



be  
think  
innovate

**GRUNDFOS** 



## **REFRIGERATION AND COOLING MANUAL**

Copyright 2012 GRUNDFOS A/S. All rights reserved.

Copyright law and international treaties protect this material. No part of this material may be reproduced in any form or by any means without prior written permission from GRUNDFOS Holding A/S.

All reasonable care has been taken to ensure the accuracy of the contents of this material: However, GRUNDFOS shall not be held liable for any losses whether direct or indirect, incidental or consequential arising out of the use of or reliance upon on any content of this material.





<b>General</b> .....	<b>6</b>
Definitions.....	7
Typical cooling application.....	8
<b>Refrigeration</b> .....	<b>9</b>
Refrigerants .....	9
A typical refrigeration process .....	9
Refrigeration in practice .....	10
Process description (1-stage system).....	11
Process description (2-stage system) .....	18
Absorption cooling.....	19
Grundfos products .....	20
<b>Traditional industry cooling</b> .....	<b>24</b>
Cold side .....	24
Warm side .....	25
Cooling tower.....	25
Construction .....	28
Free cooling.....	30
Water treatment.....	30
Seawater cooling.....	33
Coating of pumps.....	34
Control principles and examples.....	35
Grundfos setup .....	40
Grundfos products .....	45
<b>Cooling unit</b> .....	<b>46</b>
Control techniques.....	46
Grundfos products .....	48
<b>General pump considerations</b> .....	<b>49</b>
Glycol.....	49
Ammonia (NH <sub>3</sub> ).....	50
Carbon dioxide (CO <sub>2</sub> ).....	50

## 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 the theory behind cooling and how it is done in practice. Furthermore it explains how a cooling plant and cooling units are built. It also describes how the systems/pumps are controlled and regulated, and the implications in terms of energy consumption when this is done correctly. Finally, it offers an overview of the various types of pump which are commonly used, and which pump is most appropriate for a given application.

Given the wide range of customers and applications that Grundfos pumps serve, for the purposes of this manual we have sought to group these by type as shown below, to enable customers to quickly locate the parts of the manual that will be of the greatest interest and relevance to them:



Customer interest	Topic	Typical sectors	Customer type
<b>Refrigeration</b>	Pumping of CO <sub>2</sub> , NH <sub>3</sub> and other refrigerants	Commercial refrigeration, Industrial refrigeration	OEM/Contractor Contractor Service companies
<b>Industrial cooling</b>	Large pumps Energy saving Water with glycol	Cooling towers, Industrial cooling (F&B)	Contractor/end user OEM
<b>Cooling units</b>	Compact pumps Reliability	Wind turbine cooling, Electronic cooling,	Medical cooling OEM

The definition of cooling varies across different industries and types of customer. This manual is concerned with mechanical cooling and refrigeration.

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 most commonly used basic cycles are normal vapour compression. This cycle operates between two pressure levels which alternate cyclically between the liquid phase and the vapour phase. This process releases and consumes energy.

Cooling, refrigeration and cryogenics are typically defined as follows.

### **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, down to  $-123^{\circ}\text{C}$ .

**Cryogenics:** Temperatures below  $-123^{\circ}\text{C}$ . Cryogenics will not be mentioned further in this manual.

## Typical cooling application

Fig. 1



Fig. 1 shows the compressor in the middle, where the refrigeration process occurs. To the left of the compressor there are four pumps which send the cooling liquid into the production. In front of the compressor are two pumps which send the hot liquid out to the cooling towers in the back. On the wall are the control cabinets and the dosing pumps which treat the cooling water.



## Refrigeration

This chapter describes the refrigeration process, including cooling below the ambient temperature.

### Refrigerants

A number of different fluids can be used as refrigerants. The choice of refrigerant depends on several factors, e.g. the desired temperatures, the plant size, location of the plant, age, etc.

Ammonia ( $\text{NH}_3$ ), carbon dioxide ( $\text{CO}_2$ ), hydrocarbon (HC), and hydrofluorocarbon (HFC) are the most common refrigerants today, though they are not the only solutions. All refrigerants have a number, e.g. ammonia is R-717 while carbon dioxide is R-744.

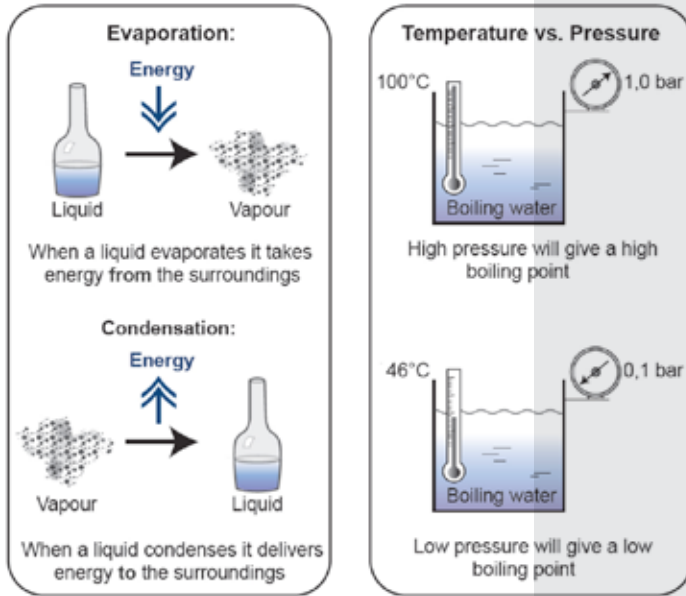
All refrigerants can be found in a chart known as the h logP chart, which describes the refrigerant's phase (liquid, vapour) at a given temperature and pressure, as well as the energy consumption. The chart includes information about each refrigerants' "refrigeration effect". This is the specific heat capacity: the  $\Delta h_f$  in kilojoule at which 1 kg of the fluid can be absorbed when it passes through the evaporator. An example of an h logP 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 after and determine how the plant is working. It also assists in determining the amount of refrigerant needed to lower the temperature a given number of degrees in the desired amount of water. Ultimately this helps to determine how great a flow the pumps must be able to handle.

### A typical refrigeration process

In a refrigeration process the refrigerant goes through two phases: evaporation and condensation. Evaporation needs energy and condensation releases energy (fig. 2).

Fig. 2

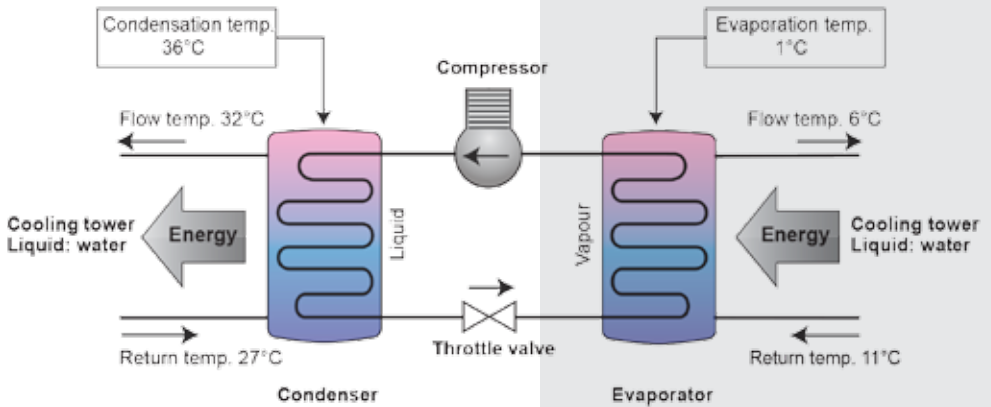


These two phases are created by a cooling compressor or an absorption unit, as the boiling point of a liquid is related to a specific pressure as shown in fig. 2.

### Refrigeration in practice

Fig. 3 shows a simple compressor cooling plant. 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 condense, which releases energy. In practice this means that the temperature in a room or product is lowered when energy is absorbed, and raised when energy is released. An increase in temperature can be counteracted by the use of a cooling tower or similar.

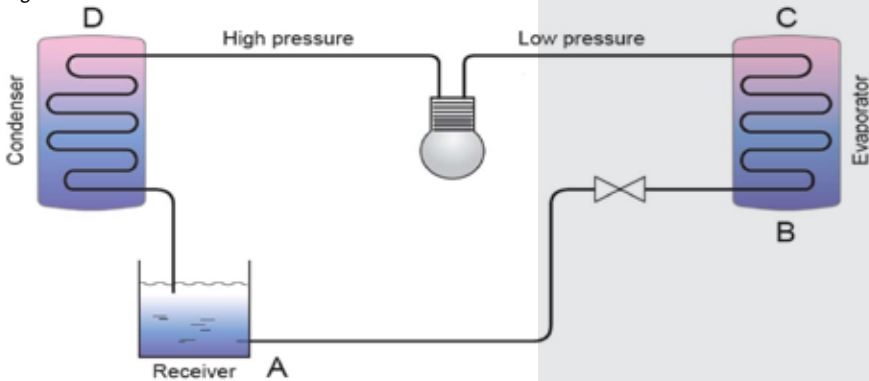
Fig. 3



### 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. Essentially, the process is identical to what takes place in your fridge at home. You remove heat within the system to make the space colder and release it via the back of the system.

Fig. 4



**A-B (Fig. 5)****Throttle valve**

Before it enters the throttle, the refrigerant is in the liquid phase 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 a constant specific heat, which means no energy is absorbed by the refrigerant or released to the surroundings (isenthalpic process).

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

**B-C (Fig. 6)****Evaporator**

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

Basically, the evaporator is a heat exchanger. When flushed on the secondary side with air, it is called direct cooling (as shown in the figure) and when flushed with another liquid it is called indirect cooling. Indirect cooling is often used in the manufacturing industry in order to avoid transporting the refrigerant within buildings.

The evaporator can either be flooded or with dry expansion. With 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 vaporised as any liquid drops in the compressor will destroy it. On the other hand overheating should be avoided because high temperatures will harm both the refrigerant and the compressor. In the flooded evaporator the refrigerant is a mix of vapour and

Fig. 5: Typical throttle valve

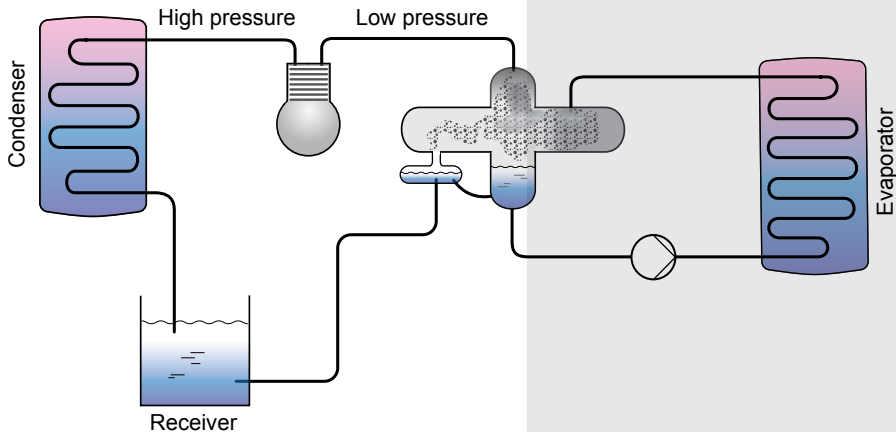


Fig. 6: Example of an evaporator in a cooling room.



liquid when it leaves the evaporator. This means it cannot go directly to the compressor, but has to be collected in a separator where the vapour and liquid are separated (fig. 7).

Fig. 7: Cooling system with flooded evaporator



As shown in 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 that:

- 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, so 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 or an RC pump. Now we actually have a pump placed in the primary side of the plant. Grundfos pumps are normally not found here. For more information about this, see the “Pumps” section of this manual.

**C-D (Fig. 8)****Compressor**

The refrigerant is moved through the compressor where the pressure is increased from the evaporator pressure to condenser pressure. This process is isentropic.

In the compressor, more heat or energy is added to the refrigerant due to the compressor's efficiency. If the process were perfect, the pressure would increase without absorbing any energy, as with the expansion valve.

**Compressor types**

The three most common compressor types are the reciprocating compressor (piston), the screw compressor and the scroll compressor.

**Reciprocating compressor (Piston) (Fig. 9)**

The reciprocating compressor is one of the most commonly used compressor types in the manufacturing industry. It can consist of up to twelve cylinders. The figure shows 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 are normally cut out in order to reduce the start current on the motor.

**Screw compressor (Fig. 10)**

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

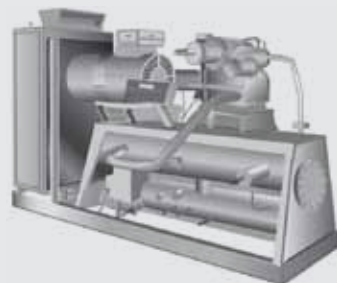
Fig. 8: A typical compressor room



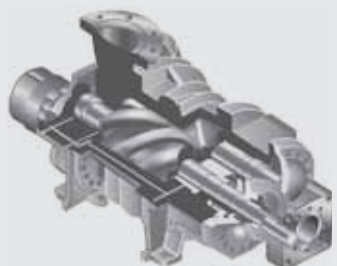
Fig. 9: Piston compressor



Fig. 10: Typical screw compressor



A cut open drawing of a screw compressor



### Scroll compressor (Fig. 11)

The scroll compressor is a smaller compressor which is 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. Compression is via two scrolls, one fixed and one orbiting (fig. 11)

The bottom image is of a scroll compressor, but it could easily have been a piston compressor as they look the same.

### D-A

#### Condenser (Fig. 12)

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, the more it turns into liquid.

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

Fig. 11: Principal on how a scroll is working

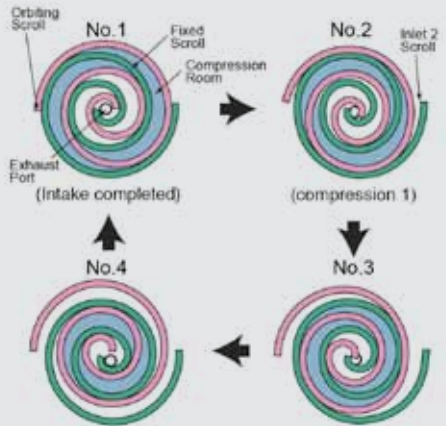
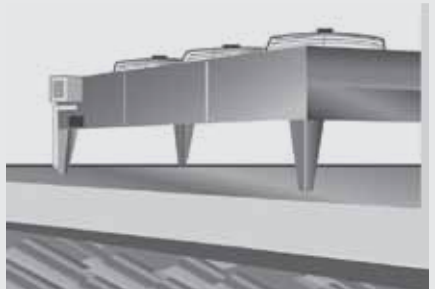
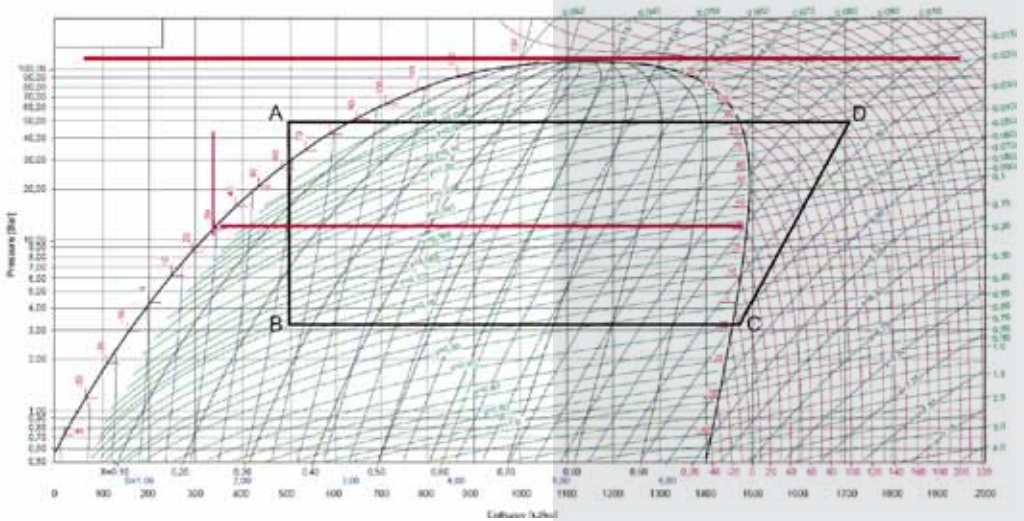


Fig. 12: Typical air-cooled condenser



## h logP chart (1-stage system)



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 vertical line is the refrigerant's temperature. Above the long red line the refrigerant is in an area called the subcritical area, in which we normally do not operate (if CO<sub>2</sub> is used as a refrigerant you would go into that area, but this process is not described in this manual).

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

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

**B-C:** Energy is added to the refrigerant in the evaporator and more and more of the refrigerant turns into vapour. At the end of the evaporator, all of the refrigerant has turned into vapour and is slightly



overheated. The temperature will in this case increase by around 8°C.

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

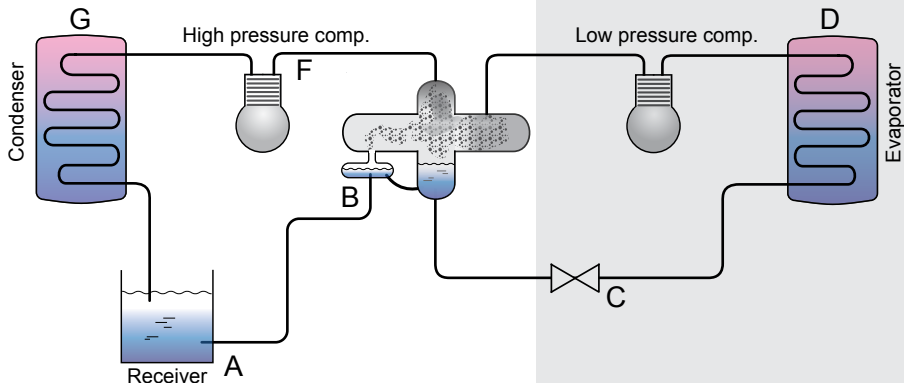
*D-A:* The overheated refrigerant is cooled down and turned back into liquid in the condenser.

## 2-stage system

The simple 1-stage cycle refrigeration plant described above and some of the figures relate to a typical small plant in e.g. a supermarket. In relation to refrigeration plants in the manufacturing industry, 2-stage systems are usually used, and they can be designed in many different ways (Fig. 13).

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 the 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.

Fig. 13: Two stage system



### Process description (2-stage system)

A-B: The refrigerant is liquid and is 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 as for a 1-stage system takes place in the evaporator. All of the refrigerant turns into vapour before it is drawn into the low pressure compressor.

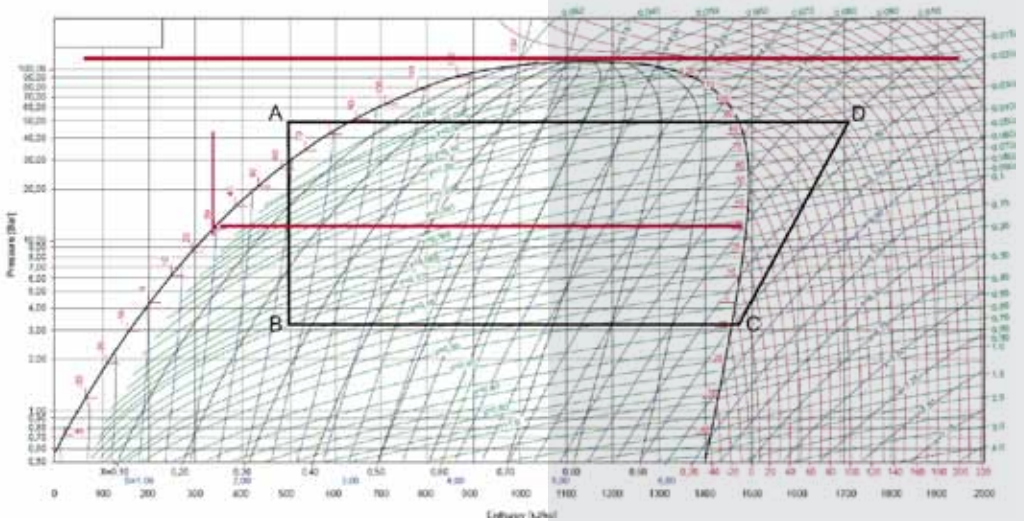
D-E: The compressor overheats the refrigerant and pushes it back into the receiver below liquid level in the receiver (not as shown in the figure). In the receiver the refrigerant is cooled down to saturation temperature again but part of it also bubbles through the liquid and is then drawn into the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

F-G: The same process as for the 1-stage system, but the outlet temperature of the refrigerant is 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 great a capacity as in the 1-stage system.



## h logP chart (2-stage system)



A comparison between the 2-stage and 1-stage systems shows that more energy can be extracted from the evaporator (C-D) 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 an advantage for the compressor, while the condenser does not require as much cooling energy.

### 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 with significant heating and cooling requirements, e.g. nurseries, slaughterhouses and office buildings. To obtain the right combination of heating and cooling to meet requirements, a cost-effective solution would be to install an absorption cooling plant as opposed to a standard compressor cooling plant.

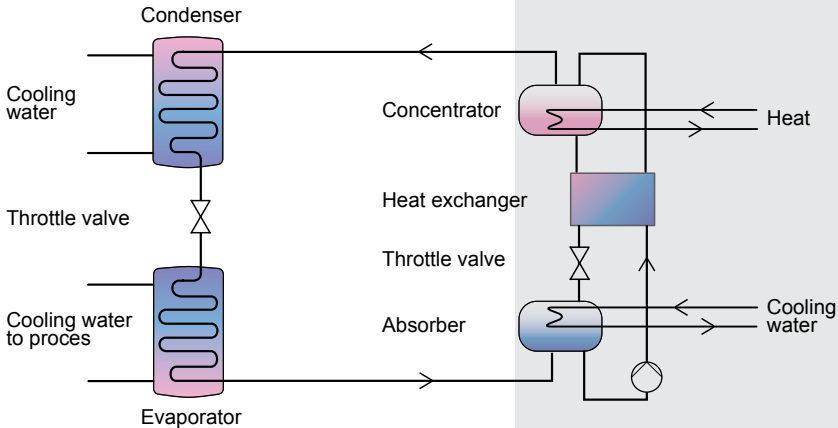
### Absorption cooling technology

An absorption cooling plant typically comprises four main components:

- Concentrator
- Condenser
- Evaporator
- Absorber

The process in absorption cooling and compressor cooling is more or less the same. Mechanical cooling uses a mechanical compressor, whereas absorption cooling uses a thermal compressor consisting of a concentrator, an absorber and a throttle valve (fig. 14).

Fig. 14: Sketch of a absorption cooling system.



To operate the plant, heat must be added to the concentrator from an external source (turbine, gas engine, waste heat, etc.), and 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/H<sub>2</sub>O plant) is then led to the condenser. In another circuit the remaining solution, now low 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 passes through an expansion valve (pressure reduction) to the evaporator. The same process takes place as in a compressor cooling plant.

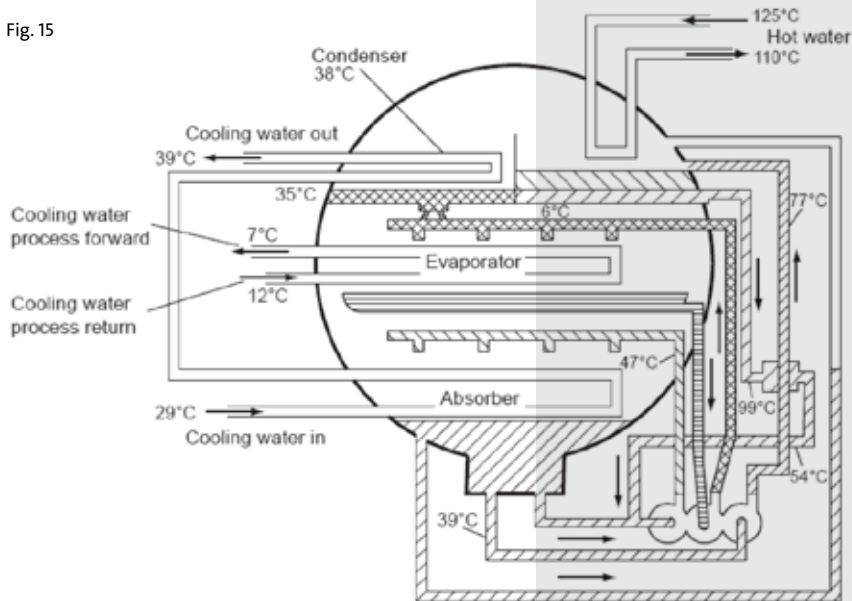
From the evaporator the refrigerant, which is now completely vaporised, is led to the absorber. Here the refrigerant is absorbed in the solution during the release of heat.

The solution, which once again contains a significant amount of refrigerant, is pumped through a heat exchanger and back to the concentrator.

This circuit is connected and the process begins again.

Fig. 15 shows a typical absorption plant.

Fig. 15



### Construction types

The absorption cooling plants available on the market are essentially of two types: one 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 cool to very low temperatures (< -30°C). This is the default mix used in the manufacturing industry.

The LiBr / H<sub>2</sub>O plant, however, is the most common type of plant. With this mixture temperatures can be cooled 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.

Like compressor cooling plants, absorption cooling plants can be constructed as 1- or 2-stage systems.

### Control techniques

To operate a refrigeration process properly, with both cost effectiveness and safety in mind, 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 regulation and control tasks are:

#### 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.



### Other

- 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.

### Grundfos products

Grundfos does not normally supply products to the primary side of these systems where the liquid is some sort of refrigerant. However, we have the RC pump there is special designed for pumping CO<sub>2</sub> if needed it can also be used for other refrigerants.

The CR pump with Mag-drive or double shaft seal can also be used for some refrigerants but not all.

RC pump



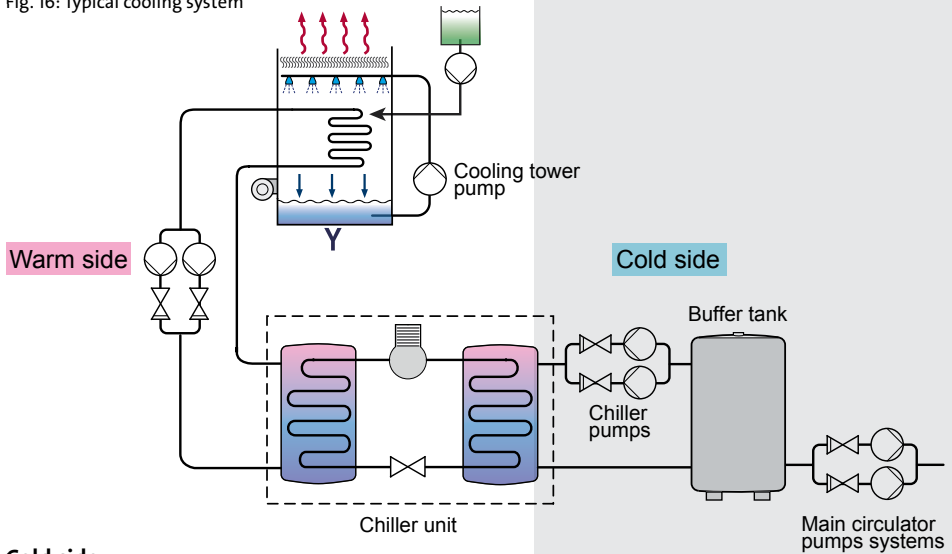
CR with Magnetic drive



## Traditional industry cooling

In the last chapter we covered how the refrigerant process in the primary side of the cooling system works. But as can be seen from fig. 16, all the pumps are normally placed on the secondary side (warm and cold side). We will look into that now.

Fig. 16: Typical cooling system



### Cold side

What happens on the secondary side of the evaporator depends very much on the industry in which the plant is installed.

For temperatures above 0°C and down to approx. -30°C, water with some kind of glycol is normally chosen.

Applications can include:

- Breweries
- Dairies
- Slaughterhouses
- Cooling of buildings with ventilation plants
- Dehumidification in industry buildings, also with ventilation
- Machine cooling
- Etc.



Fig. 17: Secondary cold side

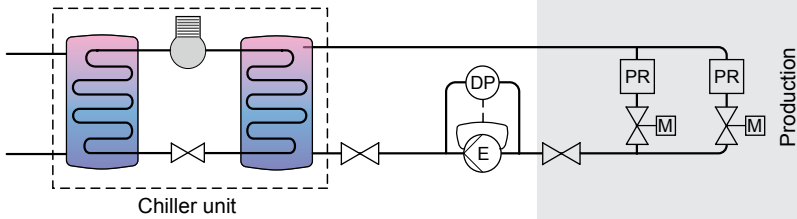
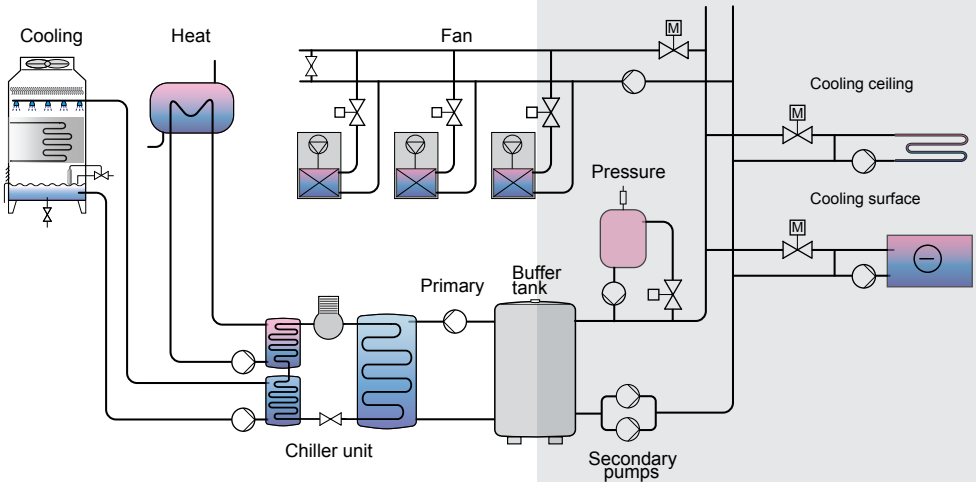


Fig. 17 shows one solution, but it can of course be put together in many different ways.

In large plants (fig. 18), e.g. air conditioning or industry plants, several pumps can be used in several different levels. Buffer tanks are also used to accumulate cooling capacity. Buffer tank sizes vary from small to very large tanks. They may be placed on the ground or buried. The pumps are normally 1-stage pumps, but multistage pumps may also be used. The pump sizes vary from the largest NB/NK as primary pumps to the small UPS pumps in the smallest cooling loops.

Fig. 18: Sketch with primary, secondary cold and warm side, and tertiary 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 is normally 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.

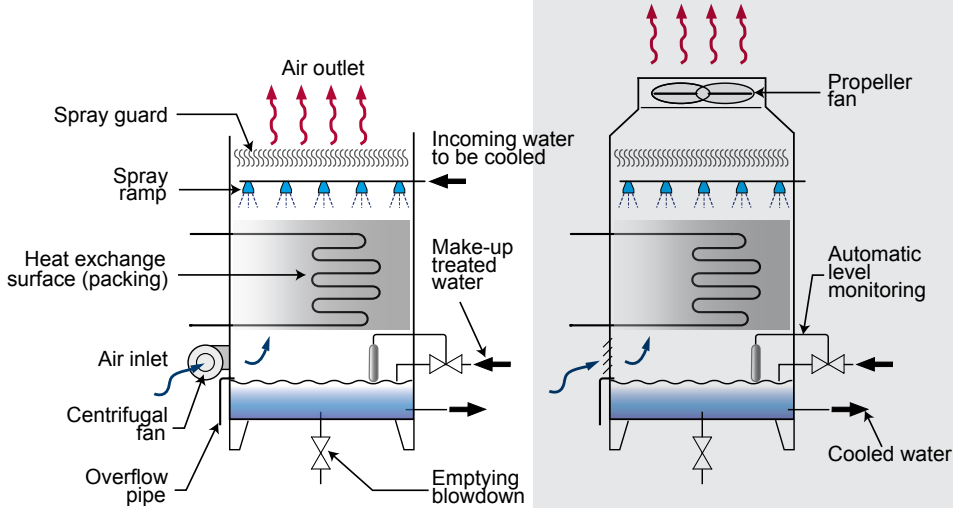
### Cooling tower

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

In the interests of 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, so as a result the water temperature will decrease. Please note that in a cooling tower water must be added due to evaporation. In Denmark, the average annual amount of make-up water is approx. 1.12 m<sup>3</sup>/h per MW of cooling capacity.

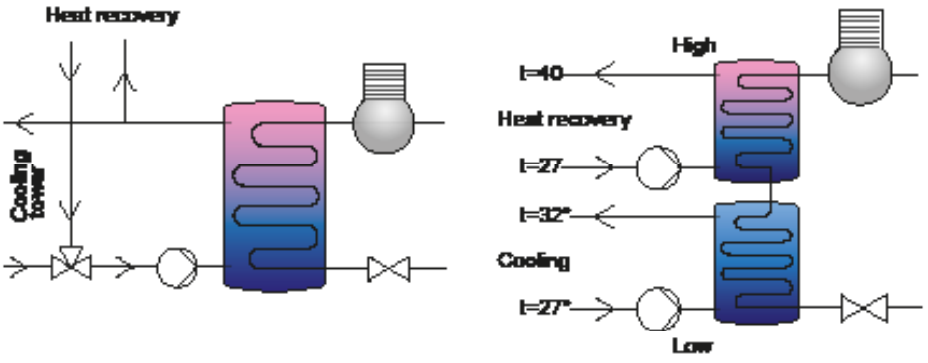
Fig. 19 depicts two different cooling towers; the only difference is the location of the ventilation fan. Please note that if the fan is located as on the tower to the right, the motor and fan are surrounded by vapour at all times.

Fig. 19: Different types of cooling towers



Depending on the application some of the heat in the condenser can sometimes be reused, as shown in fig. 20.

Fig. 20: Examples on how the heat in the condenser can be used



## Construction

Fig. 21

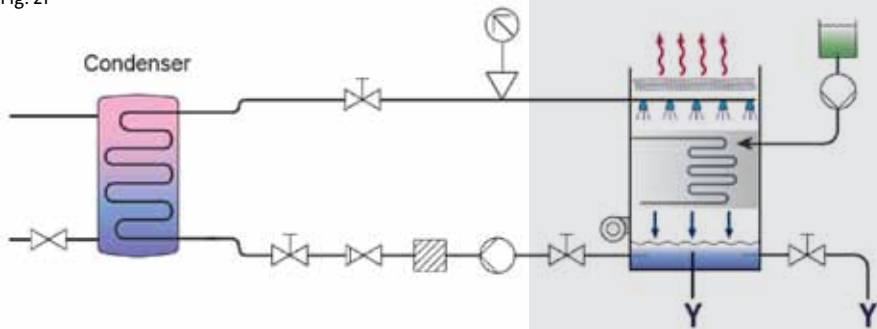
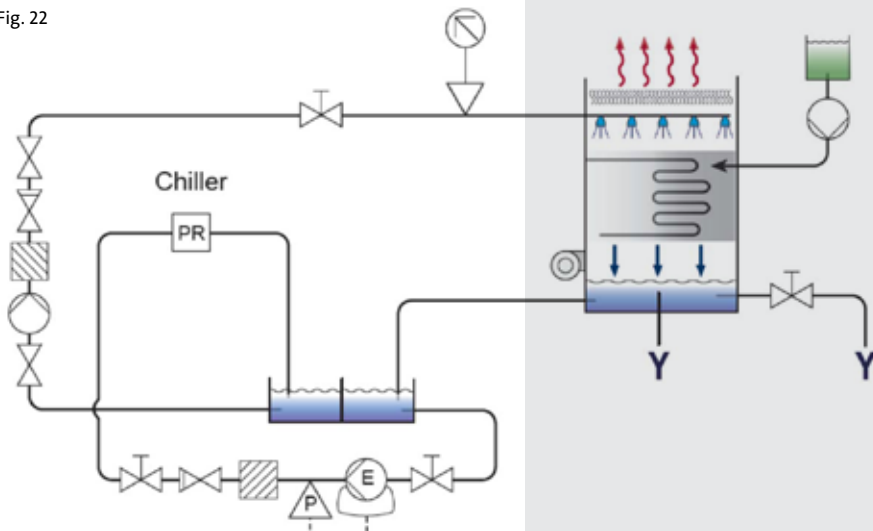


Fig. 21 shows a principle sketch of a cooling tower connected to the condenser. The ventilation fan is also shown blowing air against the direction of the water. In this system, anti-corrosives are also added to the tower.

In large plants a buffer tank is often installed. The system can be constructed as shown in fig. 22.

Fig. 22



The buffer tank is divided into 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 in the figure is somewhat 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.

A typical cooling tower in the manufacturing industry



Two cooling towers at a power plant



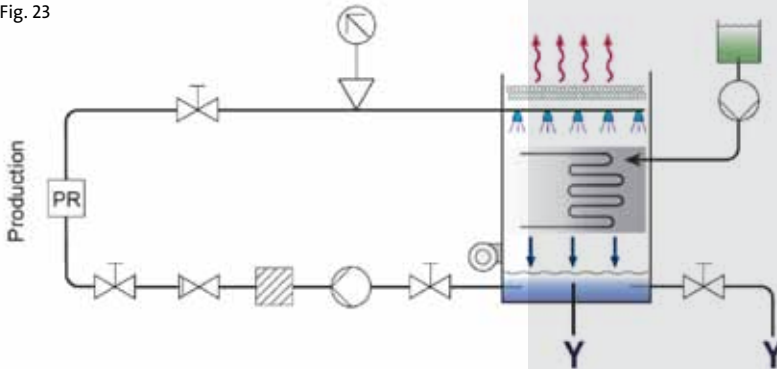
Cooling towers at a coal fired power plant



### Free cooling

The cooling business is increasingly focusing on energy reduction, and the term “free cooling” is becoming more and more popular. “Free cooling” essentially refers to cooling in a natural way, without using mechanical cooling. Fig. 23 shows the construction of a free cooling plant.

Fig. 23



As shown in the figure, the cooling is simply led directly from the process to the cooling tower. Unsurprisingly, this process is highly dependent on the outdoor temperature and the limit for how low you can go with regard to temperature is relative high. Because it is all ways the ambient temperature that decides that.

Free cooling is normally used to cool office and similar buildings.

### Water treatment

In cooling water systems, water is lost through evaporation, bleed-off, and drift. To replace the lost water and maintain its cooling function, more make-up water must be added to the tower system. Because of the water losses, the dissolved solids in the original system's water volume, plus dissolved solids added by the make-up water, rapidly accumulate in the system. On the other hand, cooling water normally offers a

hospitable environment for microbes and biofilms.

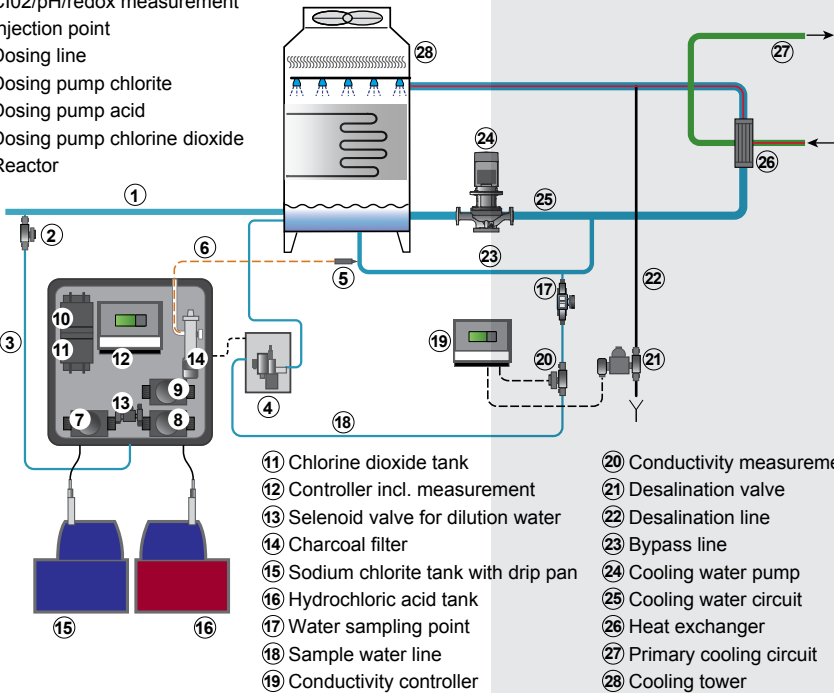
There are two main types of power plant:

- Closed-cycle systems (57% in the US) use evaporation to discharge heat in large cooling towers and recycle water within a power plant. Water consumption is low, and is limited to the amount lost by evaporation. Closed-cycle cooling systems are more expensive than once-through systems.
- Once-through systems (43% in the US) take in cold water, which is highly filtered to ultrapure specifications, and then return it to its source at elevated temperatures. Water demand for once-through systems is 30 to 50 times higher than for closed-cycle systems, because closed-cycle systems reprocess water within the plant.

#### **Quality required - triangle of utility water analysis**

- All cooling systems require full control of the whole treatment triangle, although open evaporative systems have an increased risk of contaminants and higher concentrations of salt. The exact treatment may vary depending on the bulk water, system size and equipment installed.
- In a conventional chemical treatment system, a service provider or self-administered water maintenance programme consists of adding an oxidising biocide and a combination scale and corrosion inhibitor to the water system. One should monitor chemical treatment to determine the effectiveness of the programme. This will prevent major operating problems in the system.

- ① Water supply line
- ② Point of dilution water removal
- ③ Dilution water line
- ④ ClO<sub>2</sub>/pH/redox measurement
- ⑤ Injection point
- ⑥ Dosing line
- ⑦ Dosing pump chlorite
- ⑧ Dosing pump acid
- ⑨ Dosing pump chlorine dioxide
- ⑩ Reactor



- ⑪ Chlorine dioxide tank
- ⑫ Controller incl. measurement
- ⑬ Selenoid valve for dilution water
- ⑭ Charcoal filter
- ⑮ Sodium chlorite tank with drip pan
- ⑯ Hydrochloric acid tank
- ⑰ Water sampling point
- ⑱ Sample water line
- ⑲ Conductivity controller
- ⑳ Conductivity measurement
- ㉑ Desalination valve
- ㉒ Desalination line
- ㉓ Bypass line
- ㉔ Cooling water pump
- ㉕ Cooling water circuit
- ㉖ Heat exchanger
- ㉗ Primary cooling circuit
- ㉘ Cooling tower

### Practical considerations

The success of a cooling water corrosion inhibitor programme is affected by the following factors:

- Water characteristics: Higher pH and higher Langelier saturation index values prevent corrosion. Within the acid range (pH < 4), the iron oxide film is continually dissolved. In cooling water, the potential for calcium carbonate precipitation increases with higher pH and alkalinity; thus the corrosion rate decreases slightly as pH is increased from 4 to 10. Above pH 10, iron becomes increasingly passive.
- Design considerations: Low water velocity, which occurs in shell-side cooling, increases deposition. This factor must be addressed in the design of the system.



- **Microbiological control:** An effective microbiological control programme is necessary to prevent severe fouling problems. Fouling caused by uncontrolled biological growth can contribute to corrosion by one or more mechanisms.
- **System control:** Even the best treatment technology available will fail without a reasonable level of control. Therefore, careful consideration must be given to system control: the accuracy with which the pH, inhibitor levels, and other water characteristics are maintained.
- **Pretreatment:** Grease and/or corrosion products from previous treatment programmes should be cleaned out, and the system should be treated with a high level of a good inhibitor before normal operation.
- **Contamination:** Contamination can also be a problem. Sulfide, ammonia, and hydrocarbons are among the most severe contaminants. Sulfide is corrosive to steel and copper alloys. Ammonia is corrosive to brass and promotes biological growth. Hydrocarbons promote fouling and biological growth.

### **Seawater cooling**

Seawater is sometimes used to get rid of the heat instead of a cooling tower. As seawater is very aggressive to a number of materials, there are a few points that must be taken into account in such cases.

The reason that seawater becomes aggressive is its high salt content (mainly chloride, typically above 3%).

Other factors that increase the aggressiveness of seawater:

- Biofilm formation
- Temperature increases
- Stagnant conditions
- Increases in chloride content (not as much influence as the two above)
- Pollution (coastal areas)
- Continuous chlorination



**“Rules of thumb”: Materials suitable for seawater****Grundfos materials:**

- Cast iron is not suitable
- EN 1.4408/1.4401 (CF8M/316) is not suitable
- EN 1.4517 (duplex) has limited resistance (max. 25°C)  
(Grundfos pumps normally marked in R version)

**Other materials:**

- Bronze is suitable at low flow rates
- Super duplex/austenitic (PREN value above 40) are suitable at moderate temperatures
- Titanium is fully resistant
- Plastics and coatings are fully resistant
- Nickel alloys are suitable

If EN 1.4517 or the R version of Grundfos pumps are used, unacceptable corrosion problems can be avoided by taking the following points into consideration.

- Seawater temperatures: max. 25- 30°C\*
- Continuous operation (max. period of standstill 6-8 hours)
- Seawater intake at a distance from the coast
- The best way is to start with a low temperature and to use no or intermittent chlorination during the first few weeks.
- \* Above 25°C flushing with fresh water should be carried out on a regular basis (ideally daily but often that will not be possible in cooling applications)

**Coating of pumps**

As an alternative to expensive materials or if the pump requested is not available in the required material, some pump types can be ceramic coated.

The coating used by Grundfos to protect against corrosion from seawater is from Chesterton.

**Control principles and examples**

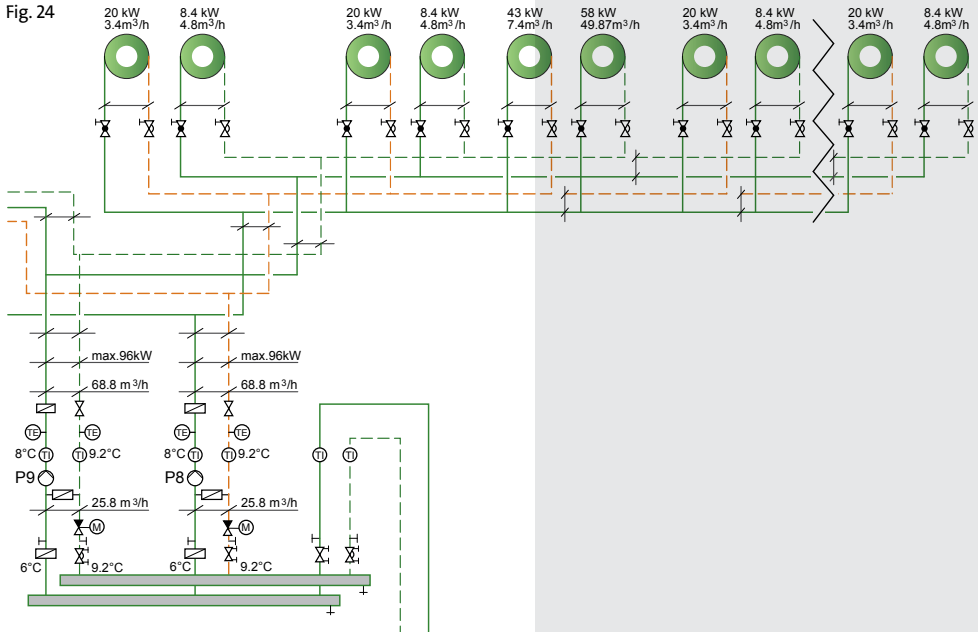
Below are some examples of how different cooling loops can be controlled and what can be done to improve their operation, and thus save energy.

Coating of pumps



**Case 1:**

Supply of cooling water with two main pumps to a number of end users, in this case moulding machines (fig. 24).



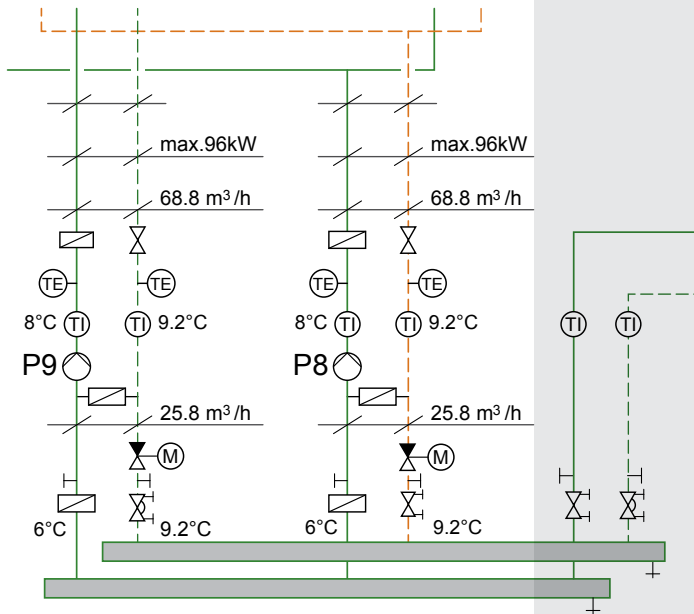
The system operates at full speed on the two main pumps and the different loops are regulated by a throttle valve and an on/off valve. The throttle valve is adjusted once during commissioning. This results in a huge energy loss and in different flows through each loop depending on how many are in use.

The recommendation from Grundfos for a system set up like this will be described in three scenarios.

**Scenario 1:**

In the first step we recommend focusing on the two main pumps because this is where the most energy is used, but also because these days they are operated without regulation, and this leads to differentiation in the flow over each moulding machine depending on the load profile.

Fig. 25



Regulation should proceed by installing frequency converters on each pump and set to maintain constant differential pressure. The sensor should be installed so that it measures the differential pressure directly over the pump (fig. 26). The perfect solution would of course be to measure between the discharge and return pipe farthest away from the pump (fig. 27), but very often it is difficult to determine where it is, and installing measuring cables more than 100 metres away can be costly.

Fig. 26: Differential pressure sensor installed over the pump

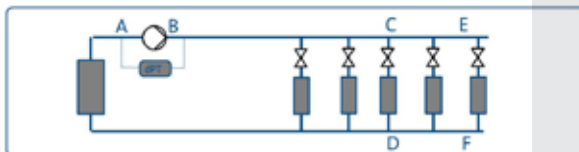
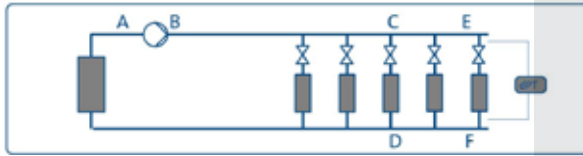


Fig. 27: Differential pressure sensor installed out in the system

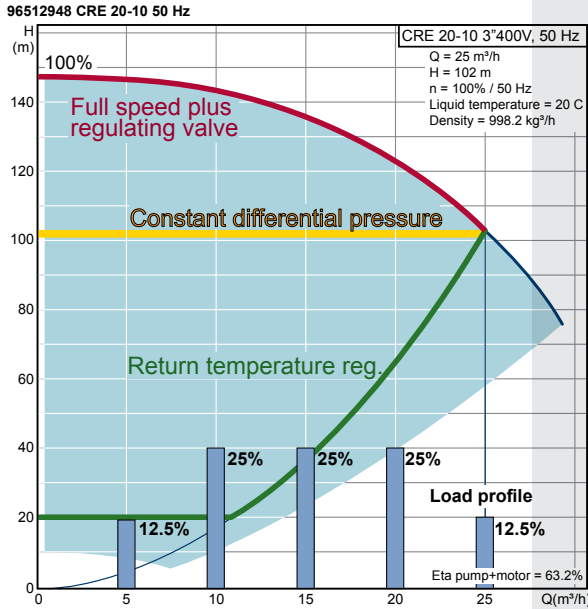


Using the above installation will ensure that the pressure is always maintained at the required level in front of each moulding machine.

Fig. 28 depicts what happens when there is no regulation. The red line indicates where the pump operates when there is no speed regulation. The closure of any valves in the system will entail a slide to the left on the red curve, meaning that the pump will create more and more pressure beyond what is needed. This will result in higher flow in the remaining machines and in a lower  $\Delta t$ . Constant differential pressure ensures that the pressure will always remain the same in the system no matter how valves are opened or closed. The yellow line indicates where it will operate when it runs at constant differential pressure.

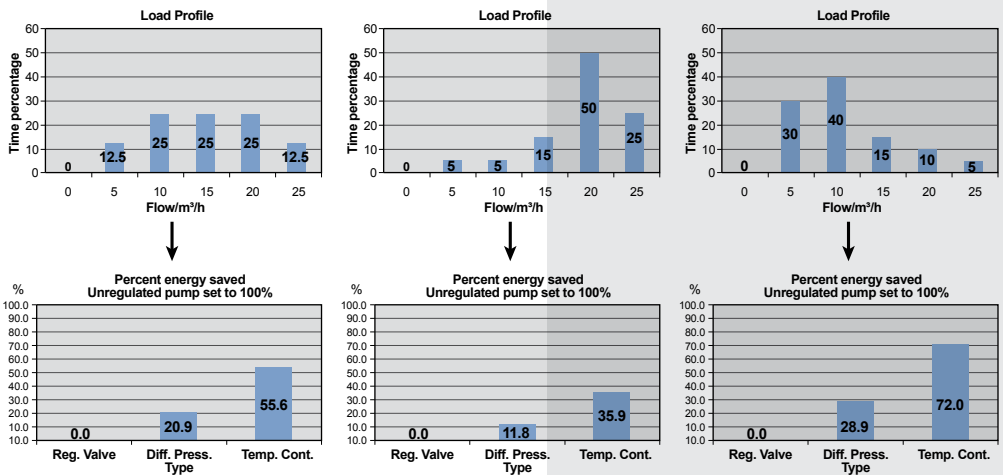
The last curve, the green one, depicts the scenario if the system is regulated on the basis of temperature. Although this is the most economical method, in a system like this it will not work as it only works where there is only one “user” in the system.

Fig. 28: various regulating strategies and load profile



As described above, step 1 ensures that the right amount of cooling water is available in the system and that energy is saved. Fig. 29 shows a comparison of the three different control setups with different load profiles.

Fig. 29



As can be seen from the above comparison, with an average load profile an energy savings of around 20.9% can be achieved by regulating the pumps according to constant differential pressure.

The energy savings in this specific setup with pump P8 and P9 can be calculated as follows. The values below are estimated from the pi diagram in fig. 28.

Flow total: 87.55 m<sup>3</sup>/h  
 Head: 7.5 bar  
 Hours of operation per year 4800 hours

Operation with no regulation:

$$P_1 = \frac{\text{flow} * \text{head} * 2.72 * \text{hours}}{\eta_{\text{pump+motor}}} = \frac{87.55 * 7.5 * 2.72 * 4800}{0.8 * 1000} = 107,161 \text{ kWh}$$

Saving with constant differential pressure:

$$P_1 = * \text{Diff pres type} \rightarrow 107,161 * 0.209 = 22,397 \text{ kWh a year}$$

The above calculations are of course only intended as a guide. If the pressure can be lowered and the system is in operation for more hours, then the saving will of course be much greater.

Also remember that if the load on the motor can be lowered through regulation, maintenance costs will be reduced.

### Scenario 2:

The same regulation on the main pumps as in step 1. The loop for each moulding machine should be regulated according to discharge temperature. This will result in energy savings and a more constant temperature difference over each machine, and will maintain the flow through each moulding machine at the required level, which in the end will lead to optimal operation regardless of the load profile on the rest of the moulding machines.

**Scenario 3:**

The same regulation on the main pumps as in step 1, but the pumps have been downsized in relation to pressure. Instead of running at 7.5 bar they should only run at a pressure that overcomes the loss in the main pipes. A pump, instead of the regulation valve mentioned in step 2, should be installed in the loop for each moulding machine. This pump should have variable speed that overcomes the internal pressure loss in the moulding machine.

This means that the main pumps can be run at a minimum and in the moulding machines where a certain pressure or flow is needed it can be created on an individual basis with the associated pump. The small pumps for each moulding machine should be controlled according to either the discharge temperature from the moulding machine or constant differential pressure over the machine. Which control is chosen depends on how many cooling loops there are in each machine and how different the pressure drops over them are.

**Grundfos setup**

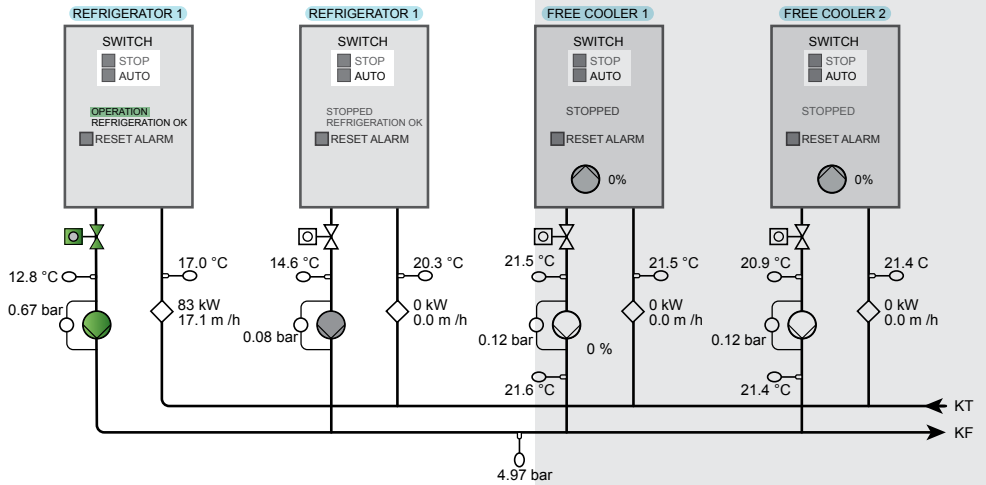
At Grundfos we produce a number of our own moulding machines. The ways in which cooling water is supplied to them are shown in fig. 30.

First we have the primary side of the system, which consists of the cooling machines and the free coolers. If the temperature outside is optimal the process is run with two free coolers, and if not then the cooling compressors are started.



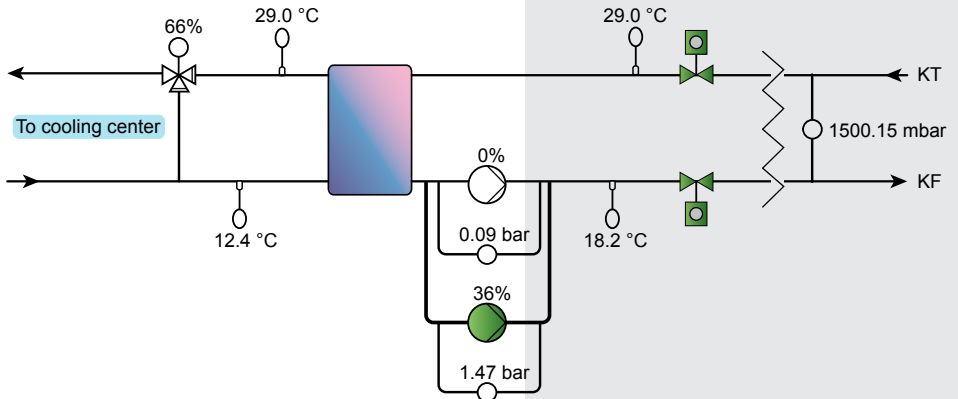


Fig. 30: Cooling system in Grundfos production



The glycol water is led by the pumps to a heat exchanger (fig. 31).

Fig. 31: Cooling system in Grundfos production



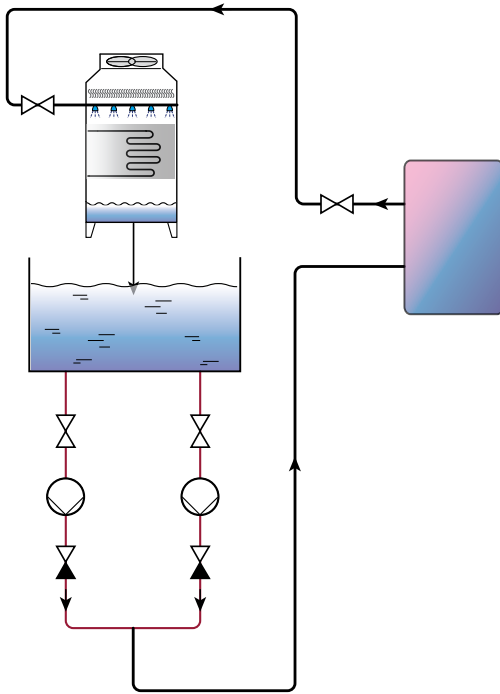
The pressure on the cooling water sent into the moulding machines is maintained by the pumps regulated according to the differential pressure sensor.

The cooling water sent into the moulding machines is used for the secondary processes in the individual machines. Each loop is manually regulated the first time the machine is started. The primary loop (the moulding form) has separate thermic units, because the required temperature differs significantly from mould to mould.

#### Case 2:

Case 2 is from a food factory in China where two pumps circulate water from the condenser in the chiller to the cooling tower (fig. 32).

Fig. 32



Typical thermic unit for cooling



The cooling tower pumps are meant to be operated in a duty standby solution with manually alternation. But in actuality one pump runs in winter and in the spring pump 2 is switched on so that both pumps run in the summer period. There is production 24-4, 350 days a year.

The pump details are as follows.

<b>Pump no 1:</b>	<b>Pump no 2:</b>
P2 : 18.5 kW, 4-pol motor	P2 : 18.5 kW, 4-pol motor
Flow: 200 m <sup>3</sup> /h	Flow: 200 m <sup>3</sup> /h
Head: 20 mV	Head: 20 mV
Age: More than 10 years	Age: More than 10 years

The temperature difference in this system when the system was inspected was very low, at around 2.5°C.

#### Calculation of the energy consumption on the existing pumps:

$$P_1 = \frac{\text{days a year} * \text{hours a day} * \text{flow in } \frac{m^3}{h} * \text{head} * \text{density} * \text{gravity}}{\eta \text{ motor} * \eta \text{ pump} * 3600} = * 3$$

$$P_1 = \frac{350 * 0.5 * 24 * 200 * 32 * 9.81 * 1000}{(0.926 - 0.1) * (0.854 - 0.15) * 3600} = * 3 = 389,752 \text{ kW} / \text{h a year}$$

#### Now the same calculations but with the new Grundfos pumps:

$$P_1 = \frac{\text{days a year} * \text{hours a day} * \text{flow in } \frac{m^3}{h} * \text{head} * \text{density} * \text{gravity}}{\eta \text{ motor} * \eta \text{ pump} * 3600} = * 3$$

$$P_1 = \frac{350 * 0.5 * 24 * 200 * 32 * 9.81 * 1000}{0.926 * 0.854 * 3600} = * 3 = 384,444 \text{ kW} / \text{h a year}$$

#### Potential savings a year by changing pumps:

$$P_{\text{saving}} = 389,725 - 284,444 = 105,307 \frac{\text{kW}}{\text{h}} \text{ a year}$$

The efficiency of the existing motors and pumps are estimated on the basis of our experience. A Grundfos pump for the same job would have an efficiency at the motor of around 92.6% and 85.4% at the pump. But because most pumps lose around 0.5 to 1.5% in efficiency a year depending on maintenance and liquid, in the calculation this is 15% lower. There have been tremendous developments in motor parts over the last few years and because the motors from Grundfos fulfil the EuP rules we estimate that a pump more than ten years old would be at least 10% lower in efficiency. However based on the appearance of these pumps and our knowledge of old “efficiency marking” it is reasonable to suppose that the efficiency of the pump/motor is actually much lower than the figures used in the calculations.

Although the savings potential in the examples is quite significant, the recommendation would be not just to replace the pumps with two new pumps, but to install a booster set of either three or four pumps regulated by frequency converters.

The speed of the pumps should be controlled according to the differential temperature, which as mentioned above is only around 2.5°C. Ideally this should be raised to around 6°C, which would enable the flow in the system to be at least halved.

Calculation of present cooling energy:

$$Q = * m_{\text{average flow a year}} * C * \Delta t = 300 * 1000 * 4.2 * 2.5 = 3150 \text{ MJ}$$

Raising the temperature to 6°C:

$$Q = * m_{\text{average flow a year}} * C * \Delta t = \frac{3150000}{4.2 * 6 * 1000} = 125 \text{ m}^3/\text{h}$$

Power consumption with new flow:

$$P_1 = \frac{350 * 0.5 * 24 * 125 * 32 * 9.81 * 1000}{0.926 * 0.854 * 3600} = * 3 = 173,352 \text{ kW / h a year}$$

So by changing the pumps, adjusting the speed and optimising the operation of the cooling towers, it is possible to achieve an energy savings of around:

$$P_{\text{saved}} = 389,725 - 173,352 = 216,399 \frac{\text{kW}}{\text{h}} \text{ a year}$$

While the above calculation is theoretical, the values used are very conservative. Most likely the savings will be greater because the pumps will not run when they are not required. Furthermore the pressure loss in the system will drop dramatically when you lower the flow in the pipes, which will also result in energy savings. Energy will probably also be saved with the chiller because it will be running with a more constant differential temperature.

## Grundfos products

### Pumps

There are few requirements, mostly determined by Q and h, in connection with pumps on the secondary side (the pumps used in the cases above), although please see the further advice under general pump considerations. The pumps could be NB/NK, TP, CR, etc.

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

For example with standard industrial cooling towers the flow is normally between 25 m<sup>3</sup>/h and 2000 m<sup>3</sup>/h. The largest cooling tower on a 700 MW coal-fired power plant needs up to 71600 m<sup>3</sup>/h of circulating water.

## Cooling unit

In relation to cooling units, at Grundfos we normally refer to cooling equipment built by OEM customers. The units could be for cooling laser welding machines, moulding machines, small chiller units, coolers for electronics, etc. They could also be used for the cooling of hydraulic oil in wind turbines.

In general the two overriding concerns of such customers are reliability and compactness.

### Control techniques

Energy saving very often is not the first priority of these units, as the focus is more on compactness and reliability. Nevertheless, the potential savings in terms of energy and regulation components can be significant if the right control method is chosen.

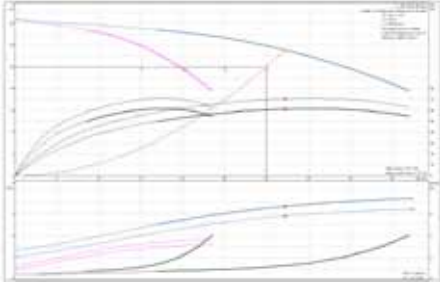
Below is an example of how much energy can be saved even with small pumps. The load profile is from a cooling unit for a wind turbine. The load profile table shows some examples for different operational hours with different flows depending on the load on the turbine.

Load profile		
Q: Flow	h: head in metres	Operation hours
30 m <sup>3</sup> /h	20 m	1760 hours/year
25 m <sup>3</sup> /h		2500 hours/year
20 m <sup>3</sup> /h		2500 hours/year
15 m <sup>3</sup> /h		2000 hours/year

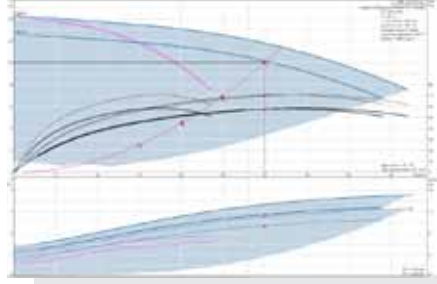


CR pumps are typically used in turbines; these can be implemented as single pumps or in small booster sets with double pumps. The table below shows four examples with different setups which can all supply the required flow.

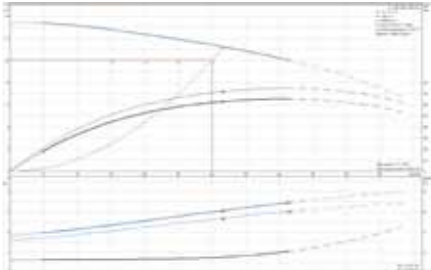
Setup 1: 2 x CR15-2 (2 parallel unregulated pumps)



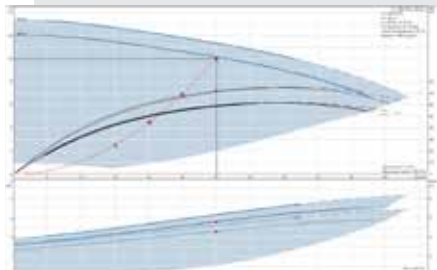
Setup 2 : 2 x CRE15-2 (2 parallel speed regulated pumps)



Setup 3: 1 x CR45-1 (Unregulated pump)



Setup 4 : 1 CRE45-1 (Speed regulated pump)



	Annual power consumption in kW/h			
	Setup 1	Setup 2	Setup 3	Setup 4
<b>Duty point 1</b>	6625	5704	6095	5532
<b>Duty point 2</b>	7869	4299	7151	4078
<b>Duty point 3</b>	7316	2453	6661	2228
<b>Duty point 4</b>	2953	870	4319	749
<b>Total</b>	24267	<b>13326</b>	24226	<b>12587</b>

It can be seen that only half the energy will be required if the pumps are controlled by frequency converters. And as mentioned above, if frequency converters are employed it is often possible to save on other components and to save money on maintenance.

The choice of a single pump or a double solution often depends on safety. For example in setup 2 it would be possible to operate in three of the duty points with only one pump. Should a pump break down power could still be produced by the wind turbine, although potentially on part load rather than full load. Obviously that would not be possible with only one pump.

### Grundfos products

The CR, MTR and the compact CM pump are the Grundfos products most often used in "units".

MTR



CME



CRNE





## General pump considerations

When choosing a pump for a cooling application, the following points must be taken into account before starting to size the pump:

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

When a certain liquid is requested, it is always a good idea to look for it in the **Grundfos Pump Liquid guide**. Almost all the liquids that Grundfos has ever pumped are listed here, along with recommendations of what to take into consideration when choosing a certain liquid. Many of the glycols used in the refrigeration and cooling industry can also be found in WinCaps or WebCaps when sizing the pump.

Information and recommendations in relation to pumping some of the most traditional liquids can be found below.

### Glycol

- The density and viscosity vary significantly depending on the concentration and the temperature of the liquid. An oversized motor may be required.
- If a NB/NK or TP pump is used, a shaft seal with reduced seal faces is normally recommended. The standard cartridge seal in a CR can also be used for glycol.
- Cast iron pumps are normally used but be aware that they sometimes add additives to the cooling water, so stainless steel pumps are required.
- The temperature of glycol is normally low, but it can also be warm, so it must be ensured that the

pump can handle this.

- Glycol is sometimes used as a cleaning agent; if a system has not been thoroughly flushed before, the oils and fats will cause problems with the seal in the first hours of operation.

### Ammonia (NH<sub>3</sub>)

- The density and viscosity of ammonia are different from that of water. It must be ensured that the pump can cope with a viscosity of around 0.3 mm<sup>2</sup>/S, and that the pump is adequately lubricated. A CR can be used for ammonia.
- Ammonia has a low boiling point, which can easily cause cavitation in the inlet of the pump. It must thus be ensured that the inlet pressure is sufficiently high.
- Ammonia is toxic so a back-to-back shaft seal or a Mag-Drive is recommended.
- When ammonia is used in refrigeration plants it always has a concentration of 100%. A mixture of ammonia with water is normally used as a household cleanser and in the manufacture of a wide variety of products, including textiles, rayon, rubber, fertiliser, and plastic. Copper and copper alloys have only limited resistance to ammonium hydroxide.

### Carbon dioxide (CO<sub>2</sub>)

The viscosity of carbon dioxide is so low that a standard pump cannot be used due to the low lubrication capability. RC pumps should be used; please see the last page.





be think innovate

---

**GRUNDFOS Holding A/S**  
Poul Due Jensens Vej 7  
DK-8850 Bjerringbro  
Tel: +45 87 50 14 00  
[www.grundfos.com](http://www.grundfos.com)

**GRUNDFOS** 

The name Grundfos, the Grundfos logo, and be think innovate are registered trademarks owned by Grundfos Holding A/S or Grundfos A/S, Denmark. All rights reserved worldwide.

98389243 1212