV1	Off	Off	Off	Off	Off	Off
	SV2	110 RB2	200 RB3	200 RB3	200 RB4	200 RB4	200 RB4

Table 6: Example (Rack with 2 compressors)

Servo-operated solenoid valves require a minimum pressure drop of approximately 0.05 bar to remain fully open. In case of insufficient refrigerant flow this value will not be reached and the solenoid valve may close unintentionally. These closures may lead to malfunctions and oscillations in the refrigerant circuit. Improper sizing of solenoid valves, ie, use of excessively large solenoid valves is the main cause of this effect. This is particularly important in capacity controlled refrigeration circuits. Therefore the decisive factor for proper solenoid valve is the respective capacity of the valve and not its connection size.

Where more than two compressors are used it may still be possible to size thermostatic expansion valves. Special care has to be given to the selection of the TXV to allow for part load operation. Good refrigerant distribution is required in the common heat exchanger as well as sufficient velocities for oil return even at part load. Two different TXV's controlled by individual solenoid valves, may be necessary. For example one at 100% full load and the second solenoid valve for 30% of full load. (see **Figure 13**).

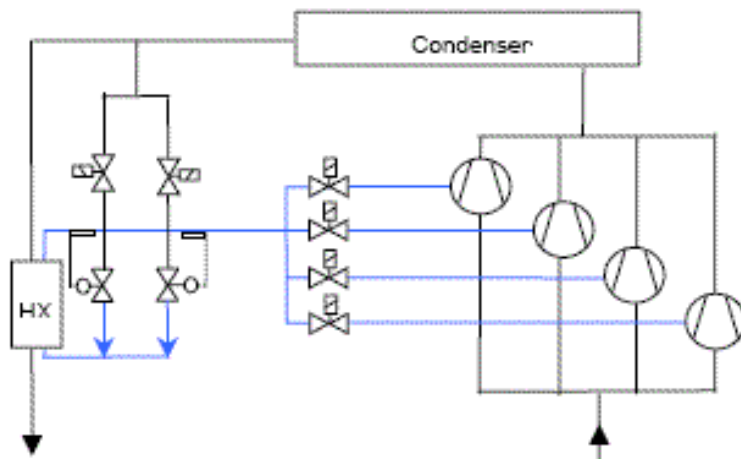


Figure 13: Control of the vapour injection superheat with two separate TXV's

9 Vapour injection header and injection line diameter

The injection line diameter should be correctly sized for vapour with minimal pressure drops if optimum performance is to be maintained. **Tables 7 & 8** below show the recommended sizes for the headers (multiple compressors) and the lines to individual compressors. These sizes should follow the size of the compressor injection connection.

Total number of compressors	Vapour injection header diameter					
	ZF13KVE	ZF18KVE	ZF24KVE	ZF33KVE	ZF40KVE	ZF48KVE
1	1/2"	1/2"	5/8"	5/8"	5/8"	5/8"
2	7/8"	5/8"	1 1/8"	1 1/8"	1 1/8"	1 1/8"
3	7/8"	3/4"	1 1/8"	1 3/8"	1 3/8"	1 5/8"
4	7/8"	7/8"	1 1/8"	1 3/8"	1 3/8"	1 5/8"
5	1 1/8"	1 1/8"	1 3/8"	1 5/8"	1 5/8"	2 1/8"
6	1 1/8"	1 1/8"	1 3/8"	1 5/8"	1 5/8"	2 1/8"

Table 7

Model	Vapour injection line diameter
ZF13KVE - TFD	1/2"
ZF18KVE - TFD	1/2"
ZF24KVE - TWD	5/8"
ZF33KVE - TWD	5/8"
ZF40KVE - TWD	5/8"
ZF48KVE - TWD	5/8"

Table 8

The diagram in **Figure 14** shows the recommended arrangement for the vapour injection with multiple compressors. The layout should be such that excessive amounts of oil do not accumulate in the header.

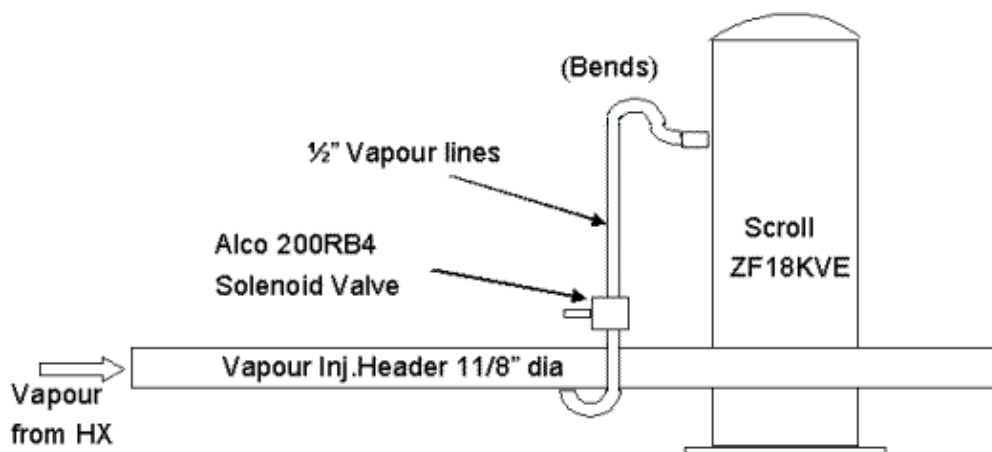


Figure 14: Example of vapour injection arrangement for five ZF18KVE scroll compressors

10 Expansion valve for main evaporator(s)

When using a thermostatic expansion valve (TXV) it must be sized taking into account the appropriate liquid subcooling and this may result in a smaller valve than would normally be the case.

11 Liquid line sizes and components

Liquid line components also need to be sized taking into account the appropriate liquid subcooling. Recommendations are shown in the following tables:

Total number of compressors	Main liquid line diameter					
	ZF13KVE	ZF18KVE	ZF24KVE	ZF33KVE	ZF40KVE	ZF48KVE
1	3/8"	3/8"	3/8"	1/2"	1/2"	5/8"
2	3/8"	1/2"	5/8"	5/8"	5/8"	7/8"
3	1/2"	5/8"	5/8"	7/8"	7/8"	7/8"
4	5/8"	5/8"	7/8"	7/8"	7/8"	1 3/8"
5	5/8"	7/8"	7/8"	1 3/8"	1 3/8"	1 3/8"
6	5/8"	7/8"	7/8"	1 3/8"	1 3/8"	1 3/8"

Table 9

Total number of compressors	Filter drier					
	ZF13KVE	ZF18KVE	ZF24KVE	ZF33KVE	ZF40KVE	ZF48KVE
1	ADK-053S	ADK-053S	ADK-053S	ADK-084S	ADK-084S	ADK-084S
2	ADK-083S	ADK-084S	ADK-084S	ADK-165S	ADK-165S	ADK-307S
3	ADK-084S	ADK-164S	ADK-165S	ADK-307S	ADK-307S	ADK-417S
4	ADK-165S	ADK-165S	ADK-307S	ADK-307S	ADK-417S	ADKS-4811T
5	ADK-165S	ADK-307S	ADK-417S	ADKS-4811T	ADKS-4811T	ADKS-4811T
6	ADK-305S	ADK-307S	ADK-757S	ADKS-4811T	ADKS-489T	ADKS-4811T

Table 10

Total number of compressors	Sight glass					
	ZF13KVE	ZF18KVE	ZF24KVE	ZF33KVE	ZF40KVE	ZF48KVE
1	MIA 038	MIA 038	MIA 038	MIA 012	MIA 012	MIA 058
2	MIA 038	MIA 012	MIA 058	MIA 058	MIA 058	MIA 078
3	MIA 012	MIA 058	MIA 058	MIA 078	MIA 078	MIA 078
4	MIA 058	MIA 058	MIA 078	MIA 078	MIA 078	AMI-2S11
5	MIA 058	MIA 078	MIA 078	AMI-2S11	AMI-2S11	AMI-2S11
6	MIA 058	MIA 078	MIA 078	AMI-2S11	AMI-2S11	AMI-2S11

Table 11

12 Line lengths and insulation

The liquid line from the HX to the expansion valve(s) needs to be well insulated. Vapour lines between both expansion devices and the heat exchangers (evaporator and subcooler) need to be kept as short as practical and well insulated. The subcooler HX should also be insulated. All lines shown in blue colour in the circuit diagrams require insulation.

Liquid line temperature rise: In many installations where the compressor(s) is (are) situated away from the evaporator(s) the liquid temperature will increase during its travel from the HX to the evaporator. Even with insulated lines this temperature rise can result in a small loss of capacity. The heat gain may be estimated by calculation methods and a typical value for liquid temperature rise is 0.7K over 10 meters when passing through areas at 20°C air

temperature. To adjust capacity for this effect in the Selection Software go to “System View => Show Vapour Injection” and enter a value for liquid temperature rise. Please refer to **Figure 9**.

13 Additional application point

13.1 Operation without vapour injection

The ZFKVE models may be operated without vapour injection to give limited capacity control.

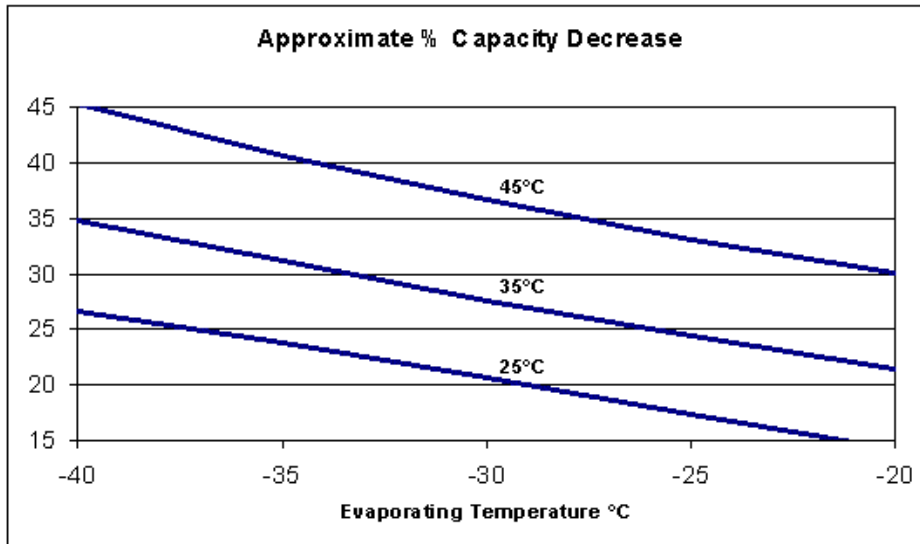


Figure 15: Chart showing approximate % capacity reduction obtained if changing to operation without VI

Figure 15 shows the approximate % capacity reduction obtained at various condensing temperatures when the vapour injection is shut off. The capacity reduction effect is limited, particularly at lower condensing temperatures, and since the COP is always higher with vapour injection it is usually preferable to maintain this mode of operation at all conditions.

13.2 Discharge temperature protection

High discharge temperature protection should always be fitted to each compressor as detailed in the application guidelines. This ensures the compressor cannot overheat in the event of loss of vapour injection cooling. It may be incorporated into the control circuit using an appropriate sensor. Some larger models have built-in protection in which case it may be desirable to install an external sensor integrated with the control circuit to avoid tripping the motor protector.

13.3 Current sensing relay

It is recommended that compressors with internal motor protection (ZF09/13/18) are fitted with a current sensing relay which is connected to close the solenoid valve in the event of motor trip.

14 Check list

Compressor Type(s): _____
 Serial Numbers: _____
 Installed by: _____
 Date Installed: _____ No of Compressors: _____
 System: _____

14.1 Saturated intermediate pressure

Check the injection pressure entering the compressor furthest from the HX. If different from design check:

- Check ΔP in the injection line ($P_{Vo} - P_{CV}$, see **Table 12** for explanation).
- Correct size T/EXV for the HX.
- T/EXV is set up correctly.
- Check ΔP in the HX. If too large check size and type of HX.

14.2 Vapour injection

The vapour injection temperature entering the compressor furthest from the HX should be 5K above the dew saturated intermediate temperature (S.I.T.). If different:

- Check ΔT across the vapour injection line ($T_{Cvi} - T_{Vo}$).
- EXV superheat is set up correctly.
- Position of sensing bulb on pipework.

14.3 Liquid temperature leaving the HX

The liquid temperature leaving the HX should be 5K above the Saturated Intermediate Pressure corresponding Temperature. Aim for circa 5K Δt at the HX = Liquid out temperature – Vapour in temperature ($T_{Lo} - T_{Vi}$). This will give efficient and economic operation.

14.4 Liquid temperature entering system evaporators

All liquid lines including liquid headers to the evaporators should be adequately insulated.

Check the liquid temperature entering the system expansion valves furthest from the HX. The temperature entering the evaporators should be within the end users specification for subcooled liquid lines.

14.5 Plate heat exchanger / Vapour injection solenoid valve operation

The function of the vapour injection solenoid valve is to control injection of the vapour into the compressors. When the compressor stops the solenoid should close stopping injection into the compressor. However, this should not affect the operation of the HX TEV's controlling the saturated intermediate pressures and temperatures.

To ensure this operation works satisfactory the following procedure is recommended, referring to the example in **Figure 16** using 4 compressors **with all of the compressors running**:

- Stop compressor No. 1:
 - Ensure compressor No.1 vapour injection solenoid valve stops the vapour injection into the compressor by checking the vapour injection pressure.
 - Check the liquid-in temperature to the HX (T_{Li}) and (T_{Lo}) the subcooled liquid-out temperature has not changed significantly. $HX \Delta T_{SC} = (T_{Li} - T_{Lo})$.
- Stop compressor No. 2, repeat checks for compressor No. 1 with compressor No. 2.
- Stop compressor No. 3, repeat checks for compressor No. 1 with compressor No. 3.
- Compressor No. 4 is still running.

LOCATION OF READING		SCROLL VI COMPRESSORS			
Compressor Configuration (e.g. 1 & 2, 1, 2, 3 & 4 etc.)					
Compressor	T_{Ci} - Temp. Inlet	$^{\circ}C$			
Compressor	P_{Ci} - Press. Inlet	Bara			
Compressor	T_{Co} - Temp. Outlet	$^{\circ}C$			
Compressor	P_{Co} - Press. Outlet	Bara			
Compressor	T_{Cvi} - Vapour Injection Inlet	$^{\circ}C$			
Compressor	P_{Cvi} - Vapour Injection Inlet	Bara			
Δp across VI line	ΔP - Difference ($P_{Cvi} - P_{vo}$)	Bar			
Compressor	P_I - Power Input	Kw			
Compressor	A - Current	Amps			
Subcooler (HX)	T_{Li} - Temp. Liquid Inlet	$^{\circ}C$			
Subcooler (HX)	T_{Lo} - Temp. Liquid Outlet	$^{\circ}C$			
Δt across HX	ΔT_{SC} - Subcooling thro' HX ($T_{Li} - T_{Lo}$)	K			
Subcooler (HX)	T_{vi} - Temp. Vapour Inlet	$^{\circ}C$			
Subcooler (HX)	P_{vi} - Press. Vapour Inlet	Bara			
Subcooler (HX)	T_{vo} - Temp. Vapour Outlet	$^{\circ}C$			
Subcooler (HX)	P_{vo} - Press. Vapour Outlet	Bara			
XV*	This valve is not shown on the diagram below				
XV*	T_{XVli} - Temp. Liquid Line entering XV	$^{\circ}C$			
XV*	T_{XVvo} - Temp. Entering Evaporator	$^{\circ}C$			
XV*	T_{XVp} - Temp. XV Bulb	$^{\circ}C$			
Δt across Evap.	$\Delta T - T_{XVp} - T_{XVvo}$	K			
XV*	Press. at XV Bulb	Bara			

Table 12

14.6 Arrangement for multiple scroll vapour injection compressors

Readings taken at compressor No. 1 below should also be taken for compressors No. 2, 3 & 4 if in situ.

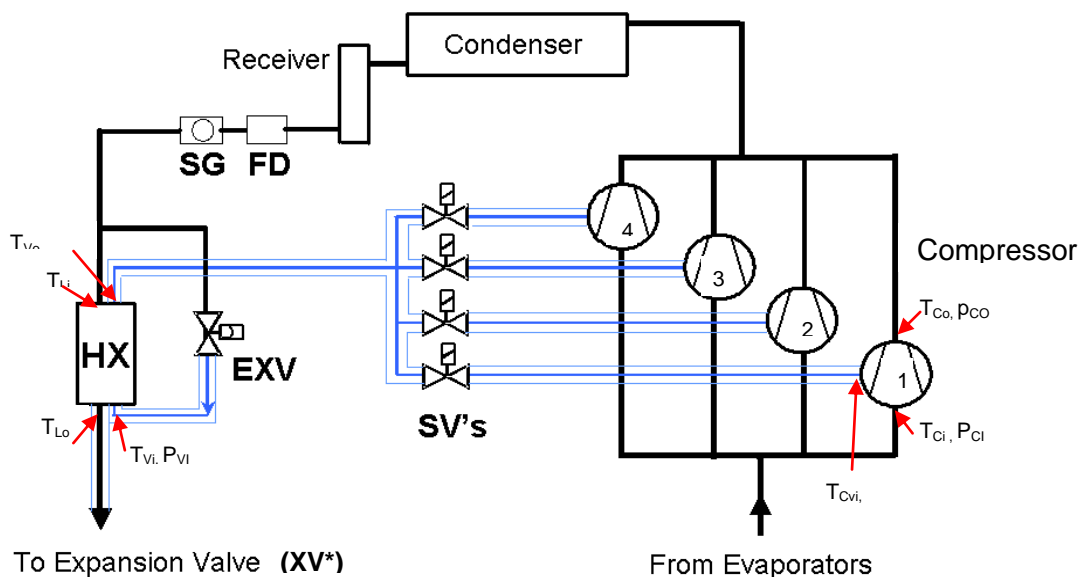


Figure 16