

PERFORMANCE IMPROVEMENTS IN COMMERCIAL REFRIGERATION WITH VAPOUR INJECTED SCROLL COMPRESSORS

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Enhancing system performance through a type of mechanical subcooling known as an economised or vapour injection cycle is relatively well known in advanced vapour-compression system applications, especially for low-temp refrigeration [1]. Traditionally this feature has only been available on large commercial screw compressors or requires two separate semi-hermetic reciprocating compressors. The advent of the vapour-injected scroll compressor, which can accommodate mid-pocket inter-stage injection, enables the economised cycle within one compressor. This paper describes the economised vapour injection scroll compressor cycle concept, its key components, and associated performance and application aspects for commercial refrigeration systems.

PRINCIPLE

The vapour-injected scroll compressor cycle is similar to a two-stage cycle with interstage cooling, but accomplished with a single compressor as shown in Figure 1. The high stage is accomplished by extracting a portion of the condenser liquid and expanding it through an expansion valve into a counterflow brazed-plate heat exchanger acting 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 its inlet enthalpy [2].

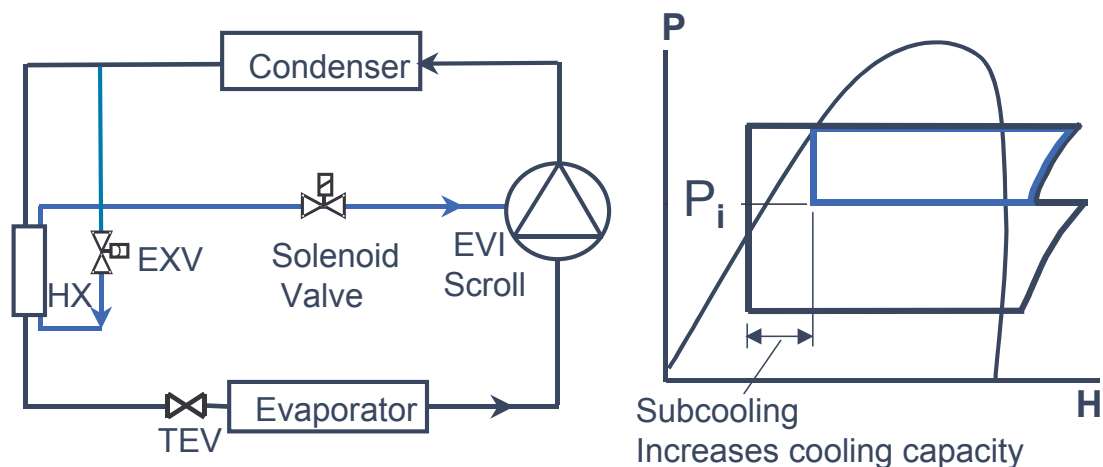


Figure 1: Vapour-injected scroll compressor cycle

Figure 2 shows the injection ports located symmetrically in the scroll compression path as well as the upper part of the compressor where it can be seen the injection tube from the shell injection port to the scroll set.

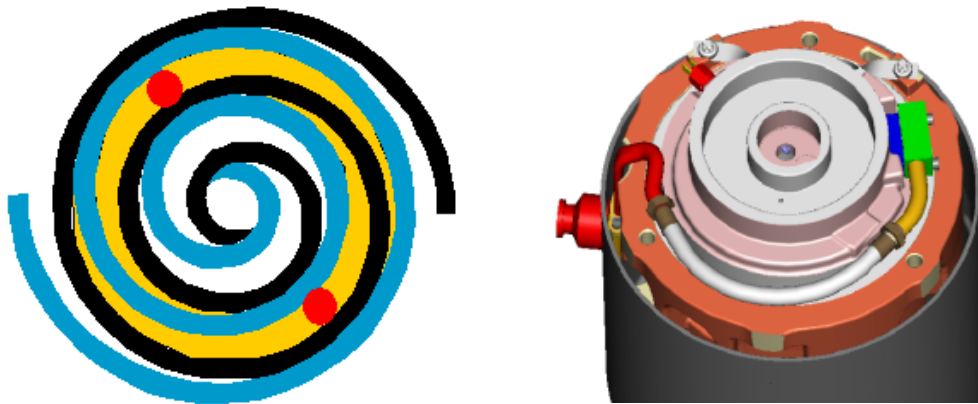


Figure 2. Vapour-injected scroll compressor

Capacity gain

Since the added capacity achieved by enhanced subcooling provides higher enthalpy gain across the evaporator, the compressor displacement required can be reduced by the percentage enthalpy gain for the same evaporator capacity.

This reduction in displacement can provide a means for capacity modulation at lower loads by turning off the vapour injection circuit using a liquid-line or vapour-line solenoid. This performance gain is much more significant than the passive liquid-suction heat exchanger, increases with pressure ratio, and fits well to HFC R404a.

COP gain:

The vapour-injected scroll compressor cycle efficiency is higher than the conventional single-stage 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.

PERFORMANCES

Figure 3 shows an example (from [3]) of percentage capacity and COP gains for a R404a vapour-injected scroll compressor versus a conventional single-stage at the low temperature (-35/40°C) reference conditions EN12900. As can be seen there is a significant gain of +45% capacity and +27% COP. This puts the vapour-injected scroll compressor into a position where it outperforms the efficiency of the best reciprocating compressor on the market.

Also, this gain in percentage term is significantly higher in actual systems since the base evaporator delta h is smaller with the evaporating outlet return gas temperature being much smaller than 20°C (Figure 4).

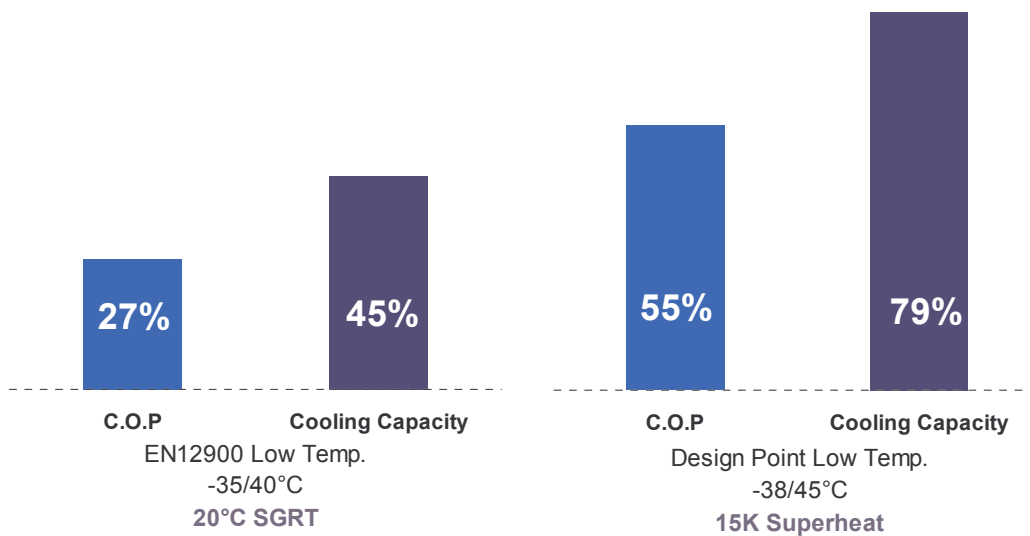


Figure 3

Figure 4

In addition to the performance gain, there are other benefits:

1. Injection of vapour provides sufficient cooling to maintain the same operating envelope as the one obtained with injection of liquid but at much better efficiency
2. It offers a means to modulate compressor capacity with varying load requirements.
3. Liquid lines and thus refrigerant charge can be reduced thanks to reduced mass flow rate with the higher enthalpy across the evaporator.
4. Suction line pressure drop is reduced compared to conventional cycle delivering the same capacity since the suction flow is reduced with the higher enthalpy across the evaporator. The suction line pressure drop reduction can be significant since it is proportional to the square of the flow. For example, a 40% reduction in flow would reduce suction line pressure drop by 64%.

LOAD AND COMPRESSOR CAPACITY

Scroll compressors do have the general advantage over traditional semi-hermetic reciprocating compressors that capacity varies less with the pressure ratio, i.e. with the condensing temperature or ambient temperature or at fixed evaporating conditions. This is due to a rather constant volumetric efficiency (no clearance volume re-expansion) compared to reciprocating compressors [4]. With vapour injected scroll, this becomes even more of an advantage, as the subcooling effect reduces with lowering condensing temperatures. Consequently, the cooling capacity remains even more constant with varying condensing temperature conditions compared to reciprocating compressors, as expressed on Figure 5. This means a better match of the load and the capacity at floating condensing temperature.

Moreover, as the ambient temperature decreases, the reciprocating compressor efficiency will decrease due to low pressure ratio (high flow) through valves optimised at higher pressure ratio (Figure 6). In addition to that effect, keep in mind that reciprocating compressors will need capacity modulation due to excessive capacity which turns in supplementary COP losses.

The resulting benefits can be summarised as follows:

- During winter operation there will be less excess cooling capacity translating into modulation of the compressors with the associated benefits in terms of ease of control, reliability and energy consumption. Limited part load operation leads to a more constant refrigerant flow in the suction line that ensures a better oil return to the compressors.
- Under summer conditions where ambient temperatures reach high values, there will be less danger of capacity shortfall and loosing the frozen goods.

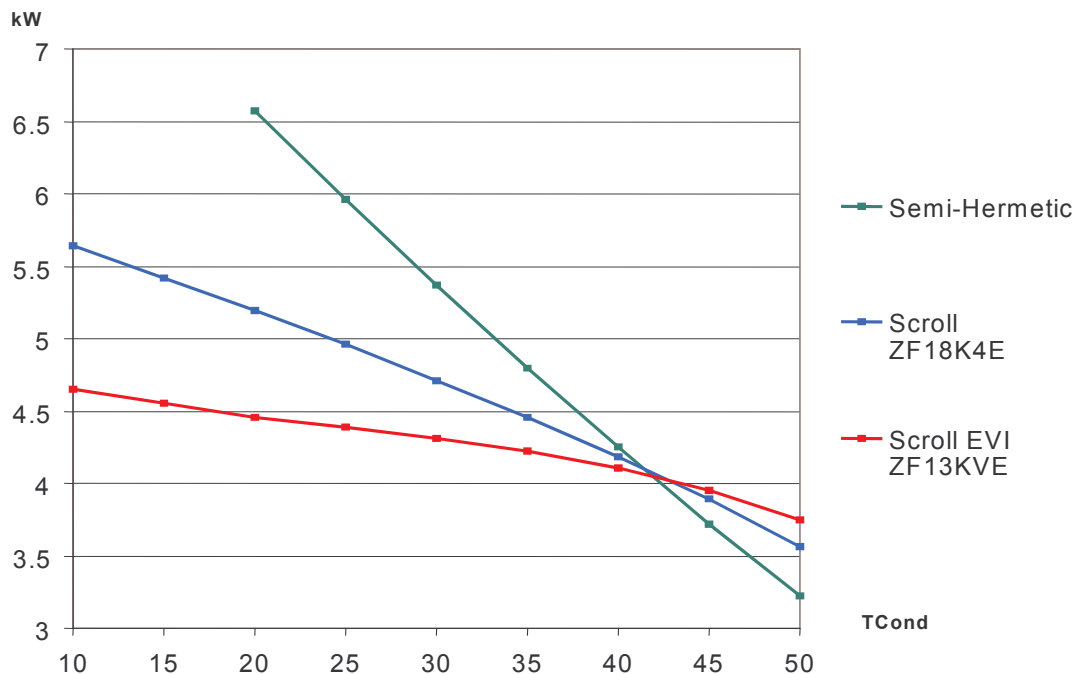


Figure 5: Comparison of the capacity of a piston, a scroll and a vapour injected scroll compressor with varying condensing temperature. Cooling capacity: 4 kW at EN12900 conditions

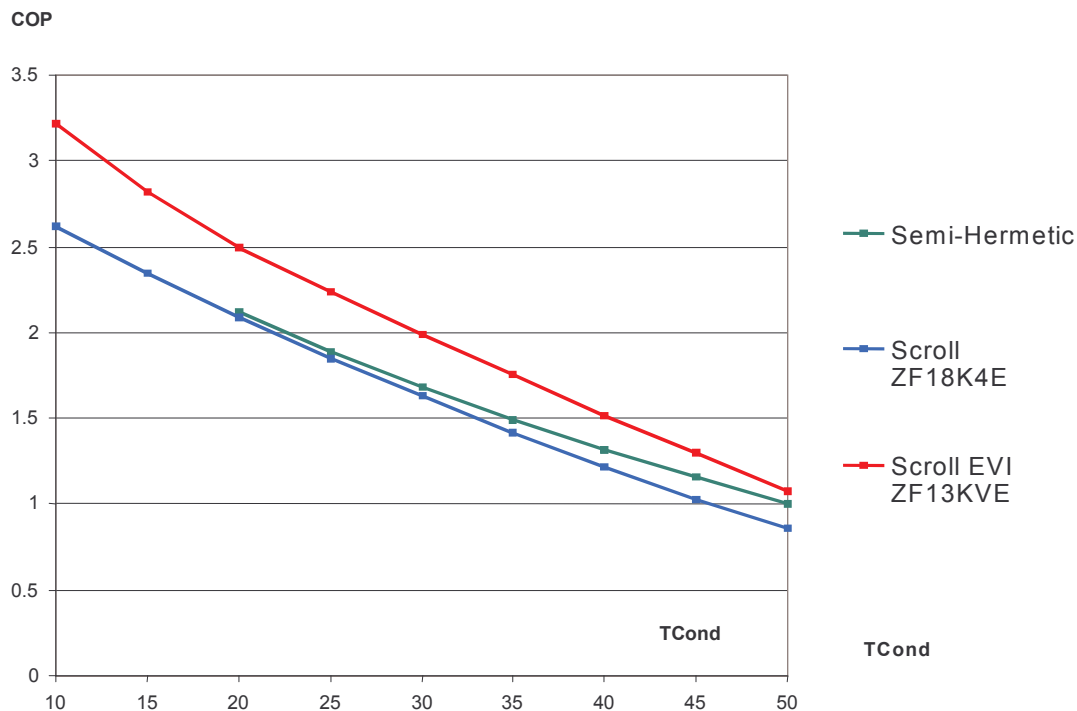


Figure 6: Comparison of the COP of a reciprocating, a scroll and a vapour injected scroll compressor with varying condensing temperature.

SYSTEM DESIGN

In standard refrigeration systems, compressors for medium and low temp. applications are installed. Very often, a subcooler powered by the MT (medium temperature) compressors subcools the liquid refrigerant of the LT (low temperature) circuit.

This helps in general to save about 3 to 8% over systems without subcooler, depending on the size of the subcooler. The MT compressor pack has of course to be designed to carry away the additional load from the subcooler, on the other hand the LT pack may become smaller. The overall cost of the 2 packs plus the subcooler exceeds in general the cost of two separate packs, but due to lower operating cost, a payback of less than 2 years can be achieved.

However, the vapour injection in the LT compressor does also use a subcooler to improve the efficiency, different to the systems setup as described above, the medium temp. pack does not need to be increased in capacity, hence no increase in cost either.

Figure 7 shows a schematic of a typical multi-compressor rack application in a supermarket that uses a mechanical sub-cooler between the MT and LT circuit. The disadvantage is that the LT rack requires an additional compressor on the MT rack to provide the extra capacity generated in the mechanical sub-cooler (expressed in orange). In addition, the low temperature compressors may require liquid injection.

Figure 8 shows the same application with vapour injected scroll compressors on the LT rack. Both circuits operate independently which improves the reliability of the system. The additional compressor on the MT rack (colour coded in orange in Figure

7) is no longer needed resulting in substantial cost improvements in the overall installation. Vapour injection substitutes liquid injection on the LT rack.

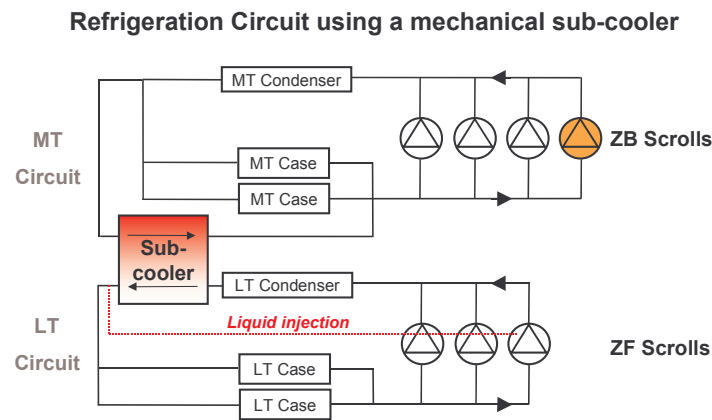


Figure 7: Conventional compressor racks using a mechanical sub-cooler between the medium and low temperature circuits

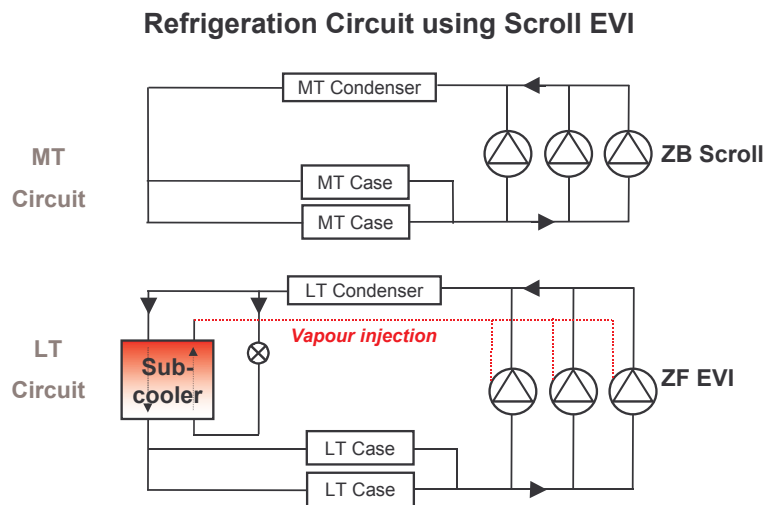


Figure 8: Compressor racks using a Copeland Scroll TM EVI for the low temperature circuit

CONCLUSIONS

Vapour-injected scroll compressors offer a versatile means of extending capacity and efficiency while improving the operating envelope for compressors in commercial refrigeration applications.

Moreover, this paper has analysed what this technology can also bring:

1. offers a means to modulate compressor capacity with varying load requirements.
2. liquid lines and thus refrigerant charge can be reduced thanks to reduced mass flow rate with the higher enthalpy across the evaporator.
3. suction line pressure drop is reduced compared to conventional cycle delivering the same capacity
4. less excess cooling capacity during winter operation translating into less modulation of the compressors with the associated benefits in terms of ease of control, reliability and energy consumption.
5. limited part load operation leads to a more constant refrigerant flow in the suction line that ensures a better oil return to the compressors
6. less danger of capacity shortfall and loosing the frozen goods under summer conditions where ambient temperatures reach high values
7. both circuits MT and LT operate independently which improves the reliability of the system.

REFERENCES

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