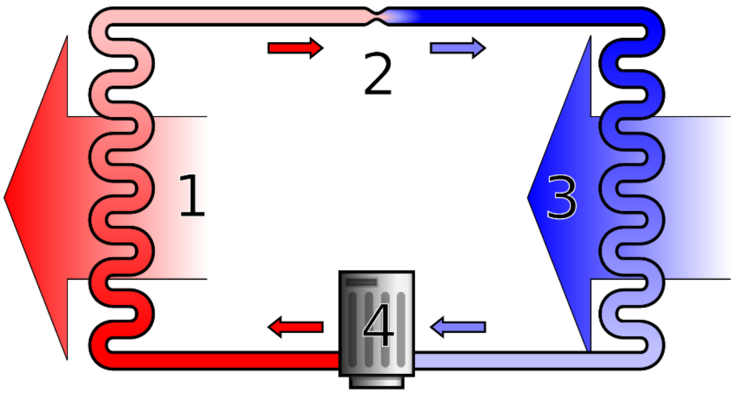


'Operating at very low temperatures requires special solutions.'

Food and Beverage sector
TRL 9

Refrigerant cycle

Operating at very low evaporation temperatures (e.g. when providing cooling for a deep-freezer and still using ambient air as a heat sink for the condenser) often requires special system solutions.

Low-temperature evaporation requires low evaporation pressures while the condensing pressure is at normal levels. It is often beneficial, and in some cases necessary, to separate the evaporation and condensing pressure levels by more than one compressor step. This is because when the pressure ratio over the compressor increases, the discharge temperature out of the compressor will also increase. Simultaneously, the compressor efficiency decreases, which increases operating costs and energy consumption. High discharge temperatures may cause both the refrigerant and the lubrication oil to decompose. This in turn could shorten the life of the compressor.

Main NEBs (Other benefits)

Increased equipment life
Refrigeration at different temperature levels

The "classic" refrigerant cycle

As a reminder, in a classic one-stage cycle, the refrigerant is transformed and exchanges heat by flowing through 4 main components:

- **Evaporator:** the refrigerant enters into the evaporator as a low-pressure liquid and then expands, absorbs heat, and evaporates, changing to a low-pressure gas at the evaporator outlet.
- **Compressor:** the compressor pumps this gas from the evaporator through the accumulator, increases its pressure, and discharges the high-pressure gas to the condenser.
- **Condenser:** in the condenser, heat is removed from the gas, which then condenses and becomes a high-pressure liquid.
- **Expansion device:** between the condenser and the evaporator an expansion device is located. The flow of refrigerant into the evaporator is controlled by the pressure differential across the expansion device or, in the case of a thermal expansion valve, by the degree of superheat of the suction gas.

The limitations of a single stage vapour compression system

Hence, a single stage vapour compression refrigeration system has one low side pressure (evaporator pressure) and one high side pressure (condenser pressure).

The performance of single stage systems shows that these systems are adequate as long as the temperature difference between evaporator and condenser (temperature lift) is small.

However, there are many applications where the temperature lift can be quite high, in particular when the required evaporator temperature is very low. For example, in frozen food industries where the required evaporator can be as low as -40°C.

As the temperature lift increases, the single stage systems become inefficient and impractical. For a given condenser temperature, as evaporator temperature decreases:

- Throttling losses increase
- Superheat losses increase

- Compressor discharge temperature increases
- Quality of the vapour at the inlet to the evaporator increases
- Specific volume at the inlet to the compressor increases

The assets of multi-stage systems

As a result of this, the refrigeration effect decreases and work of compression increases. Due to these drawbacks, single stage systems are not recommended when the evaporator temperature becomes very low (or when the condenser temperature becomes high). In such cases multi-stage systems are used.

In practice, for fluorocarbon and ammonia-based refrigeration systems, a single stage system is generally used up to an evaporator temperature of –30°C. A two-stage system is used up to –60°C and a three-stage system is used for temperatures below –60°C.

Apart from high temperature lift applications, multi-stage systems are also used in applications requiring refrigeration at different temperatures. For example, in a dairy plant refrigeration may be required at –30°C for making ice cream and at 2°C for chilling milk. In such cases it may be advantageous to use a multi-evaporator system with the low temperature evaporator operating at –30°C and the high temperature evaporator operating at 2°C

Two-stage system

A two-stage system is a refrigeration system working with a two-stage compression and mostly also with a two-stage expansion. Flash gas is separated from liquid refrigerant in an intermediate receiver between the two expansion valves. The high-stage compressor will then remove the flash gas. The removal of the gas between the expansion stages reduces the quality of the refrigerant vapor that enters the evaporator. Each mass unit of refrigerant passing through the evaporator will then be able to absorb more heat, reducing the required refrigerant mass flow rate for a given cooling capacity. This in turn reduces the required low-stage compressor size. Because of the enhanced heat transfer coefficient in the evaporator, the heat transfer area needed is also reduced.

Intercooler

An intercooler system uses an intermediate evaporation step to cool the discharge gas from the first compressor step.

The refrigerant liquid leaving the condenser is split into two streams. The smaller part of the liquid is fed through an intermediate expansion valve, and then allowed to evaporate on one side of the intercooler. The main flow is sub-cooled by leading it through the other side of the intercooler. The sub-cooled refrigerant liquid leaving the intercooler is fed through the main expansion valve and then through the main evaporator.

The sub-cooling decreases the inlet vapor quality, which reduces the refrigerant mass flow rate through the evaporator and the required low-stage compressor size for a given cooling capacity. This results in efficient gas cooling. The discharge gas from the high stage compressor can be kept at an acceptable temperature, and the compressor efficiency is increased.

Cascade systems

The cascade system consists of two separate refrigeration circuits connected only by an intermediate cascade heat exchanger. The high-temperature circuit is cooled by an air condenser at ambient temperature, and uses the cascade heat exchanger as the system evaporator. The low-temperature system produces the low-temperature cooling in the cold evaporator, and uses the cascade exchanger as a condenser. The cascade heat exchanger connects the two refrigerant circuits thermally by acting simultaneously as an evaporator and a condenser.

The primary advantage of a cascade system is that the two stages do not necessarily contain the same refrigerants. A refrigerant with a higher vapor pressure can be used in the low-temperature system, while a refrigerant with a lower vapor pressure is suitable for the high-temperature system.

Multi-stage refrigeration cycles can also achieve very low temperatures efficiently, but there are some major disadvantages compared with the cascade cycle. In multi-stage refrigeration, the same refrigerant must work at the highest and the lowest pressure levels. The selection of refrigerant to avoid excessively large pressures in the ambient condenser, and evaporation pressures below one atmosphere in the cold evaporator, can be difficult.

Opportunities and barriers to implementation

Opportunities	*Barriers*
Increased equipment life	Additional cost for adding a new system
Refrigeration at different levels of temperature	
Temperature difference between evaporator (low temperature) and condenser (high temperature) is higher	
Increased compressor efficiency	
Lower operating costs and energy consumption (electricity, gas)	

References

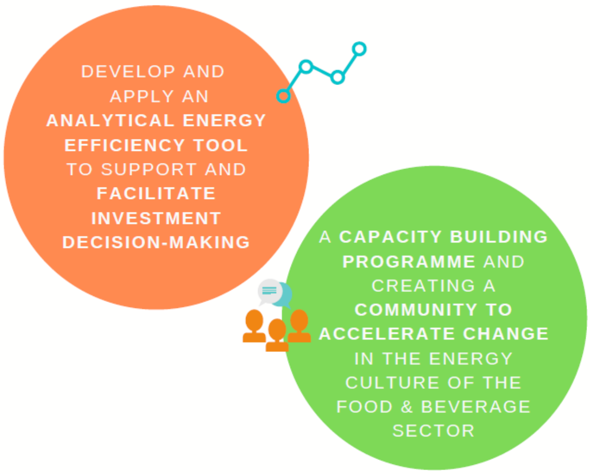
[1] Multi-Stage Vapour Compression Refrigeration Systems Version 1 ME, IIT Kharagpur
[2] SWEP Refrigeration handbook – Low temperature systems

About ICCEE

The project ICCEE, www.iccee.eu, funded by the EU programme Horizon 2020, aims at improving energy efficiency in the cold chain of the food & beverage sector and making it easier for the sector to:

- undertake energy efficiency measures across the entire supply chain and
- accelerate the implementation of energy audit results.

ICCEE follows a holistic approach that moves from a single company perspective to the assessment of the entire cold supply chain. Existing financing schemes for SMEs will be assessed: the optimal ones will support the implementation of energy efficiency measures. ICCEE objectives build on 2 pillars:



The ICCEE project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement no. 847040.