How-80°C works

Froilabo's flagship products, very low temperature freezers are available in two different ranges, the TRUST and the EVOLUTION. The only visible difference between these two ranges is their user interface. The technique for generating cold and the cooling unit is the same. Have you ever wondered how your freezer works? Through which processes it's possible to reach a temperature as low as -80°C? If so, this article was made for you!

There are three decisive elements that allow us to lower the temperature to -80°C. The first is the use of refrigerants that allow us to control the temperature drop. Then, knowing how the cooling unit of a freezer works is essential. Finally, such a technical challenge is possible thanks to good insulation to optimise performances of our freezers.

- Why invest in a -80°C freezer?

The objective is the conservation and long-term storage of different types of organic or inorganic samples that would degrade or be too active at room temperature. The so-called "normal" freezing, around -20°C, does not allow the long-term conservation of biological samples because some organisms remain slightly active at this temperature.

- What role do refrigerants play when the temperature drops?

Refrigerants are chosen according to the operating temperatures of the two exchangers involved in the refrigeration circuit: the condenser and the evaporator. The fluids used to obtain low temperatures are different from air conditioning fluids for example.

What is a refrigerant?

A refrigerant can be pure or a mixture of pure fluids. It can be present in different states: liquid, gaseous or both, depending on the temperature or pressure.

Refrigerants are substances used for their thermodynamic properties in cooling systems (air conditioning, freezer, refrigerator) or heat production systems (heat pump). These substances are used via the principle that any change of state leads to the release or consumption of energy. From a chemical and thermodynamic point of view, energy is needed to disorganize matter, so the molecules are spaced apart (liquid to gas), whereas the bringing together and organization of the molecules (gas to liquid) releases energy. To sum up, during physical transformation:

- To pass from the liquid state to the gaseous state, external energy is needed.
- The transition from the gaseous to the liquid state releases energy.

These properties can thus be exploited in a compression and expansion cycle to produce cold or heat.

Refrigerants are selected according to:

- Their evaporation temperature, generally rather low.
- Pressures related to the change of physical state.
- The amount of energy they can absorb.

There is a wide variety of different fluids on the market. IUPAC (International Union of Pure and Applied Chemistry) lists more than 320 different ones.

These refrigerants have a specific nomenclature. Each fluid is assigned a nomenclature consisting of the letter R (for "refrigerant") followed by a 2 to 5 digit/letter code that corresponds to its molecular structure.

There are different categories of refrigerants, differentiated by their chemical composition:

- Chlorofluorocarbons (CFCs)
- Hydrochlorofluorocarbons (HCFCs)
- Hydrofluorocarbons (HFCs)
- Perfluorocarbons (PFCs) or Perfluorinated Hydrocarbons (PHFCs)
- Hydrocarbons or organic compounds that do not fall into the above-mentioned categories
- Inorganic compounds such as ammonia
- So-called "natural" fluids such as CO2
- Hydrofluoroolefins (HFO) or Hydrofluoroalkenes

CFCs and HCFCs, which are chlorinated gases, deplete the ozone layer and are powerful greenhouse gases. They are regulated by the Montreal Protocol, ratified on 16 September 1987. CFCs, such as Freon 12, are no longer used today. HCFCs have been banned from the market since 1 January 2015 by Regulation *1005/2009/EC*[1]. This measure concerns all fluids, whether virgin or recycled.

HFCs, unlike CFCs and HCFCs, don't contain chlorine. They have no effect on the ozone layer but do contribute to the greenhouse effect and are, in fact, regulated by the Kyoto Protocol, ratified on 11 December 1997. This issue is at the origin of the new European F-Gas regulation which came into force on 1 January 2015, according to regulation n° *517/2014*[2]. The aim of this regulation is to limit greenhouse gas emissions in the context of the fight against global warming. These fluids are classified according to their GWP and all the standards aim to authorize only gases with a reduced GWP.

A solution to HFCs can be found in so-called natural fluids such as CO_2 (GWP = 1), also known as R744. As its use is relatively restrictive (high pressure), it has been preferred to use other natural fluids, such as hydrocarbons (such as propane, also called R290) that have excellent thermodynamic properties but are flammable. At Froilabo, our products are now available in standard and natural gas versions.

Another family of refrigerants is now being developed: HFOs. These fluids have the advantage of having a low GWP and energy efficiency comparable to HFCs. But, at the moment, they are not compatible with our cold applications. These fluids are very similar to HFCs but have a double bond that allows them to be less stable in the atmosphere and have a shorter lifetime, and therefore a lower GWP. However, this double bond does give them a certain flammability.

The main idea of the current transitional period is to find alternatives to all existing gases. The aim being to reduce the overall impact of cold generating appliances while maintaining high performance. These fluids are at the heart of the problems of all manufacturers using them for their applications.

- <u>What role does the cooling unit play in the temperature decrease until -80°C?</u>

There are currently two types of cold: mechanical cold which will be discussed here. And cryogenic cold which uses gases such as CO_2 (T_b = -78.5°C, at 1atm), N_2 (T_b = -195.8°C, at 1atm) or He (T_b = -269°C, at 1atm) to cool the samples.

[1] Regulation n°1005/2009 of 16/09/09 relative to substances depleting the ozone layer
[2] Regulation (EU) n°517/2014 of 16/04/14 on fluorinated greenhouse gases and repealing Regulation (EC) n°842/2006 (N°517/2014, published in the Official Journal of the European Union on 20 May 2014)

For mechanical refrigeration, refrigerants are used because they have special physical properties, such as the ease of changing state at low pressures and low temperatures, which is necessary for the operation of the refrigeration unit.

The concept of the cooling unit is not recent and dates back to the middle of the 19th century thanks to Lord Kelvin: a refrigerant circulates in a closed loop and changes state easily under the influence of pressure.

Seemingly simple, an ultra-low temperature freezer meets the various technical challenges involved in its design but reaching temperatures of -80°C is a real challenge.

A basic refrigeration system consists of 4 elements (*figure 1*) responsible for cold production:

The evaporator: it contains the refrigerant at normal atmospheric pressure P1; the liquid vaporizes, so energy is required. This energy is taken from the interior of the freezer. The internal air and the samples present are therefore cooled. The evaporator is the main component in the refrigeration process.

The compressor: in the compressor, the pressure of the fluid becomes P2 > P1. The fluid is always gaseous, and its temperature rises to T2 > T1.

The condenser: in the condenser, the gas cools in contact with the ambient air, which causes the gas to liquefy (change from a gaseous state to a liquid state): this releases calories, and therefore heat (this explains why the back of the refrigerator is hot).

The expansion valve: it allows the pressure of the refrigerant liquid to be lowered to its initial value (P1). The pressure drops, so the temperature drops as well.

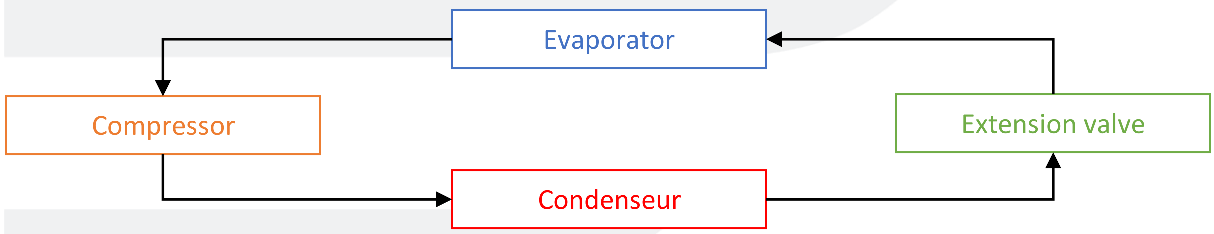


Figure 1: Simplified diagram of a refrigeration circuit

The first challenge concerns the creation of cold itself. There are in fact several freezing systems: cascade double compressors, independent double compressors and Stirling engine. These are the main ones used worldwide. We will discuss here with the system used at Froilabo, the double compressors in cascade.

The system consists of two hermetic circuits (one "high temperature" and one "low temperature" circuit) connected by a plate heat exchanger. This plate heat exchanger plays an essential role as it allows heat exchange between the two circuits. In each circuit, it acts both as an evaporator for the high-pressure part and as a condenser for the low-pressure part. The more efficient the heat exchange between the two circuits, the better the overall performance of the unit will be, ensuring lower consumption and greater homogeneity.

Each circuit has a different refrigerant gas with the characteristics required for the temperatures reached by the circuit (for example: R417A or R290 for the high-pressure circuit and R508B or R170 for the low-pressure circuit).

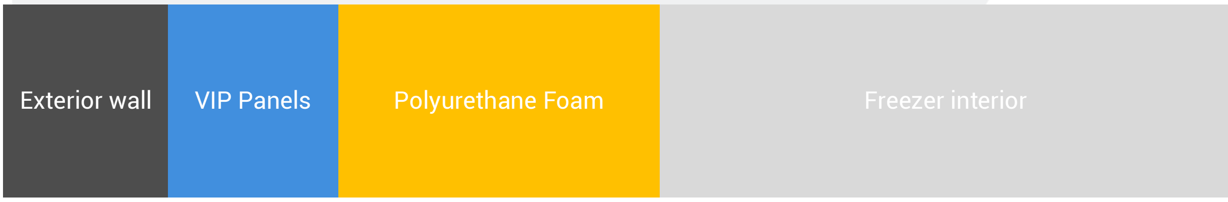
- <u>How does the insulation have an impact on the optimization of the performance of the freezers?</u>

The last challenge is simple, but nevertheless crucial to ensure the good performance of the equipment: how to keep the cold inside the freezer?

Heat transfer in general takes place in three different ways: convection, conduction and radiation. The creation of a vacuum in the freezer wall virtually eliminates convection, since convection is based on the transfer of thermal energy by mass displacement of gas molecules. Conduction is also greatly diminished by the absence of contact parts throughout almost the entire freezer. The proportion due to radiation is very small.

The use of Vacuum Insulated Panels (VIP) therefore provides a form of thermal insulation that is 6 to 8 times more efficient than conventional wool insulation. VIP panels are used in freezer frames to provide insulation performance superior to that of conventional insulation materials. They consist of a gas-tight wall surrounding a rigid core from which air has been evacuated.

Thanks to insulation (Figure 2) on all six sides of the freezer, the vacuum panels (VIP) used in the freezer design, coupled with high-density polyurethane foam, reduce the thermal conductivity to values below 0.005 $W.m^{-1}.K^{-1}$. Copper is an excellent conductor. It has one of the highest thermal conductivities of all metals at 380 $W.m^{-1}.K^{-1}$. In order to obtain the same value with conventional insulation, much thicker walls would be required. The use of such panels therefore also saves space inside the freezer and thus the ratio of interior volume to floor space.



<u>Figure 2:</u> Sliced diagram of the insulated wall of a freezer

Are you interested in this subject on the cold? Our team is also passionate about answering your questions about refrigeration and our product ranges.