REFRIGERATION AND COOLING MANUAL
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# Table of Contents

- General ........................................................................ 6
- Definitions .................................................................... 6
- Refrigerants ................................................................... 7
- A typical refrigeration process .................................... 8
- Process description (1 stage system) ......................... 9
  - Reciprocating compressor (piston) Fig. 8 ............ 11
  - Screw compressor Fig. 9 ........................................ 11
  - Scroll compressor Fig. 10 ...................................... 11
  - $h \log P$ chart (1 stage system) ............................ 12
  - 2 stage system ...................................................... 13
- Process description (2 stage system) .................... 14
  - $h \log P$ chart (2 stage system) ............................ 15
- Absorption cooling ...................................................... 15
  - Absorption cooling technology ............................ 16
  - Construction types .............................................. 17
- Complete cooling plant ........................................... 18
- Cold side .................................................................... 18
- Warm side ................................................................... 19
  - Cooling tower ....................................................... 19
  - Construction ........................................................ 20
  - Picture of cooling towers ...................................... 21
- Free cooling ............................................................... 22
- Pumps .......................................................................... 22
  - Pump considerations ............................................. 23
  - Glycol ................................................................. 24
  - Ammonia (NH3) .................................................... 24
  - Carbon dioxide (CO2) ........................................... 25
- Regulation and control ............................................... 25
- Carbon dioxide (CO2) .............................................. 26
General

The ability of cooling or freezing something is a growing market both in the manufacturing industry and in the air-conditioning market. Grundfos is pleased to be the preferred supplier of pumps for cooling systems for these customers.

Grundfos pumps are reliable, efficient and cover a wide performance range. As an experienced consultant in the implementation of pumping systems, we engage in a process of close partnership and dialogue to find the best solution for your system.

Grundfos is a global enterprise with a worldwide service network. When you need export or on-the-spot advice in a particular part of the world, we have the technical expertise close by.

This Refrigeration and Cooling Manual describes how a typical refrigeration plant in the manufacturing industry is working. It should also provide an idea of how some of the components used in such a plant could look like. Furthermore it will hopefully give you an idea of which pumps are being used and which to propose to a customer.

Definitions

Cooling
Cooling of a space or substance above or down to the ambient temperature.

Refrigeration
Cooling of a space or substance below the ambient temperature. This is normally below the ambient temperature and down to −123°C.

Cryogenics
The temperature below −123°C. However, this will not be mentioned further in this manual.

The definitions elaborated on in this manual is mechanical cooling and refrigeration. Mostly as it is this plant that Grundfos offers pumps to; especially to the secondary side of the plant.

Mechanical cooling and refrigeration is primarily an application of thermodynamics where the cooling medium, or refrigerant, goes through a cycle in order to be recovered for reuse. The commonly used basic cycles is normal vapour-compression. This cycle operates between two pressure levels, which alternate cyclically between the liquid phase and the vapour phase. This process provides and takes energy.

Refrigerants

A lot of different fluids can be used as refrigerants. Which refrigerant is being used depends on a lot of factors, e.g. the desired temperatures, the plant size, location of the plant, age, etc.

Nowadays the following refrigerants: ammonia (NH3), carbon dioxide (CO2), hydrocarbon (HC), hydrofluorocarbon (HFC) is being used. All refrigerants have a number, e.g. ammonia has the number R-717 while carbon dioxide has the number R-744. Just remember that the ones mentioned here are not the only solutions.

A chart has been made for all refrigerants called the h logP chart. This chart describes in detail on which stage the refrigerant is on what pressure. For example, is it a liquid, is it vapour, what temperature does it have, and what is the energy consumption. By means of this chart you will also be able to tell the refrigerants’ ‘refrigeration effect’. This is the specific
heat capacity; \( \Delta h_f \) in kilojoule where 1 kg of the fluid can be absorbed when it passes through the evaporator. An example of an \( h \log p \) chart is shown in connection with the process description of the 1 and 2 stage systems.

In practice, the graph is used to size the cooling plant. In the sense that one can determine the amount of refrigerant needed to lower the temperature a given number of degrees in the desired amount of water. In the end this helps to decide how big a flow the pumps must be able to handle.

### A typical refrigeration process

In a refrigeration process the refrigerant goes through two phases. The evaporation process and the condensation process. The evaporation needs energy and the condensation releases energy fig. 1.

These two phases are created by a cooling compressor or an absorption unit as the boiling point of a liquid is related to a specific pressure as shown in figure 1.

In fig. 2 a simple compressor cooling plant is shown. In the evaporator the pressure is low, which will make the refrigerant boil and absorb energy from the surroundings. In the condenser the pressure is raised with the aid of the compressor. This makes the refrigerant condensate which releases energy.

### Process description (1 stage system)

Now that we have seen a sketch of a simple 1 stage system, we will take a look at what happens in the individual components and describe the cycle of refrigeration. The markings A, B, C, and D in fig. 3 is provided for your reference in the explanation.

**A-B (Fig. 4)**

**Throttle valve**

The refrigerant is before the throttle on liquid base due to the high pressure. When it passes through the throttle to the evaporator (low pressure side) part of the refrigerant will start boiling. The process takes place with constant specific heat, which means no energy is absorbed in the refrigerant or transported to the surroundings (isenthalpic process).

The extent to which the throttle must open is controlled automatically, either electronically or mechanically.

**B-C (Fig. 5)**

**Evaporator**

The refrigerant absorbs heat (energy) in the evaporator, either from air or from a secondary refrigerant, e.g. water. When the refrigerant leaves the evaporator it is vaporised. The pressure is the same in the process and is called an isobar process.

Indirect cooling is often used in the manufacturing industry in order to avoid transporting the refrigerant within buildings.

Example of an evaporator in a cooling room.

The evaporator can either be flooded or with dry expansion. In case of dry expansion the refrigerant
is completely vaporised when leaving the evaporator. This is normally used in smaller plants. It is very important that all of the refrigeration has been turned into vapour as liquid drops in the compressor will destroy it. On the other hand you don’t want to overheat it because high temperature will both harm the refrigerant and the compressor. In the flooded evaporator the refrigerant is a mix between vapour and liquid when it leaves the evaporator. This means it can’t go directly to the compressor, but has to be collected in a separator where the vapour and liquid are separated fig. 6.

As shown on the figure the refrigerant returning from the evaporator is a mix of vapour and liquid.

The biggest difference and advantage of this system compared to the 1 stage plant is:
- The evaporators are flooded. This means that the refrigerant is not overheated and therefore the system is not unnecessarily overheated.
- The compressor draws vapour from the top of the separator. Because it’s from the top there is no chance of liquid in the compressor.

Another difference in this system is the mounted circulation pump which circulates the refrigerant in the evaporators. Depending on the refrigerant, this could be a CRN Mag-Drive. Now we actually have a pump placed in the primary side of the plant. Grundfos pumps are normally not found here. See more under pumps. When we are launching the RC pump for Carbon dioxide it will also be placed here.

C-D (Fig. 7.)
Compressor
The refrigerant is moved through the compressor where the pressure is increased from the evaporator pressure to condenser pressure. The process is isentropic.

In the compressor, more heat or energy are added to the refrigerant due to the compressor efficiency. Had it been a perfect process, the pressure would increase without absorbing any energy as with the expansion valve.

A typical compressor room.
The 3 most common compressor types are the reciprocating compressor (piston), the screw compressor and the scroll compressor.

Reciprocating compressor (Piston) Fig. 8.
The reciprocating compressor is one of the most commonly used compressor types in the manufacturing industry. It can consist of up to 12 cylinders. See the picture of a typical construction of a reciprocating compressor.
The compressor is normally controlled by reducing the revolutions or by cutting out some of the cylinders. When the compressor is started most of the cylinders normally are cut out in order to reduce the start current on the motor.

Screw compressor Fig. 9.
The screw compressor is used to a great extent in the manufacturing industry. Its advantage is the size; it is small, but has a big capacity. It can be used for almost all refrigerants. It is easy to regulate from 10 to 100 % with a slide valve.

Scroll compressor Fig. 10
The scroll compressor is a smaller compressor and normally used in heating and water cooling plants. It is a very simple compressor type with almost no moving mechanical parts, which means no maintenance. The compression is made by two scrolls, one fixed and one orbiting scroll. See the figure to the right.
D-A
Condenser Fig. 11.
The heat consumed in the refrigerant from the evaporator process and in the compressor must be removed in the condenser. In the top of the condenser only the overheated energy is removed. But the longer it passes down through the condenser, more and more turn into liquid.

Like the evaporator, the condenser is basically a heat exchanger. It can be either flushed on the secondary side with air as on the picture. Or with another liquid, e.g. water, as seen normally in the manufacturing industry.

In the chart you can see as follows:
The Y-axis shows the pressure of the refrigerant. The X-axis shows the energy content of one kg of the refrigerant. The thin red line coming down here is the refrigerant’s temperature. Above the big red line the refrigerant is in an area called the subcritical area and we normally do not operate in this area. (If you use CO2 as a refrigerant you would go into that area, but this process is not described in this manual). In the area below this line the refrigerant is in a mix of liquid and vapour. In this area and below the big red line everything is liquid. In this area and below the big red line everything is vapourised.

If we take a look at the cooling process in the chart, the following takes place:

A-B: The pressure and temperature is dropping over the nozzle valve from the high pressure side to the low pressure side in the system. Some of the refrigerant turn into vapour as we go from the area where everything is liquid to the mix area.

B-C: Energy is added to the refrigerant in the evaporator and more and more of the refrigerant turn into vapour. And at the end of the evaporator, all of the refrigerant have turned into vapour and have become a bit overheated. The temperature will in this case increase around 8°C.

C-D: In the compressor the pressure will increase again and the refrigerant will be heated even more because of the efficiency loss in the compressor.

D-A: Through the condenser the overheated refrigerant will be cooled down and turn into liquid again.

2 stage system
The simple 1 stage cycle refrigeration plant described above and some of the pictures shown stem from a typical small plant in e.g. a supermarket. In relation to manufacturing industry refrigeration plants, 2 stage systems are usual used, and they can be designed in many different ways, Fig. 12.

2 stage systems are also used where very low temperatures are desired. This is achieved by stopping the compression and cooling the gas before it is recompressed. The total compression energy is also less. The temperature of the gas from high pressure compressor will be lower than if compression was done in 1 stage. This also ensures that the oil for lubricating and cooling the compressor is not destroyed as easily.
**Process description (2 stage system)**

A-B: The refrigerant is liquid and is being transported to the intermediary reservoir via a level controlled expansion valve. This turns part of the refrigerant into vapour which will bubble through the liquid and be drawn into the high pressure compressor. However, most of it will remain in the reservoir as liquid.

B-C: The liquid that flows to the nozzle C is at saturation temperature as the liquid in the receiver is boiling.

C-D: The same process for a 1 stage system takes place in the evaporator. The entire refrigerant turns into vapour before it is being drawn into the low pressure compressor.

D-E: The compressor overheats the refrigerant and pushes it back into the receiver below liquid level in the receiver. (And not as shown on the picture). In the receiver the refrigerant is being cooled down to saturation temperature again but part of it also bubbles through the liquid and is then drawn into the high pressure compressor.

F-G: The same process as for the 1 stage system; the outlet temperature of the refrigerant is just lower in the 2 stage system.

G-A: The same process as in the 1 stage system. However due to the lower refrigerant temperature from the compressor, the condenser does not require as big a capacity as in the 1 stage system.

**h logP chart (2 stage system)**

If you compare the 2 stage system and the 1 stage system you can see that the amount of energy you can take out of the evaporator (C-D) is bigger in the 2 stage system. The temperature from the high pressure compressor (F) is approx. 35°C lower in the 2 stage system. This is positive for the compressor, but you also do not have to use so much cooling energy in the condenser.

**Absorption cooling**

An absorption cooling plant produces cold from heat. The combination of heating and cooling is interesting for those parts of the manufacturing industry where large heating and cooling requirements are prominent, e.g. nurseries, slaughterhouses and office buildings. For the right combination of heating and cooling needs, a favourable economic environment could be achieved by installing an absorption cooling plant compared to a standard compressor cooling plant.
Absorption cooling technology

An absorption cooling plant typically comprises four main components:
- Concentrator
- Condenser
- Evaporator
- Absorber

The technique in absorption cooling and compressor cooling is more or less the same. In mechanical cooling a mechanical compressor is included instead of in absorption cooling where a thermal compressor consisting of a concentrator, an absorber and a throttle valve is installed, fig. 13:

To operate the plant, heat must be added to the concentrator from an external source (turbine, gas engine, waste heat, etc.). And heat must be removed through a cooling tower.

The cooling process is initiated by adding heat to the concentrator. This makes the concentration boil and the refrigerant (e.g. water in a LiBr/H2O plant) will be led to the condenser. In another circuit the remaining solution, now poor in refrigerant, flows from the concentrator to the absorber through a heat exchanger and a throttle valve (pressure reduction).

The evaporated refrigerant from the concentrator is condensed in the condenser and passed through an expansion valve (pressure reduction) to the evaporator. The same process takes place as in a compressor cooling plant.

From the evaporator the refrigerant, being completely vaporised by now, is led to the absorber. Here the refrigerant is absorbed in the solution during the release of heat.

The solution, now refilled again with the refrigerant, is pumped through a heat exchanger and back to the concentrator.

This circuit is connected and the process begins again.

In fig. 14 you can see a picture and a figure of an absorption plant.

Construction types

Basically two types of absorption cooling plants are available on the market. One type is based on a liquid mixture of lithium bromide and water, and the other on water and ammonia.

In a water / ammonia plant, the ammonia acts as a refrigerant and the water as an absorber. This means that these plant types are able to produce cooling at very low temperatures (< -30°C). This is the default mix used in the manufacturing industry.

The LiBr / H2O plant, however, is the most common type of plant. With this mixture you can produce cooling with temperatures down to approx. 5°C as the water acts as a refrigerant and the lithium bromide as an absorber.

This type of construction is normally used for comfort cooling or for food refrigeration.

Absorption cooling plants can, just as compressor cooling plants, be constructed as 1 or 2 stage systems.
Warm side

On the secondary side of the condenser, air or water is always used with some kind of antifreeze.

Air is normally chosen for smaller plants, e.g. for cooling a building.

Water is used in the manufacturing industry, where it normally is pumped from the condenser to a cooling tower to remove the heat. On ships or installations close to a lake or the sea, the condenser can be cooled with water directly from those sources.

Cooling tower

The principle is very simple – cooling towers work by evaporating a small part of the circulated cooling water. The towers are normally referred to as “evaporation towers”. In an evaporation cooling tower the circulated cooling water comes into direct contact with air from the atmosphere.

To obtain great efficiency, it is important that the water is aerated as much as possible to obtain a large contact surface between the water and the air. This makes some of the water evaporate and, as seen under the function of the evaporator, this process requires energy, and as a result the water temperature will decrease. Please note that in a cooling tower you will have to add water due to the evaporation. In Denmark, an annual average amount of make-up water is approx. 1.12 m³/h per MW cooling capacity.

In fig. 18 two different cooling towers; the only difference is the location of the ventilation fan. Please note that if the fan is located as on the picture to the right, the motor and fan are surrounded with vapour at all time.
Depending on the application you sometimes reuse some of the heat in the condenser, as shown in fig. 19.

**Construction**

Fig. 19 shows a principle sketch of a cooling tower connected to the condenser. On the sketch the ventilation fan is also shown blowing the air against the water direction. In this system, anti-corrosives are also added to the tower.

In large plants a buffer tank is often installed. The system can be constructed as shown in fig. 20.

The buffer tank is divided in two; a cold and a warm side. The cooling tower circulates the water from the warm side in the tank and through the cooling tower and back to the cold side of the tank. In the chiller or condenser the circulation takes place in the opposite direction. From the cold side of the tank, through the condenser, and back to the warm side of the tank.

The buffer tank on the figure is a little bit misdrawn. The centre wall does not go all the way to the top of the tank, but is lower than the water line to allow the water to float from one side to the other.
**Free cooling**

Within the cooling business, the focus is increasingly on energy reduction like in all other places. The word or process “free cooling” is becoming more and more popular. Basically the phenomenon “free cooling” means cooling in a natural way without using mechanical cooling. In fig. 21 is shown a picture of how to construct a free cooling plant.

And as you can see it is the cooling is simply led directly from the process to the cooling tower. As you can imagine you are very dependent on the outdoor temperature and the limit for how low you can go with regard to temperature is relative high.

Free cooling is normally used to cool office buildings and so on.

**Pumps**

In connection with pumps on the secondary side, there are not many requirements. It is almost only the Q and h which are setting the demands. But see more advises under pump considerations, next page. The pumps could be NB/NK, TP, CR and so on.

On the primary side it is a little bit more difficult. Basically we do not deliver pumps for this side, but as seen above, customers sometimes need a pump for this side. Whether or not Grundfos is capable of delivering the pump, depends very much on the refrigerant type. If the desired refrigerant is ammonia we can pump it with a CR pump with double shaft seal or by using a Mag-Drive solution. But again it depends very much on the refrigerant type, and if you are in doubt look in the Pump Liquid guide.

The sizes of the pumps differ of course very much depending on the application. Basically all types of pumps from the smallest UP pump over the high pressure CR high speed pumps, and up to the HS pumps are being used.

If we for example talk standard industrial cooling towers we normally see a flow between 25 m3/h and 2000 m3/h. For example the biggest cooling tower on a 700 MW coal fired power plant needs a circulated water amount of up to 71600 m3/h.

**Pump considerations**

When choosing a pump for a cooling application, there are some standard things you will always need to know before you start sizing the pump, i.a.

- Flow
- Head
- Liquid type
- Temperature of the liquid
- Concentration of the liquid
- Viscosity
- Density
- Additives added to the liquid

When you get a request for a certain liquid it is always a good idea to look for it in the Pump Liquid guide. Almost all liquids we have ever pumped in Grundfos are listed here, the program will recommend what to take into consideration when choosing a certain liquid. Many of the glycols used in the refrigeration and cooling industry you can also find in the engineering manual "Viscosity and Density" placed in the Salesmens library.

Below you will find some pieces of information’s and recommendations regarding pumping some of the most traditional liquids.
Glycol

• The density and viscosity vary very much depending on the concentration and the temperature of the liquid. You might need an oversized motor.
• If it is a NB/NK or a TP pump you use, it’s normally recommendable to choose a shaft seal with reduced seal faces. The standard cartridge seal in a CR can be used for glycol.
• Normally cast iron pumps are used but be aware that sometimes they add additives to in the cooling water so you need to use stainless steel pumps.
• The temperature of glycol is normally very, but can also be warm, so you have to be sure that the pump can deal with that.
• Glycol is in some situations used as a cleaning agent ; if a system has not be thoroughly flushed before, the oils and fats will cause problems with the seal during the first operation hours.

Ammonia (NH₃)

• The density and viscosity are different from that of water. Because the viscosity is around 0.3 mm²/S you have to be sure that the pump can cope with that. Maybe the lubrication of the pump wouldn’t be satisfactorily. A CR is okay for ammonia.
• Ammonia has a low boiling point, which can easily cause cavitation in the inlet of the pump. So make sure the inlet pressure is high sufficiently.
• Ammonia is toxic so a back to back shaft seal or a Mag-Drive is recommended.
• When ammonia is used in refrigeration plants it has always a concentration of 100 %. When you hear ammonia mixed with water it is normally used as a household cleanser and in the manufacture of a wide variety of products, including textiles, rayon, rubber, fertilizer, and plastic. Copper and copper alloys have only limited resistance to ammonium hydroxide.

Carbon dioxide (CO₂)

• The viscosity of carbon dioxide is so low that you can’t pump it with a standard pump do to the low lubrication capability. The pump for this liquid should be a RC pumps, see the last page.

Regulation and control

To run a refrigeration process properly, both financially but also to ensure a safe operation, some automation and monitoring equipment must be installed. The complexity of the automatic regulation and control depends to a great extent on the size of the system and where it is installed. The most important tasks for the regulation and control are the following:

Cold side

• Evaporator pressure regulation.
• Capacity regulation on the compressor.
• Flow regulation (not so common).

Warm side

• The advantage of regulating the warm side is application-specific.

Others

• Correct distribution of the refrigerant in the system.
• Regulation of secondary refrigerant to the condenser. (water or air)
• Defrosting of the evaporator if the secondary side is air.
• Monitoring equipment (overpressure, underpressure and oil pressure)
• Protection of electrical motors.
Carbon dioxide (CO2)

A newcomer within the refrigeration industry and at Grundfos is a CO2 pump. It is a new pump developed by Grundfos for the primary side of the refrigeration plant.

For more questions or information on the CO2 pump, please contact Product Manager Mr. Bjarne Dindler Rasmussen (RSU)