Pumpen Intelligenz.

Fundamental principles of pump technology

Pump Basics

AIR CONDITIONING COMPANY

CONTENT


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Fundamental principles of pump technology

Pumps are a vital element of life and comfort for all human beings. Pumps move the fluid whether it is hot or cold, dirty or clean. They do it in a way that is extremely efficient and conserves the environment.

In the field of building technology, pumps have a very important role. They are used for a variety of functions. The most familiar of these is the heating circulating pump. Therefore, it will be the focus of our discussions on the following pages.

In addition, pumps are used in the fields of water supply and wastewater disposal:
- In pressure booster stations, which are used whenever the city water pressure is not sufficient for supplying a building;
- Drinking water circulation pumps, which ensure that hot water is always available at each tap;
- Wastewater lifting pumps, which are required when wastewater or sewage comes from below the backflow level;
- Pumps in fountains or aquariums;
- Pumps for fire-fighting applications;
- Pumps for cold and cooling water;
- Rainwater utilisation systems for toilet flushing, for washing machines, cleaning and irrigation;
- Many other applications.

It is important to remember in this regard that different media have different viscosity levels (such as raw sewage or water-glycol mixtures). Certain standards and guidelines specific to each country must be followed, which may require special pumps and technologies to be selected (such as explosion protection, German Drinking Water Ordinance).

The objective of this brochure is to provide foundational knowledge of pump technology to persons who are currently in vocational or professional training or retraining. Using simple, explanatory sentences, drawings, and examples, it is intended to provide a sufficient base of knowledge for real-world use. This should make the proper selection and use of pumps a matter of everyday routine.

In the chapter entitled Did you know... you can, for each section, test your own comprehension of the material by answering a series of multiple-choice questions.

As an additional option for gaining more in-depth knowledge based on these “Pump Basics,” we also present our selection of informational materials. It includes resources for self-study as well as the field-experience-oriented, hands-on training seminars we offer.

Refer to the chapter on “Informational materials,” page 59

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History of pump technology

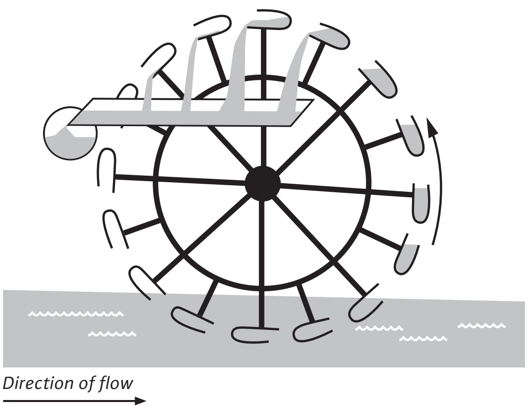
Water Supply

When thinking of pumps and their history, one might recall that since the earliest times, people have sought technical means of lifting fluids–particularly water–to a higher level. This was used both to irrigate fields and to fill the moats that surrounded fortified cities and castles.

The simplest scooping tool is the human hand–and two hands are better than one!

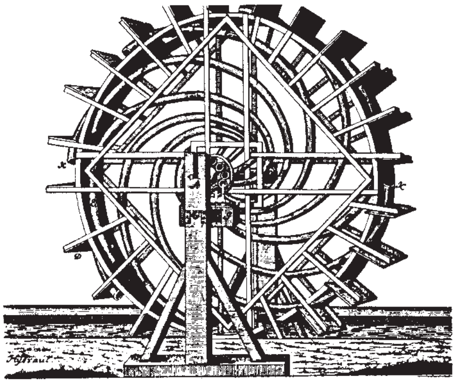
Thus, our prehistoric ancestors quickly had the idea of making clay vessels into scoops. This was the first step towards the invention of the bucket. Multiple buckets were then suspended from a chain or wheel. People or animals used their energy to set this water scoop in motion and lift water. Archaeological digs have found bucket conveyors of this kind in both Egypt and China from around 1000 BC. The following illustration is a reconstruction of a Chinese scoop wheel. This is a wheel with attached clay pots, which pour out the water when they reach the top.

Illustration of a Chinese scoop wheel



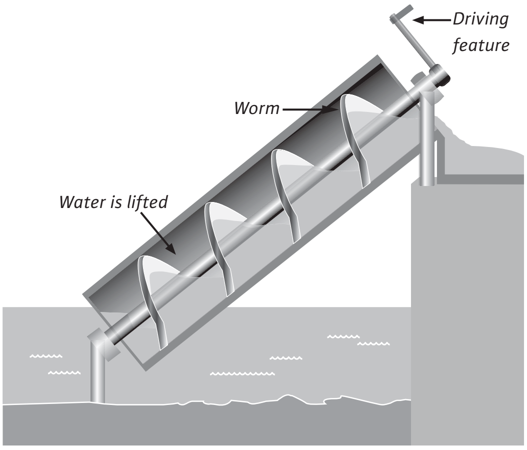
An ingenious improvement on this concept was devised in 1724 by Jacob Leupold (1674–1727), who built bent pipes into a wheel. Turning the wheel forced the water to be lifted to the middle axis of the wheel. The flow of water in a river also serves as the drive of this lifting plant. A particularly noteworthy feature of this design is the shape of the bent pipes. It is remarkably similar to the shape of today's centrifugal pumps.

Illustration of Jacob Leupold's water wheel



Archimedes (287–212 BC), the greatest mathematician and scientist of ancient times, described the screw that would later be named after him in 250 BC. It lifted water by turning a spiral/worm in a pipe. However, some of the water always flowed back, as effective sealing was then unknown. As a result, a relationship was observed between the incline of the screw and the flow rate. A choice could be made in operation between a greater quantity or a greater delivery head. The steeper the incline of the screw, the higher the delivery head when the quantity decreases.

Illustration of Archimedes' screw



Here, too, the operating behaviour is remarkably similar to today's centrifugal pumps. The pump curve–which, of course, was an unknown concept at the time–shows the same relationship between the delivery head and the flow rate. Information gathered from various historical sources has revealed that these screw pumps were operated at inclines between 37° and 45°. They produced delivery heads of between 2 m and 6 m and maximum flow rates of about 10 m^3/h.

Refer to the chapter on "Impellers," page 22

Wastewater disposal

Although water supply has always been the most basic necessity for human life, it was only later–almost too late, in fact–that effective wastewater disposal came into existence.

Wherever settlements, towns and cities formed, excrement, filth and sewage polluted streets, paths and other open areas.

Aside from the horrible smell, this also caused diseases and epidemics. Bodies of water were polluted and the groundwater became undrinkable.

The first sewers were built between 3000 and 2000 B C. Under the Palace of Minos at Knossos (Crete), brick-lined channels and terra cotta pipes have been discovered that served to collect and drain rainwater, bath water and sewage. The Romans built sewers in and underneath the streets–the largest and most famous being the city's Cloaca Maxima, parts of which are remarkably well preserved to this day. From here, water was fed to the river Tiber (the city of Cologne, Germany also has some underground tunnels you can walk through that were sewers in Roman times).

Since no further progress was made in the thousands of years that followed, untreated sewage was still being fed into streams, rivers, lakes and seas as late as the nineteenth century. Industrialisation and the growth of cities made effective wastewater disposal essential.

The first centralised sewer and wastewater treatment system in Germany was created in Hamburg in 1856.
As late as the 90s, many household sewage systems in Germany still consisted of septic pits and drainage pits. Only later did legal decisions and regional requirements require these to be connected to the public sewer system.

Today, the drains of almost all houses are connected directly to the public sewer system. Where this is impossible, lifting plants or pressure drainage systems are used.

Industrial and household wastewater is fed through far-reaching sewer systems, retention ponds, treatment plants and clarification ponds, and biologically or chemically cleaned in the process. After treatment, the water is returned to natural circulation.

The most varied pumps and pump systems are used in wastewater disposal. Here are just a few examples:
- Lifting plants
- Submersible pumps
- Sump pumps (with and without macerator)
- Drainage pumps
- Agitator pumps

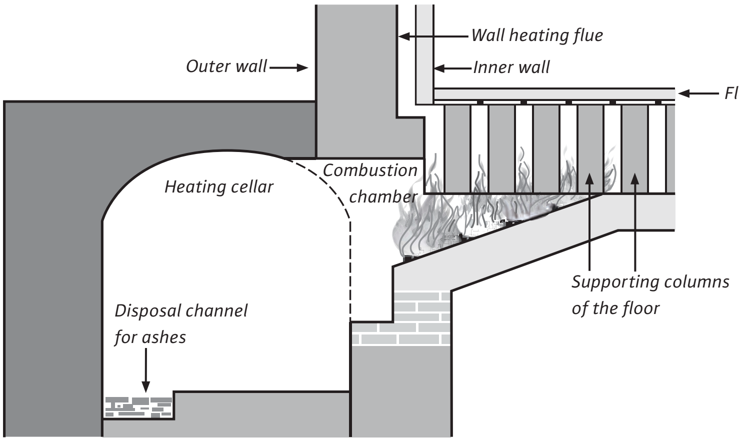
Heating technology

Hypocaust heating systems

Relics of what are called hypocaust heating systems from Roman times have been found in Germany. These are an early form of floor heating. The smoke and hot air from an open fire were channelled through special chambers underneath the floors, thus heating the floors. The gases then escaped to the outside through wall flues.

In the centuries to follow, particularly in castles and fortresses, the chimneys, which likewise covered open fires, were not built in a strictly vertical direction. Instead, the hot fumes were channelled past living quarters–one of the first forms of central heating. Another invention was a system separation using walled stone chambers in the cellar. The fire heated fresh air, which could then be guided directly into the common rooms.

Illustration of a hypocaust heating system from Roman times

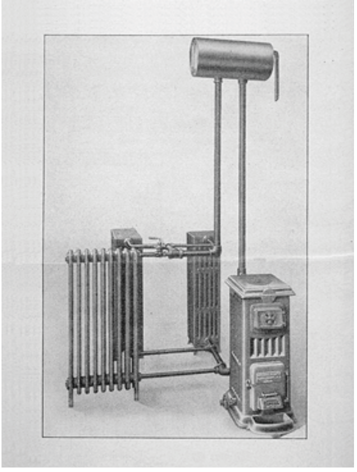


Steam heating system

Steam heating systems were a by-product of the steam engine, which came into widespread use in the second half of the eighteenth century. The leftover steam, which did not condense in the steam engine, was guided into offices and living spaces by heat exchangers. One thought was to use the residual energy of a steam heating system to drive a turbine.

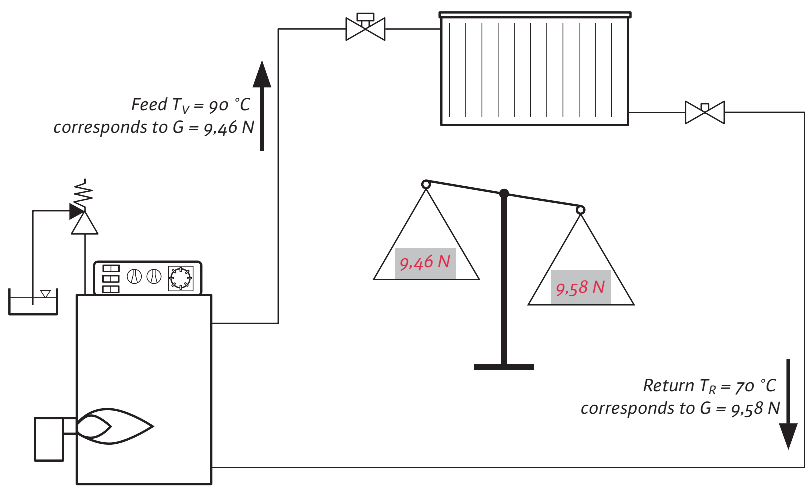
Gravitational heating system

The next stage of development was the gravitational heating system. Experience showed that to provide a room temperature of 20°C, water only needed to be heated to approx. 90°C, which is just under the boiling point. The hot water rose upwards in pipelines with very large diameters. Once it had given off some of its heat (cooled off), it flowed back to the boiler through gravity.



Gravitational heating system with boiler, expansion tank and radiator

Schematic of a gravitational heating system



The different gravitational forces push the water up and down.

As early as the early twentieth century, the slow start-up of this kind of gravitational circulation system led to the idea of building what are known as "circulation accelerators" into the pipelines of a heating system.

The electric motors of those days were not suitable for use as drives, as they operated with open slip ring rotors. These could have caused major accidents in a water-based heating system.

First heating circulating pump

It was not until Swabian engineer Gottlob Bauknecht invented the enclosed or "canned" electric motor that it became possible to use one for a circulation accelerator. His friend, the Westphalian engineer Wilhelm Opländer, developed a design of this type, for which he was awarded a patent in 1929.

Zu der Patentschrift 540 139
Kl. 36c Gr. 4

Dipl.-Ing. Wilhelm Opländer in Dortmund

Aus einem Propeller bestehender Umlaufbeschleuniger in der Leitung einer Warmwasserheizungsanlage

Patentiert im Deutschen Reiche vom 13. November 1929 ab

A pump wheel in the shape of a propeller was installed in a pipe elbow. It was driven by a sealed shaft which, in turn, was driven by the electric motor.

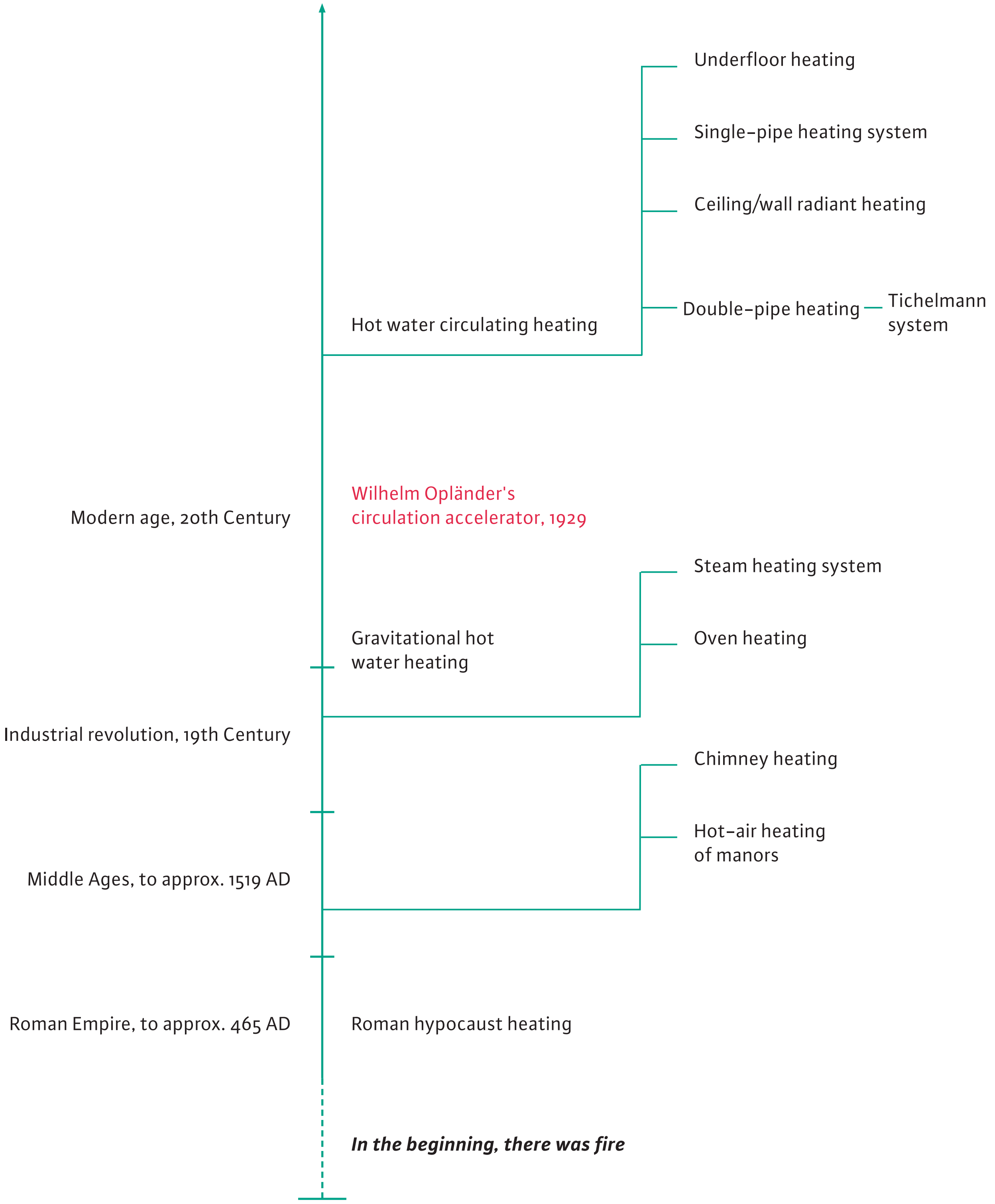
However, no one yet thought to use the term pump for this accelerator. Only later was this term used in this context. This is because, as we have already seen, pumps were associated with lifting water.

These circulation accelerators were built until approximately 1955, and their use allowed the heating water temperature to be lowered even further.

Today, there are a variety of heating systems, the most modern of which work with very low water temperatures. Without the heart of the heating system—the heating circulating pump—heating technology of this kind be impossible.

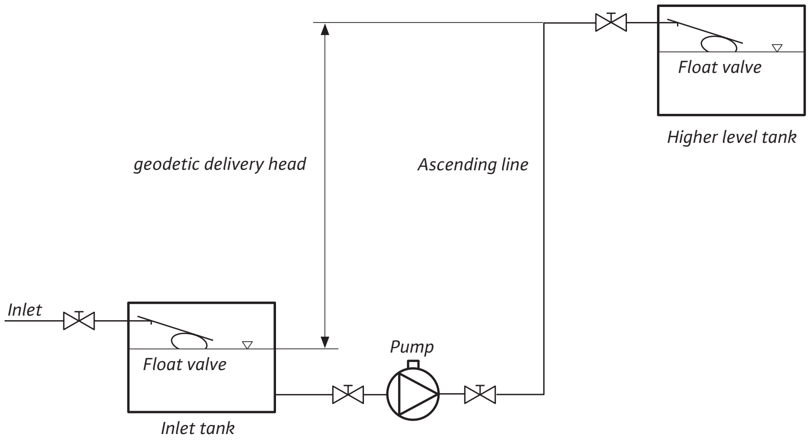
First heating circulating pump,
the "elbow pump", model year 1929,
HP type DN 67/0.25 kW

Evolution of the heating system



Pumping systems

Open water pumping system



Pump system for pumping water to a higher level

Refer to the chapter on "Adjusting the pump to the heat demand," page 35

Open water pumping system

The schematic diagram at the left shows the components that belong to a pump system that pumps a fluid from a low-lying inlet tank to a tank that is at a higher elevation. The pump transports the water from the bottom tank to the required height.

Here, it is not sufficient to design the capacity of the pump for the geodetic delivery head. This is because there must still be enough flow pressure at the last faucet, such as a shower on the top floor of a hotel. The pipe friction losses that occur in the ascending line must also be taken into account.

Pump delivery head = geodetic delivery head + flow pressure + pipeline losses

The individual sections of the line must be able to be blocked off using fittings so that necessary repairs can be carried out. This is particularly true for pumps, as otherwise large quantities of water have to be drained from the ascending lines before the pump is repaired or replaced.

Furthermore, float valves or other controller units must be provided in the lower-lying inlet tank and in the higher-level tank to prevent any overflows.

In addition, a pressure switch can be installed at an appropriate location in the ascending line to switch off the pump when all taps have been closed and no more water is being withdrawn.

Closed heating system

At the right is a schematic illustration of the functional differences between a heating system and a water pumping system.

While a water pumping system is an open system with an open outlet (a tapping point such as a faucet), a heating system is a self-enclosed system.

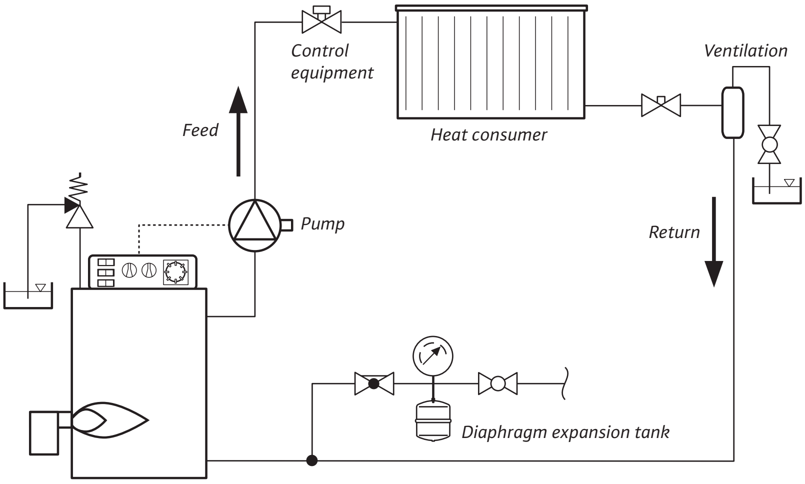
To understand the principle even more easily, consider that all the heating water does is keep moving or circulating in the pipelines.

The heating system can be divided into the following components:
- Heat generator
- Heat transport and distribution system
- Diaphragm expansion tank for pressure continuity and pressure control
- Heat consumers
- Control equipment
- Safety valve

Heat generators are defined here as units such as boilers that use gas, oil, or solid fuel, as well as circulating water heaters. They also include electric storage heating systems with central water heating, district heating stations and heat pumps.

The heat transport and distribution system includes all pipelines, distribution and collection stations, and, of course, the circulating pump. The pump output in a heating system is to be designed only to overcome the overall resistance of the system. The building height is not taken into consideration, as the water that the pump forces into the feed line pushes the water in the return line back to the boiler.

Closed heating system



Circulating system using the example of a heating system

The diaphragm expansion tank is responsible for compensating for the changing water volume in the heating system, depending on the operating temperatures, while simultaneously maintaining pressure continuity.

Heat consumers are the heating surfaces in the rooms to be heated (radiators, convector heaters, panel heaters etc.). Heat energy flows from points at a lower temperature to points at a higher temperature–and the greater the temperature difference, the quicker the flow. This transfer takes place by means of three different physical processes:
- Heat conduction
- Convection
- Radiation.

Note to remember:
The building height is not taken into consideration, as the water that the pump forces into the feed line pushes the water in the return line back to the boiler.

Today, no technical problem can be solved without a good control system. Thus, it is only natural that control units are a part of every heating system. The most easily understood of these are thermostatic radiator valves for maintaining constant room temperature. Nowadays, there are also highly advanced mechanical, electrical and electronic controls in heating boilers, mixing valves and, of course, in pumps.

Refer to the chapter on "Rough pump design for standard heating systems," page 41

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Water – our means of transport

In hot water central heating systems, water is used to transport heat from the generator to the consumer.

The most important properties of water are:
- Heat storage capacity
- Increase of volume, both when heated and when cooled
- Decrease of density with increasing and decreasing volume
- Boiling characteristics under external pressure
- Gravitational buoyancy

These physical properties will be discussed below.

Specific heat storage capacity

An important property of every heat-carrying medium is its heat storage capacity. When expressed in terms of the mass and temperature differential of the material, this is referred to as the specific heat storage capacity.

The symbol for this is c, and the unit of measure is $kJ/(kg \cdot K)$

The specific heat storage capacity is the quantity of heat that must be transferred to 1 kg of the material (such as water) in order to heat it by 1°C. Conversely, the material gives off the same amount of energy when it cools.

The average specific heat storage capacity for water between 0°C and 100°C is:

$c = 4.19\ kJ/(kg \cdot K)$ or $c = 1.16\ Wh/(kg \cdot K)$

The quantity of heat that is absorbed or given off Q, measured in J or kJ, is the product of the mass m, measured in kg, the specific heat storage capacity c, and the temperature difference $\Delta\vartheta$ measured in K. This is the difference between the feed and return temperature of a heating system.
The formula is:

$Q = m \cdot c \cdot \Delta\vartheta$
$m = V \cdot \rho$

V = Water volume in m^3
ρ = Density kg/m^3

The mass m is the water volume V, measured in m^3, multiplied by the density ρ of the water, measured in kg/m^3. Therefore, the formula can also be written as follows:

$Q = V \cdot \rho \cdot c\ (\vartheta_V - \vartheta_R)$

It is true that the density of the water changes along with the water temperature. However, to make energy considerations simpler, the calculation uses $\rho = 1\ kg/dm^3$ between 4°C and 90°C.

The physical terms "energy," "work" and "quantity of heat" are equivalent.

The following formula is used to convert Joules into other permitted units:

$1J = 1\ Nm = 1\ Ws$ or $1\ MJ = 0.278\ kWh$

Note:
The specific heat storage capacity is the quantity of heat that must be transferred to 1 kg of the material (such as water) in order to heat it by 1°C. Conversely, the material gives off the same amount of energy when it cools.

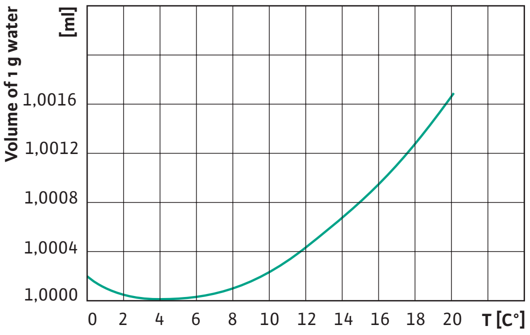
ϑ = *Theta*
ρ = *Rho*

Volume increase and decrease

All materials on the earth expand when heated and contract when cooled. The sole exception to this rule is water. This unique property is called the anomaly of water.

Water has its greatest density at +4°C, which is 1 dm^3 = 1 l = 1 kg.

Change in water volume



Volume change of water when heated/cooled. Highest density at 4°C: ρ_{max} = 1000 kg/m^3

If the water is heated or cooled from this temperature point, its volume increases, meaning that its density decreases and it becomes specifically lighter.

This can be seen quite well in a tank with measured overflow.

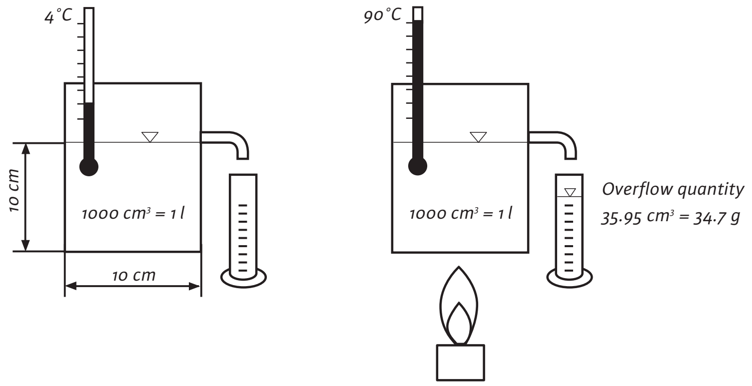
In the tank, exactly 1,000 cm^3 water are at a temperature of +4°C. If the water is heated, some of it will flow through the overflow into the measuring glass. If the water is heated to 90°C, there are precisely 35.95 cm^3, which correspond to 34.7 g, in the measuring glass.

Water also expands when cooled to a temperature below +4°C. This anomaly of water is why rivers and lakes freeze over in winter. It is why ice floes float on the water, allowing them to be melted by the spring sun. That would not happen if the ice sank to the bottom because it was specifically heavier.

However, this expansion behaviour can be perilous when human beings use water. For example, auto engines and water pipes explode if they freeze. To prevent this, antifreeze compounds are added to the water. In heating systems, glycols are often used; refer to the manufacturer's specifications for the proportion of glycol.

Water cube of 1000 cm^3 contains 1000 g at 4°C

1000 cm^3 water at 90°C = 965.3 g



When water is heated or cooled, its density becomes lower, meaning that it becomes specifically lighter and the volume increases.

Boiling characteristics of water

If water is heated past 90°C, it will boil in an open container at 100°C. If the water temperature is measured during the boiling process, it remains constant at 100°C until the last drop has vaporised. Therefore, the constant supply of heat is used to completely vaporise the water and thus to change its aggregate state. This energy is also referred to as latent (hidden) heat. If the heat continues to be applied, the temperature rises again.

The condition for the sequence reflected here that a normal air pressure (NN) of 1.013 hPa must exist at the water level. At any other air pressure, the boiling point moves away from 100°C.

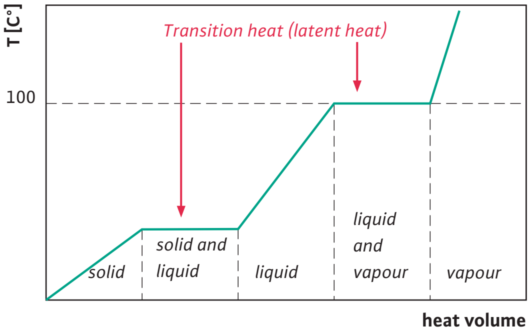
If we were to repeat the experiment just described at a height of 3000 m–for example on the Zugspitze, Germany's highest mountain–we would find that water already boils at 90°C. The cause of this behaviour is the fact that the air pressure decreases at higher elevations.

The lower the air pressure on the surface of the water, the lower the boiling temperature will be. Conversely, the boiling temperature can be increased by increasing the pressure on the surface of the water. This principle is used in pressure-cookers, for example.

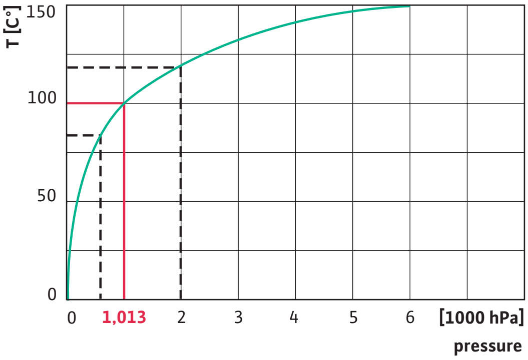
The graphic to the right shows how the boiling temperature of water changes depending on the pressure.

Heating systems are purposely pressurised. This prevents gas bubbles from forming in critical operating states. This also prevents air from penetrating the water system from the outside.

Change of aggregate state at increasing temperatures



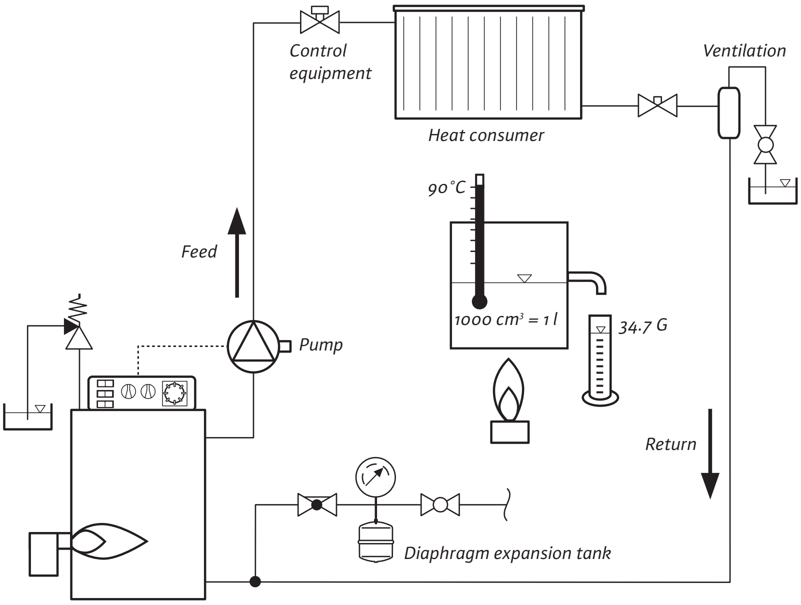
Boiling point of water as a function of pressure



Expansion of the heating water and protection against excess pressure

Hot water heating systems are operated at feed temperatures of up to 90°C. The water is normally at a temperature of 15°C when filled, and then expands when heated.
This increase of volume may not result in excess pressure or cause the fluid to escape.

Illustration of a heating system with integrated safety valve



When the heat is switched off in summer, the water returns to its previous volume. Therefore, a sufficiently large holding tank must be provided for the expansion water. Older heating systems have open, built-in expansion tanks. They are always located above the highest pipeline section. When the heating temperature rises, causing the water to expand, the water level in this tank also rises. Likewise, it falls when the heating temperature falls.

Today's heating systems use diaphragm expansion tanks (DET).

It must be ensured that when the system pressure is increased, the pipelines and other parts of the system are not pressurised to an extent beyond that permitted. Therefore, it is mandatory to equip each heating system with a safety valve.

Note to remember:
When there is excess pressure, the safety valve must open and blow out the expansion water.

When there is excess pressure, the safety valve must open and blow out the expansion water that cannot be held by the diaphragm expansion tank. However, in a carefully designed and maintained system, this operating state should never happen in the first place.

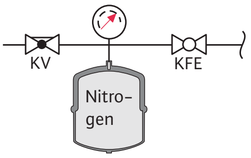
The above considerations did not take into account the fact that the heating circulating pump increases the system pressure even more.

The interaction of the maximum heating water temperature, the pump selected, the size of the diaphragm expansion tank and the response point of the safety valve must be considered very carefully. Selecting the parts of the system randomly – or even based on the purchase price – is never an acceptable option.

The tank is delivered filled with nitrogen. The inlet pressure of the diaphragm expansion tank must be adjusted to the heating system. The expansion water from the heating system enters the tank and compresses the gas cushion via a diaphragm. Gases can be compressed, but fluids cannot.

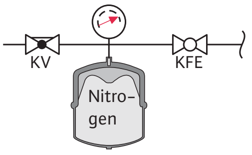
Compensation for the changing water volume in the heating system:

(1) DET condition at
installation



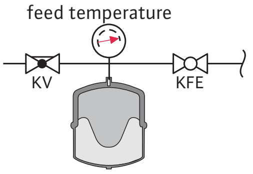
DET inlet pressure 1.0/1.5 bar

(2) System filled /cold



Water reserve DET inlet
pressure +0.5 bar

(3) System at max.
feed temperature



Water quantity = water reserve
+ expansion

Pressure

Definition of pressure

Pressure is the measured static pressure of fluids and gases in pressure vessels or pipelines relative to the atmosphere (Pa, mbar, bar).

Standing pressure

Static pressure when no medium is flowing. Static pressure = level above the corresponding measuring point + inlet pressure in diaphragm expansion tank.

Flow pressure

Dynamic pressure when a medium is flowing. Flow pressure = dynamic pressure – pressure drop.

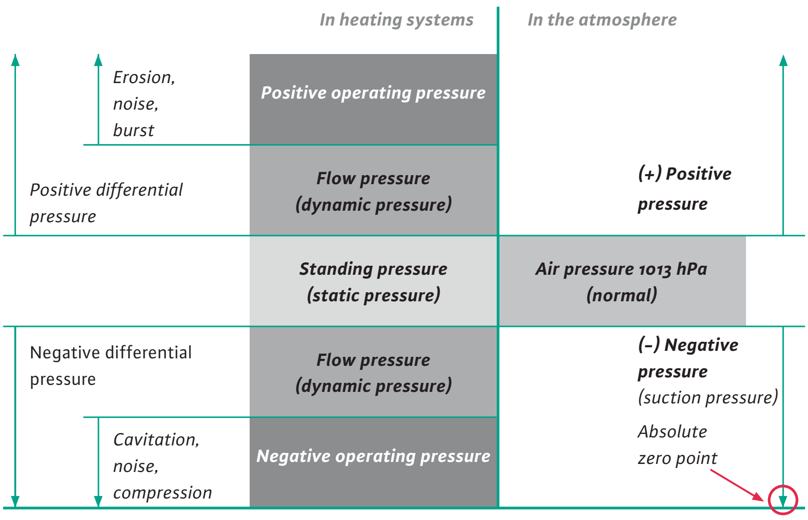
Pump pressure

Pressure generated on the discharge side of the centrifugal pump during operation. Depending on the system, this value can differ from the differential pressure.

Differential pressure

Pressure generated by the centrifugal pump to overcome the sum of all resistances in a system. It is measured between the suction and discharge side of the centrifugal pump. Because of the decrease in pump pressure due to the losses along the pipelines, the boiler fittings and the consumers, the operating pressure differs at each location of the system.

System pressure, pressure build-up



Operating pressure

Pressure that exists or can exist when operating a system or individual parts of it.

Permitted operating pressure

Maximum value for the operating pressure determined for safety reasons.

Cavitation

Cavitation is defined as the formation and implosion of gas bubbles (cavities) as a result of local negative pressure formation under the vaporisation pressure of the pumped fluid at the impeller inlet. This results in decreased output (delivery head) and efficiency, and causes rough running, noise and material damage to the interior of the pump.

Through the expansion and collapse (implosion) of tiny air bubbles in areas of higher pressure (for example, in an advanced state, at the impeller outlet) microscopic explosions cause pressure impacts that damage or destroy the hydraulics. The first signs of this are noise from or damage to the impeller inlet.

One important value for a centrifugal pump is the NPSH (Net Positive Suction Head). This specifies the minimum pressure at the pump inlet that is required by this pump type to work without cavitation, meaning the additional pressure required to prevent evaporation of the fluid and to keep it in a fluid state.

Pump factors that affect the NPSH are the impeller type and pump speed. Environmental factors that affect it are the fluid temperature, water coverage and atmospheric pressure.

Preventing cavitation

To prevent cavitation, the pumped fluid must be fed to the centrifugal pump at a certain inlet height. This minimum inlet height depends on the temperature and pressure of the pumped fluid.

Other ways to prevent cavitation include:
- Increasing the static pressure
- Lowering the fluid temperature (reducing the vapour pressure PD)
- Selecting a pump with a lower maintained pressure head (minimum inlet height, NPSH)

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Design of centrifugal pumps

In the plumbing and HVAC industries, centrifugal pumps are used in the most varied fields. Their distinguishing features are the type of their design and the way they convert energy.

Self-priming and non-self-priming pumps

A self-priming pump is conditionally able to bleed the suction line, i.e. to evacuate air. The pump may need to be filled multiple times at commissioning. The theoretical max. suction head is 10.33 and is dependent on the air pressure (1013 hPa = normal).

For technical reasons, only a max. suction head h_s of 7–8 m can be attained. This value contains not only the height difference from the lowest possible water surface to the suction port of the pump, but also the resistance losses in the connection lines, pump and fittings.

When designing the pump, note that the suction head h_s must be included in the designed delivery head, preceded by a minus sign.

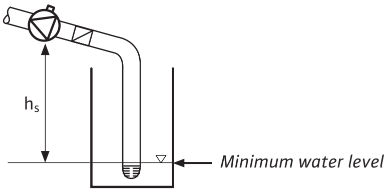
The suction line must be at least the same nominal diameter as the pump port, or one nominal diameter larger if possible. Its length should be kept as short as possible.

Long suction lines create increased friction resistances that are highly detrimental to the suction head.

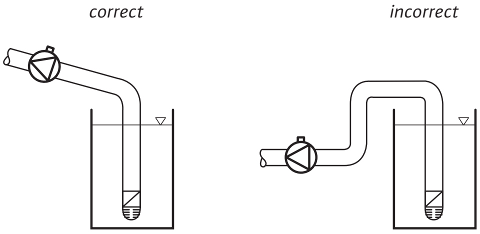
The suction line should be positioned so that it is always going uphill towards the pump. If hose material is used for the suction line, spiral suction hoses are preferable because of its strength and resistance to leaks. It is imperative to prevent leaks as otherwise damage and malfunction of the pump may result.

For suction operation, a foot valve is always recommended to prevent the pump and suction line from running empty. A foot valve with strainer also protects the pump and downstream systems from coarse impurities such as leaves, wood, rocks, and bugs. If it is not possible to use a foot valve, for suction operation, a non-return flap/valve should be installed ahead of the pump (pump suction port).

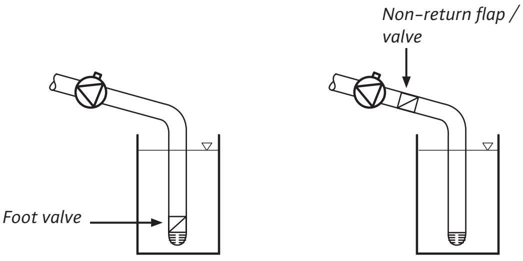
Suction head of the pump h_s



Positioning the suction line



Suction operation



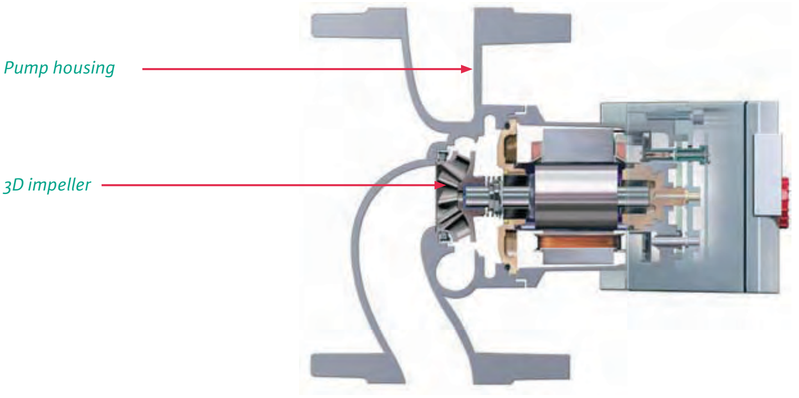
Installation with foot valve or non-return flap/valve

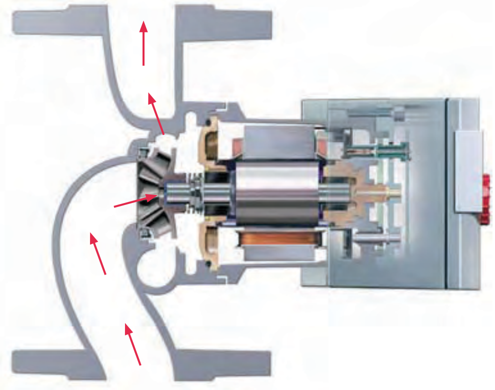
A non-self-priming pump is not capable of evacuating air from the suction line.

When non-self-priming pumps are used, the pump and suction line must be completely filled at all times.
If air gets into the pump through leak points such as the stuffing box of the gate valve or through a foot valve in the suction line that does not close, the pump and suction line must be refilled.

Function of centrifugal pumps

Cut-away view of a glandless pump





The fluid enters the impeller axially and is deflected radially

Pumps are necessary for transporting fluids and for overcoming the flow resistances encountered in the pipe system. In pump systems with different fluid levels, this also involves overcoming the geodetic head difference.

Because of their design and the way they convert energy, centrifugal pumps are hydraulic fluid flow engines. Although there is a variety of types, one feature shared by all centrifugal pumps is that the fluid enters an impeller axially.

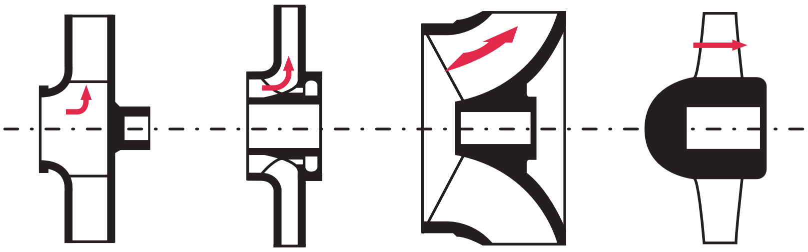
An electric motor drives the pump shaft on which the impeller is seated. The water that enters the impeller axially through the suction port and the suction neck is deflected by the impeller vanes in a radial movement. The centrifugal forces that affect each particle of fluid cause both the speed and pressure to increase when water flows through the vane area.

After the fluid exits the impeller, it is collected in the volute housing. The flow velocity is slowed somewhat by the housing construction. The pressure is further increased by the energy conversion.

A pump consists of the following main components:
- Pump housing
- Motor
- Impeller

Impellers

Impeller types



Radial impeller *Radial impeller 3D* *Semi-axial impeller* *Axial impeller*

Impellers come in a variety of types and can be either open or closed.

The impellers in the majority of today's pumps have a 3D design that combines the advantages of an axial wheel with those of a radial wheel.

Pump efficiency

The efficiency of any machine is the ratio of its power output to its power input. This ratio is symbolised by the Greek letter η (eta).

Since there is no such thing as a lossless drive, η is always less than 1 (100 %). For a heating circulating pump, the total efficiency is made up of the motor efficiency η_M (electrical and mechanical) and the hydraulic efficiency η_P. Multiplying these two values together yields the total efficiency η_{tot}.

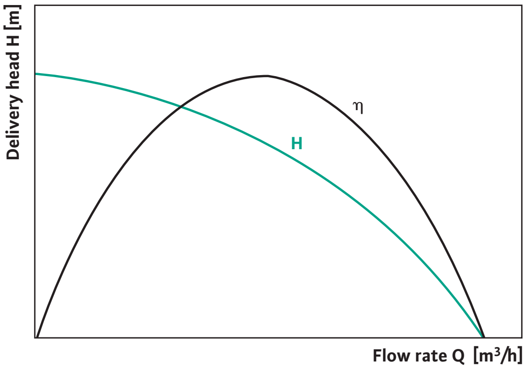
$$\eta_{tot} = \eta_M \cdot \eta_P$$

Depending on which of the many pump types and sizes are examined, the efficiency can vary quite widely. For glandless pumps, the efficiencies η_{tot} are between 5 % and 54 % (high-efficiency pump); for glanded pumps, η_{tot} is between 30 % and 80 %.

Even within the pump curve field, the current efficiency at any given time also changes between zero and a maximum value.

Although a high pump pressure is generated if the pump works against a closed valve, because no water is flowing, the efficiency of the pump is zero. The same holds true for an open pipe. Although there is a large quantity of water, no pressure is built up and thus no efficiency is achieved.

Pump curve and efficiency



The best total efficiency of the heating circulating pump is in the middle field of the pump curve. In the catalogues of pump manufacturers, these optimum duty points are specially identified for each pump.

A pump never operates at a single defined point. Therefore, when designing the pump system, make sure that the duty point of the pump is in the middle one-third of the pump curve for most of the heating season. This will ensure that it works in the optimum efficiency range.

The pump efficiency is determined by the following formula:

$$\eta_p = \frac{Q \cdot H \cdot \rho}{367 \cdot P_2}$$

η_P = Pump efficiency
Q [m^3/h] = Flow rate
H [m] = Delivery head
P_2 [kW] = Output at the pump shaft
367 = Conversion constant
ρ [kg/m^3] = Density of the fluid

The efficiency (or output) of a pump depends on its design.

The following tables provide an overview of the efficiency depending on the selected motor power and the pump design (glandless/glanded pumps).

Efficiency of standard glandless pumps (guide values)

Pumps with motor power P_2	η_{tot}
up to 100 W	approx. 5 % – approx. 25 %
100 to 500 W	approx. 20 % – approx. 40 %
500 to 2500 W	approx. 30 % – approx. 50 %

Efficiency of glanded pumps (guide values)

Pumps with motor power P_2	η_{tot}
up to 1.5 kW	approx. 30 % – approx. 65 %
1.5 to 7.5 kW	approx. 35 % – approx. 75 %
7.5 to 45.0 kW	approx. 40 % – approx. 80 %

Power consumption of centrifugal pumps

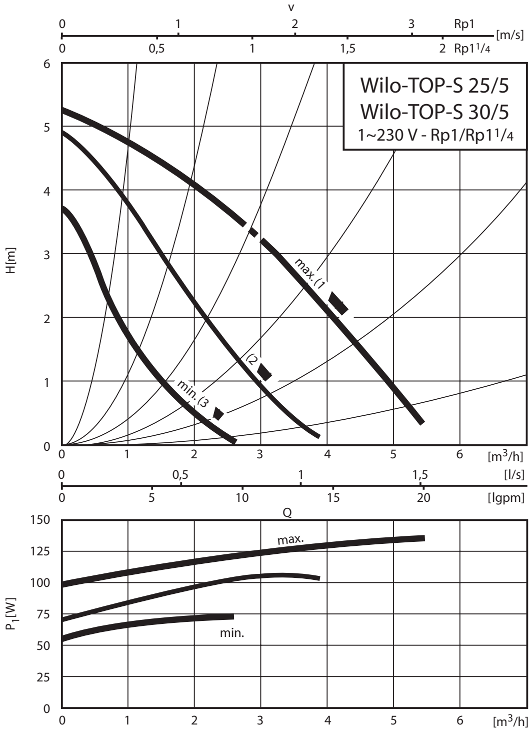
As we have seen in a previous section, an electric motor drives the pump shaft on which the impeller is seated. The pressure boost generated in the pump, and the flow rate through the pump, are the hydraulic output of the electrical drive energy. The energy required by the motor is called the power consumption P_1 of the pump.

Refer to the chapter on "Curves," page 31

Output curve of the pumps

The output curves of centrifugal pumps are shown in a diagram: the vertical axis, the ordinate, plots the power consumption P_1 of the pump in watts [W]. The horizontal axis or abscissa plots the flow rate Q of the pump in cubic metres per hour [m^3/h]. (This is also true for the pump curve, which we will discuss later.) The scale gradations are selected based on the same scale. In catalogues, these two curves are frequently superimposed to clearly illustrate the relationships.

Wilo-TOP-S pump curve



Relationship between pump curve and output curve

Refer to the chapter on "Infinitely variable speed control," page 36

The output curve shows the following relationships: the power consumption of the motor is lowest when the flow rate is also low. When the flow rate increases, the power consumption likewise increases. However, the power consumption changes at a significantly higher ratio than the flow rate.

The effect of the motor speed

If the speed of the pump changes, but all other conditions of the system remain the same, the power consumption P changes roughly proportionately to the speed n cubed.

$$\frac{P_1}{P_2} \approx \left(\frac{n_1}{n_2}\right)^3$$

Based on this knowledge, the pump can be controlled in a logical way and adapted to the heating energy demand. If the speed is doubled, the flow rate increases in the same proportion. The delivery head increases fourfold. The required drive energy is then multiplied by approximately eight. If the speed is lowered, the flow rate, the delivery head in the pipe system and the power consumption are all reduced in the same proportions described above.

Design-related fixed speeds

A distinguishing characteristic of centrifugal pump is the delivery head, which depends on the motor used and the fixed speed that is defined. Pumps with a speed of n > 1500 rpm are called high-speed pumps, and pumps with a speed of n < 1500 rpm are called low-speed pumps.

However, the motor design of low-speed pumps is somewhat more complex, and thus they can be more expensive. However, in situations where use of a low-speed pump is possible or even necessary due to the conditions of the heating circuit, using a higher-speed pump would result in unnecessarily high power consumption. Therefore, the higher purchase price of a lower-speed pump is offset by the substantial savings of drive energy. This quickly pays back the higher initial outlay.

By providing a controlled decrease in speed corresponding to decreased heat demand, the infinitely variable control of the pump electronics provides a significant savings.

Glandless pumps

The installation of a glandless pump, either in the feed or return, moves the water quickly and intensively. As a result, pipelines with smaller pipe cross-sections can be used. The lowers the costs of the heating system. This also means that there is significantly less water in the lines of the heating system. The heating system can react more quickly to temperature fluctuations and can be regulated better.

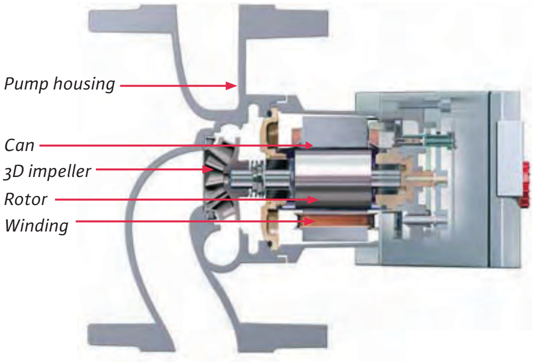
Features

The distinguishing feature of the impeller of a centrifugal pump is its radial acceleration of water. The shaft that drives the impeller is made of stainless steel; the bearings of this shaft are made of sintered carbon or ceramic material. The rotor of the motor, which seated on the shaft, runs in the fluid. The water lubricates the bearings and cools the motor.

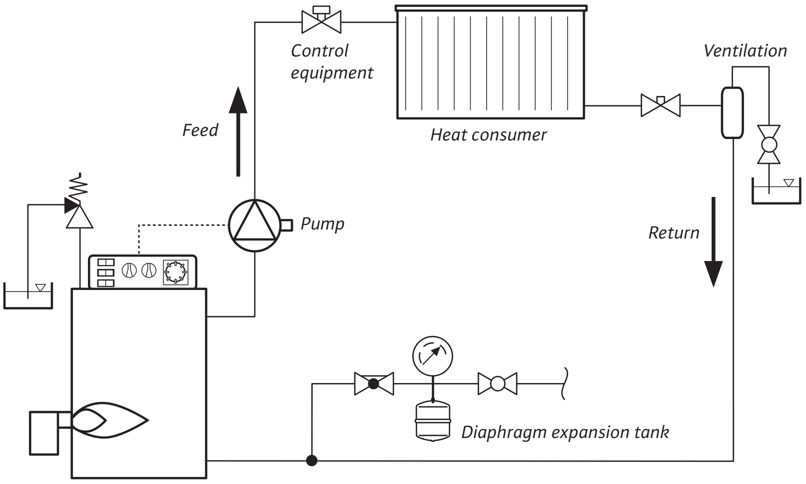
A "can" surrounds the voltage-carrying stator of the motor. It is made of non-magnetisable stainless steel or carbon fibre and has a wall thickness of 0.1 to 0.3 mm.

For special applications such as water pumping systems, pump motors with a fixed speed are used.

If the glandless pump is used in a heating circuit, for example, and thus has to supply heat energy to the radiator, it must adjust to the changing heat demand of the house. Depending on the external temperature and external heat, a different quantity of heating water is required. The thermostatic radiator valves, which are installed ahead of the heating surfaces, determine the delivery rate.



Pump heating system



Thus, the motors of glandless pumps are switched between multiple speeds. The speed can also be changed manually using switches or plugs. Automation can be provided by adding switching and control systems that operate depending on time, pressure differential or temperature.

Since 1988, there have been designs with integrated electronics that provide infinitely variable speed control.

The electrical connection of glandless pumps, depending on the size and required pump output, is either 1~230 V AC or 3~400 V three-phase current.

Glandless pumps feature very smooth running and because of their design, have no shaft seal.

Today's generation of glandless pumps is built on the modular principle. Depending on the pump size and required pump output, the modules are built into different configurations. Therefore, any repairs that may be required can be carried out more easily by simply replacing spare parts.

An important property of this kind of pump is that is capable of bleeding itself at commissioning.

Advantages: smaller pipe cross sections, less water content, faster reaction to temperature fluctuations, lower installation costs

First fully electronic glandless pump with integrated, infinitely variable speed control

Installation positions

Glandless pumps with a nominal port diameter of up to R 1¼ are supplied as screwed pumps. Larger pumps are manufactured with flange connections. These pumps can be installed in the pipeline horizontally or vertically without a foundation.

As mentioned previously, the bearings of the circulating pump are lubricated by the fluid. The media also serves to cool the motor. Therefore, circulation through the can must be ensured at all times.

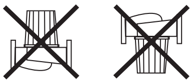
Also, the pump shaft must always be arranged horizontally (glandless pumps, heating). Installation with the shaft standing or hanging vertically causes unstable operating behaviour and thus rapid failure of the pump.

Refer to the installation and operating manual for detailed information about installation positions.

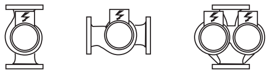
The glandless pumps we have described have good running characteristics by virtue of their design. They are relatively inexpensive to manufacture.

Installation positions for glandless pumps (partial listing)

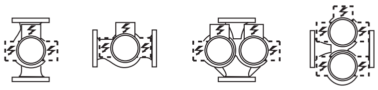
Installation positions not permitted



Permitted without restriction for pumps with infinitely variable control



Permitted without restriction for pumps with 1, 3 or 4 speeds



Glanded pumps

Features

Glanded pumps are used for pumping at high flow rates. They are also better suited for pumping cooling water and aggressive media. Unlike glandless pumps, the fluid does not contact the motor.

Another difference from the glandless pump is the way the water-carrying pump housing/shaft is sealed off from the atmosphere. This seal is created by a stuffing box packing or a mechanical seal.

The motors of standard glanded pumps are normal three-phase motors with a fixed basic speed. They are normally controlled via an external, electronic speed control system. Today, glanded pumps are available with integrated electronic speed control which, thanks to technical developments, is available for increasingly large motor outputs.

The total efficiency of glanded pumps is substantially better than that of glandless pumps.

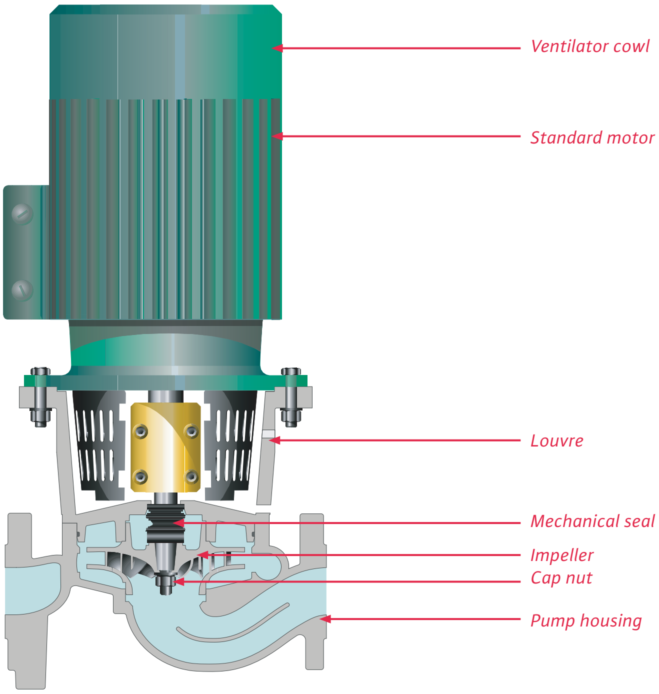
Glanded pumps are divided into three different primary designs:

Inline pumps
Pumps in which the suction port and discharge port are in a single axis and have the same nominal diameter are called inline pumps. Inline pumps have an air-cooled and flange-mounted standard motor.

This type of pump has proven very useful when large outputs are required in building systems. These pumps can be built directly into the pipeline. Either the pipeline is held by brackets or the pump is mounted on a foundation or a separate bracket.

Monobloc pumps
Monobloc pumps are single-speed low-pressure centrifugal pumps in block design with a standard air-cooled motor. The volute housing has an axial suction port and a radial discharge port. Angled or motor feet are installed on the pumps as standard equipment.

Structure of a glanded pump



Standard pumps
For these centrifugal pumps with axial inlet, the pump, coupling and motor are mounted on the same base plate and thus are suitable for foundation installation only.

Depending on the fluid and operating conditions, they are equipped with a mechanical seal or stuffing box. The vertical discharge port determines the nominal diameter of these pump. The horizontal suction port is normally one nominal diameter larger.

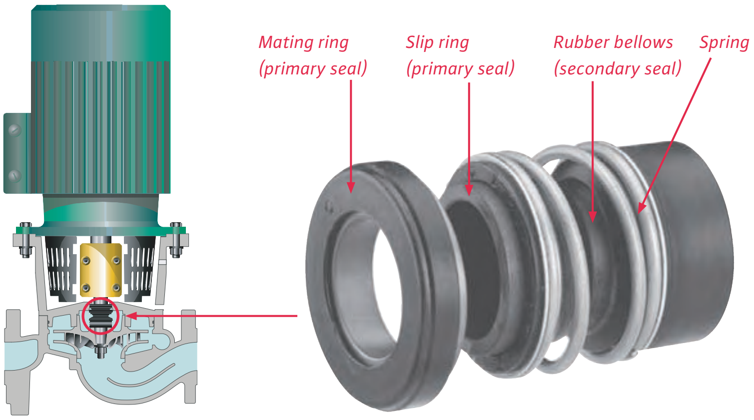
Refer to the chapter on "Shaft seals," page 28

Note to remember:
Mechanical seals are subject to wear and tear. Dry-running is not permissible and will lead to the destruction of the sealing faces.

Shaft seals

As we have seen in the previous section, the shaft can be sealed (especially, and optionally, in the case of standard pumps) from the atmosphere by means of a mechanical seal or a stuffing box packing. Following are descriptions of these two sealing options.

Mechanical seal in a glanded pump



Mechanical seals

The basic design of mechanical seals is two rings with highly polished sealing surfaces. They are pushed together by a spring and run against each other in operation. Mechanical seals are dynamic seals and are used to seal rotating shafts at medium to high working pressures.

The sealing area of the mechanical seal comprises two surface ground, wear-resistant faces (e.g. silicon or carbon rings), which are held together by axial forces. The slip ring (dynamic) rotates with the shaft while the mating ring (static) remains stationary in the housing.

A thin film of water forms between the sliding surfaces that serves as lubrication and cooling.

This can result in various kinds of friction of the sliding surfaces: mixed friction, boundary friction or dry friction, of which the latter (which occurs when there is no lubricating film) causes immediate destruction. The service life depends on the operating conditions such as the composition and temperature of the pumped liquid.

Stuffing boxes

Materials for stuffing boxes include high-quality synthetic yarns such as Kevlar® or Twaron®, PTFE, yarns made of expanded graphite, synthetic mineral fibre yarns as well as natural fibres such as hemp, cotton or ramie. The stuffing box material is available by the metre or as compression-moulded rings, either dry or with special impregnations according to the application. When the material is purchased by the metre, a ring is first cut out and shaped. Then, the stuffing box ring is installed around the pump shaft and pressed into place using the stuffing box gland.

Installation positions

Permitted installation positions

- Inline pumps are designed for direct horizontal and vertical installation in a pipeline.
- Enough clearance should be provided for uninstalling the motor, louvre and impeller.
- When the pump is mounted, the pipeline must be free from tension and the pump must be supported on the pump feet (if present).

Installation positions not permitted

- Installation with the motor and terminal box facing downwards is not permitted.
- If the motor power exceeds a certain level, the manufacturer should be consulted before the pump shaft is installed in a horizontal position.

Special notes on monobloc pumps

- Monobloc pumps must be installed on adequate foundations or brackets.
- Installation of monobloc pumps with the motor and terminal box facing downwards is not permitted. All other installation positions are possible.

Refer to the installation and operating manual for detailed information about installation positions.

High-pressure centrifugal pumps

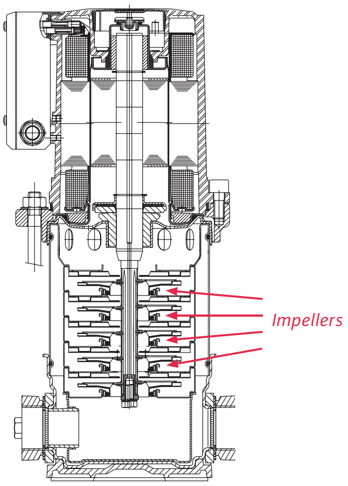
These pumps typically feature multi-component designs with impellers and stage chambers.

The delivery rate of a pump depends on the size of the impeller and other factors. The delivery head of high-pressure centrifugal pumps is generated by multiple impellers/idlers arranged in series. The kinetic energy is converted into pressure, some in the impeller and some in the downstream idler.

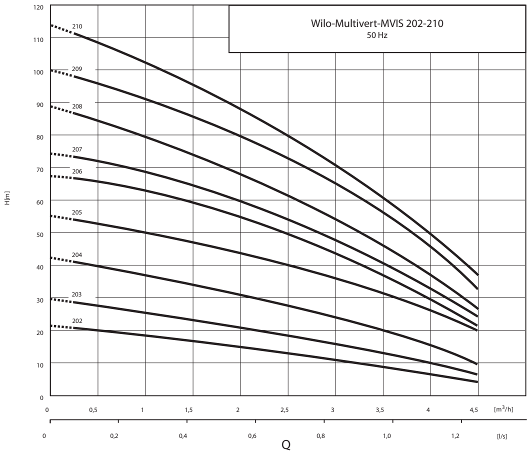
Having multiple speeds allows high-pressure centrifugal pumps to attain higher pressure levels than single-speed, low-pressure centrifugal pumps are capable of.

Very large types have up to 20 speeds. Thus, they achieve delivery heads of up to 250 m. Almost all of the high-pressure centrifugal pumps we have described belong to the glanded pump family. However, manufacturers have recently also been successful in equipping them with glandless motors.

Cut-out of a high-pressure centrifugal pump



High-pressure centrifugal pump curve



Example of a high-pressure centrifugal pump with glandless motor


0,5
1,0
Differenzdruckanzeiger
überdrucksicher bis 25 bar
1,5
1,6
Kl. 2,5
bar
50.6
W
ENERGIE/KOSTEN
MESSEN/ZEIT
LEISTUNG
MIN/MAX
PowerMonitor
Pro

Curves

Pump curve

The pressure boost in the pump is called the delivery head.

Definition of delivery head

The delivery head of a pump H is the usable mechanical work transferred by the pump to the pumped fluid, expressed in terms of the gravitational force of the pumped fluid under the local acceleration of gravity.

$$H = \frac{E}{G} \ [m]$$

E = Usable mechanical energy [N • m]
G = Gravitational force [N]

Here, the pressure boost generated in the pump and the flow rate through the pump are dependent on each other. This dependence is shown in a diagram as a pump curve.

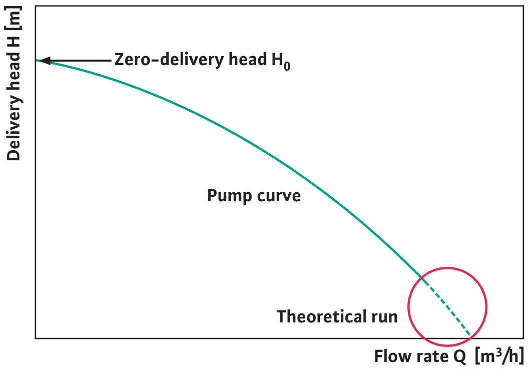
The vertical axis, the ordinate, plots the delivery head H of the pump in metres [m]. Other axis scales are possible. The following conversion values apply:

10 m = 1 bar = 100,000 Pa = 100 kPa

The horizontal axis, the abscissa, plots the scale for the flow rate Q of the pump in cubic metres per hour [m^3/h]. Another axis scale, such as litres per second (l/s), is also possible.

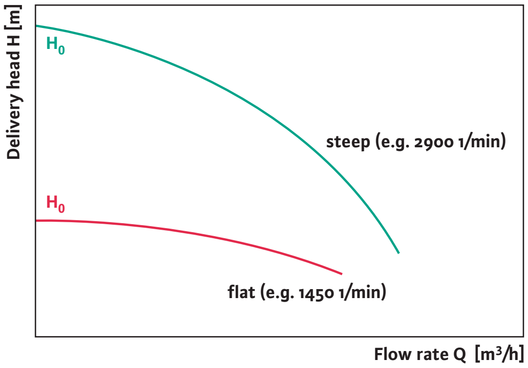
The curve shows the following relationships: the electrical drive energy (taking into account the total efficiency) is converted in the pump into the hydraulic energy forms of pressure boost and motion. If the pump runs against a closed valve, the maximum pump pressure results. This is referred to as the delivery head when Q = 0, or “H_0”, of the pump. If the valve is opened slowly, the fluid begins to flow. This converts some of the drive energy into kinetic energy. The original pressure can then no longer be maintained. The pump curve begins to fall. Theoretically, the pump curve will intersect with the flow axis at the point when only kinetic energy is transmitted to the water and no more pressure is built up. However, since a pipe system always has internal resistance, real pump curves end before reaching the flow axis.

Pump curve



Pump curve shape

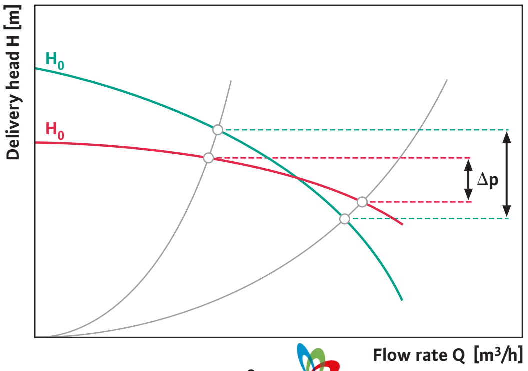
The following illustration shows the different slopes of pump curves which can result depending on the motor speed, for example.



Different slope, for example depending on the motor speed with the same pump housing and impeller

Different flow rate and pressure changes result depending on the slope and changing duty points:

- Flat pump curve
  - Large change in flow rate, but small change in pressure
- Steep pump curve
  - Small change in flow rate, but large change in pressure

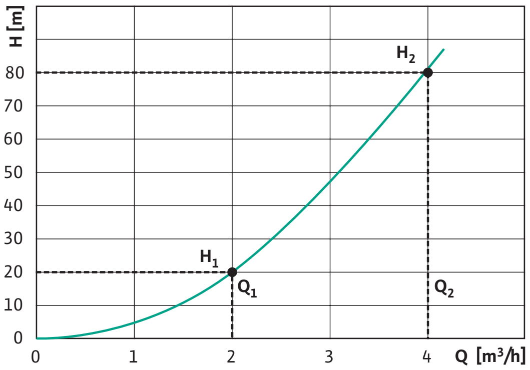


Different flow rate and pressure changes

System curve

The internal pipe friction resistance causes a pressure drop in the pumped fluid that corresponds to the overall length. The pressure drop also depends on the temperature of the flowing fluid, its viscosity, the flow velocity, the fittings, the units, and the pipe friction resistance, which consists of the pipe diameter, pipe roughness and pipe length. It is shown in a system curve. The same diagram is used as for the pump curve.

System curve



The curve shows the following relationships:

Pipe friction resistance is caused by the friction of the water against the pipe walls, the friction of the water droplets against each other, and the direction changes in the moulded parts. When there is a change in the flow rate, such as that caused by the thermostatic radiator valves opening and closing, the water velocity also changes, and thus also the pipe friction resistance. Since the unchanged pipe cross-section must be considered a single area of flow, the resistance changes quadratically. Therefore, a diagram will be in the shape of a parabola.

The following mathematical relationship results:

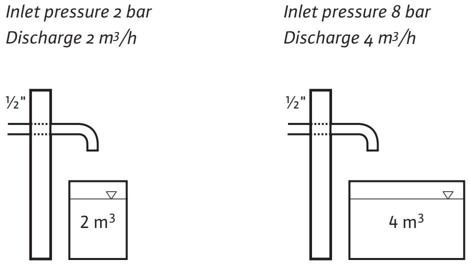
$$\frac{H_1}{H_2} = \left(\frac{Q_1}{Q_2}\right)^2$$

Conclusion

If the flow rate in the pipe system is halved, the delivery head decreases to one-quarter of its previous level. If the flow rate doubles, the delivery head is multiplied by four.

For example, consider the discharge of water from a faucet valve. At an inlet pressure of 2 bar, which corresponds to a pump delivery head of approx. 20 m, water flows from a DN $^1/_2$ faucet valve at a flow rate of 2 m^3/h. To double the flow rate, the inlet pressure must be increased from 2 to 8 bar.

Discharge from a faucet at different inlet pressures


Inlet pressure 2 bar
Discharge 2 m³/h

Inlet pressure 8 bar
Discharge 4 m³/h

Duty point

The point at which the pump curve and the system curve intersect is the current duty point of the heating or water supply system.

This means that at this point, there is equilibrium between the power output of the pump and the power consumption required to overcome the resistance of the pipe system. The pump delivery head is always equal to the flow resistance of the system. This yields the flow rate that the pump can supply.

It must be considered that the flow rate cannot fall below a certain minimum. Otherwise, the pump compartment can overheat, destroying the pump. The manufacturer's specifications must be followed. A duty point that is outside the pump curve will damage the motor.

The duty point also changes continuously due to the changes of the flow rate during operation. The planning engineer must find a design duty point that matches the maximum requirements. For heating circulating pumps, this is the heating load of the building; for pressure boosting systems, this is the peak flow rate for all faucets.

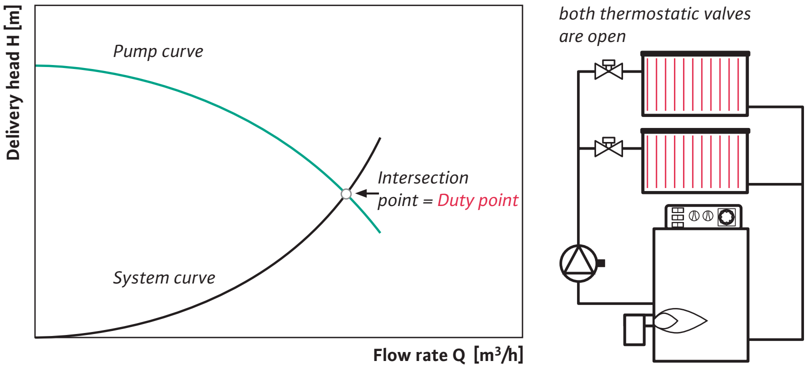
All other duty points occurring in practical operation are to the left of this design duty point in the curve diagram.

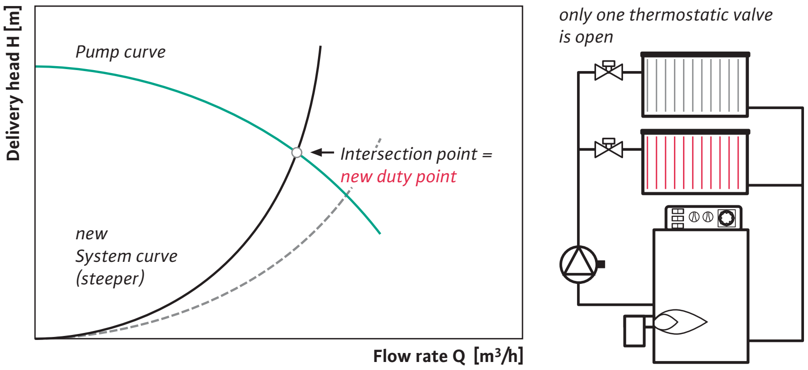
The two illustrations at the right show that the change in the duty point results from the change in flow resistance.

If the duty point shifts towards the left of the design point, the delivery head of the pump will necessarily increase. This causes flow noises in the valves.

The installation of controlled pumps adapts the delivery head and the flow rate to the demand load. At the same time, it significantly reduces operating costs.

The self-adjusting duty point





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AIR CONDITIONING COMPANY

Adjusting the pump to the heat demand

Because our climate has four distinct seasons, there is substantial fluctuation in outside temperatures. From summertime highs of 20°C to 30°C, temperatures drop to -15°C to -20°C and even lower in winter. Obviously, such fluctuations are not acceptable for indoor temperatures of living quarters. In the earliest times, fire was used to heat caves. Later, heating systems were developed, as described in the first part of "Pump Basics."

Weather fluctuations

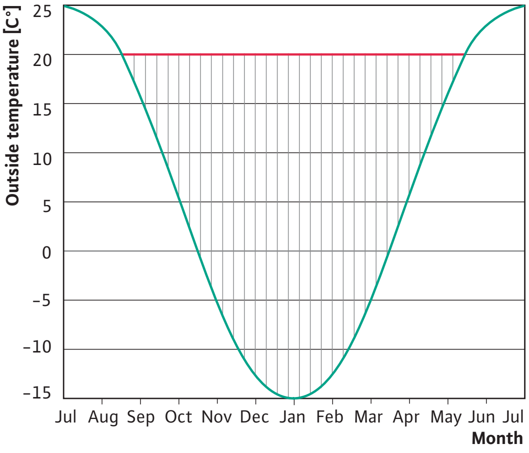
In the illustration to the right, the area shaded with vertical lines makes it very clear that seasonal fluctuations in outside temperature require very different amounts of heat energy.

When the kinds of energy used for heating (wood, coal and early oil heating systems, as well as the state-subsidised heat in the old East Germany) were very inexpensive, it did not matter how much fuel was used. At worst, one simply needed to open a window or two. This is jokingly referred to as a “two-step control”-the window is either open or closed!

The first oil crisis in 1973 created awareness of the need to conserve energy.

Good thermal insulation for buildings has since become a matter of course. The legal requirements have been changing constantly to keep pace with developments in construction technology. Naturally, heating technology has developed at a similar pace. First to come into widespread use were thermostatic radiator valves, which adjust the room temperature to a comfortable level.

Outside temperature depending on the season



The shaded area must be filled by heat energy.

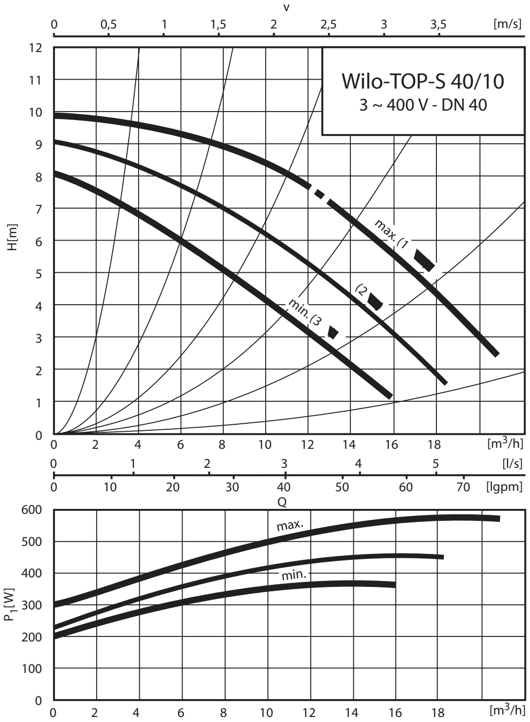
The restriction of the hot water quantity caused by these valves increased the pump pressure of the fixed-speed pump (along the pump curve), thus causing flow noises in the valves. To solve this problem, the overflow valve was invented and installed as a means of releasing the excess pressure.

Refer to the chapter on “Duty point,” page 33

Pump speed selection

Pump manufacturers offer glandless pumps with manual speed selection. As described in the previous sections, the flow rate decreases with the speed in adaptation to the amount of fluid allowed to pass through the thermostat and control valves. This allows the circulating pump to react directly to the room temperature control.

Wilo-TOP-S pump curve



Wilo-TOP-S glandless pump with 3 selectable speeds

So that the speed of the motors can be changed, they are constructed using different internal forcers. If less water is flowing through the heating pipes, there is also less pipe resistance, allowing the pump to work with a lower delivery head. At the same time, the motor power consumption is substantially reduced.

Since then, a wide variety of control units have been developed for switching heating circulating pumps between speeds. This allows the circulating pump to react directly to the room temperature control. The overflow valve thus becomes unnecessary. The control units change the speed automatically depending on the following variables:

- Time
- Water temperature
- Differential pressure
- Other variables specific to the system

Infinitely variable speed control

Infinitely variable adjustment of glanded pumps with high motor power to heating requirements was possible as early as the first half of the 80s. Electronic frequency converters were used to control these pumps.

To understand this technology, recall the familiar current frequency of 50 Hz (Hertz). This means that the current alternates between a plus and a minus pole 50 times a second. The rotor of the pump motor is moved at a corresponding speed.

Electronic components can be used to make the current faster or slower and thus continuously adjust the frequency, for example between 100 Hz and 0 Hz.

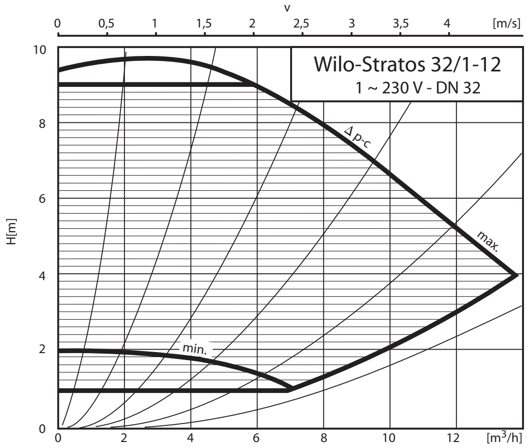
However, for reasons related to the motor, the frequency in heating systems is not reduced to under 20 Hz or less than 40 % of the maximum speed. Since the maximum heat output is designed only for the very coldest days, it will rarely be necessary to operate the motors at the maximum frequency.

While very large transformer units were still required twenty years ago, a way has since been found to make these frequency converters small enough to work in terminal boxes attached directly to a pump, as is the case with the Wilo-Stratos.

An integrated speed control, which is infinitely variable and differential-pressure-sensitive, ensures that the delivery head remains constant once it has been set. The required flow rate, which depends on weather and utilisation factors, does not affect the delivery head.

Since 2001, a new technical advance has taken hold in glandless pump technology. The latest generation of these pumps, also called high-efficiency pumps, is able to combine enormous energy savings with excellent efficiency using state-of-the-art ECM (Electronically Commutated Motor or permanent magnet motor) technology.

Pump curve field of a Wilo-Stratos



Infinitely variable speed control was possible for small pumps as early as 1988, but used a different electronic technology. The technology used at the time, phase angle control, is comparable to the dimmer controls used in lighting.

Infinitely variable speed control of the Wilo-Stratos high-efficiency pump

Refer to the chapter on "Glandless pumps," page 25

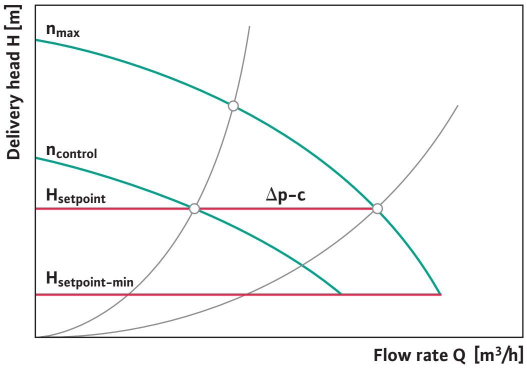
Control modes

The electronically controlled pumps on the market today can be equipped with electronics that allow various operating and control modes.

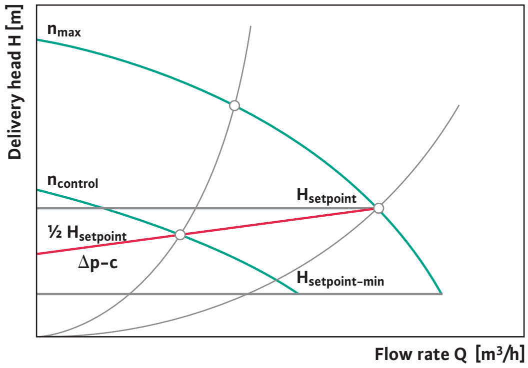
Here, there are control modes that the pump can execute itself, and operating modes whereby the pump, instead of regulating itself, is adjusted to specific duty points using commands.

The following is an overview of the most common control and operating modes. Additional control units and systems can be used to process and transmit a wide variety of other data.

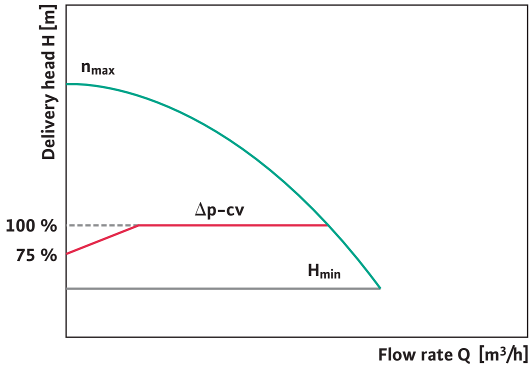
Pump curves for different control modes



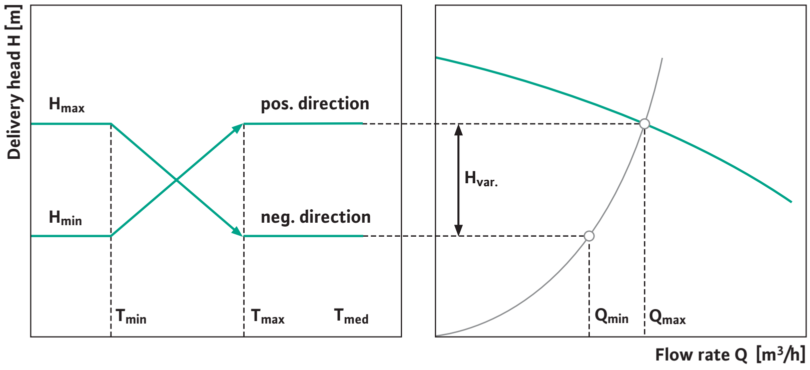
Constant differential pressure: Δp-c



Variable differential pressure: Δp-v



Constant/variable differential pressure: Δp-cv



Temperature-dependent differential pressure control: Δp-T, depending on the resulting change of the flow rate

The selectable control modes are:

Δp-c – Constant differential pressure

The electronics keep the differential pressure generated by the pump constant over the permitted flow rate range at the differential pressure setpoint H_S up to the maximum pump curve.

Δp-v – Variable differential pressure

The electronics change the differential pressure setpoint to be maintained by the pump, for example in a linear fashion between H_S and $^1/_2 H_S$. The differential pressure setpoint H increases or decreases with the flow rate Q.

Δp-cv – Constant/variable differential pressure

In this control mode, the electronics keep the differential pressure generated by the pump constant at the set differential pressure up to a certain flow rate (H_S 100 %). If the flow rate falls below that, the electronics change the differential pressure to be maintained by the pump in a linear fashion, for example between H_S 100 % and H_S 75 %.

Δp-T – Temperature-dependent differential pressure control

In this control mode, the electronics change the differential pressure to be maintained by the pump depending on the measured fluid temperature.

Two settings are possible for this control function:

- Control with positive direction (pitch)
  When the temperature of the fluid increases, the differential pressure setpoint is increased in a linear fashion between H_{min} and H_{max}. This is used, for example, in standard boilers with floating feed temperature.
- Control with negative direction (pitch)
  When the temperature of the fluid increases, the differential pressure setpoint is decreased in a linear fashion between H_{max} and H_{min}. This is used, for example, in condensing boilers in which a certain minimum return temperature must be maintained in order to achieve the greatest possible degree of utilisation of the heating medium. To do this, it is mandatory to install the pump in the return of the system.

The selectable operating modes are:

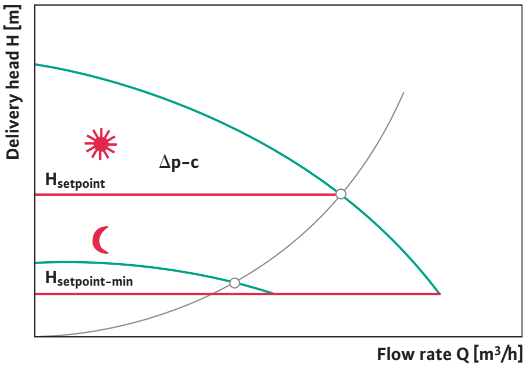
Automatic setback (autopilot)
The new electronically controlled glandless pumps have an automatic setback (autopilot) function. When the feed temperature is reduced, the pump sets back to a reduced constant speed (low-load operation with fuzzy control). This setting ensures that the power consumption of the pump is reduced to a minimum and is the optimum setting for most cases.

The autopilot setback mode may be enabled only if the system has been hydraulically calibrated. Failure to comply with this instruction can cause undersupplied parts of the system to freeze in case of frost.

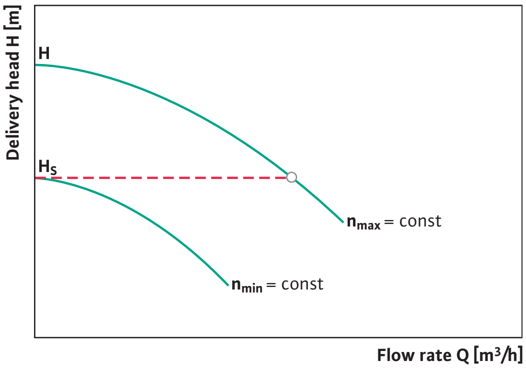
Manual mode
This operating mode is available for electronically controlled pumps that meet or exceed a certain motor power. The pump speed is set to a constant value between n_{min} and n_{max} at the electronics module of the pump. Manual operating mode disables the differential pressure control on the module.

DDC (Direct Digital Controls) and BA connection (connection to the building automation system)
In these operating modes, the setpoint is transmitted to the pump electronics via the corresponding building management system. The setpoint is taken from the building automation (BA) system via a setpoint/actual value comparison, and can then be transferred as a 0–10 V/0–20mA or 2–10 V/4–20mA analogue signal, or as a digital signal (PLR or LON interface on the pump).

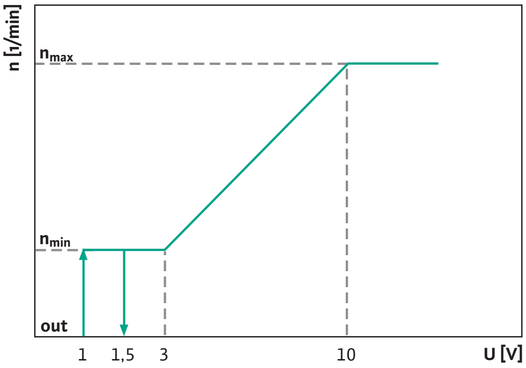
Pump curves for different operating modes



Automatic setback mode (autopilot)



Manual operating mode



DDC operating mode – analogue control unit

azarnasim

AIR CONDITIONING COMPANY

Rough pump design for standard heating systems

The flow rate required of a heating pump depends on the heat consumption of the building being heated. The delivery head, on the other hand, is determined by the pipe friction resistance that is present. When a new heating system is installed, these variables can be easily calculated using the high-quality computer programs available today. However, this calculation is more difficult when existing heating systems are renovated. Various rough estimates can be employed to calculate the necessary pump capacity data.

Pump flow rate

When installing a new circulating pump into a heating system, its size is determined according to the flow rate using the following formula:

$$Q_{PU} = \frac{Q_N}{1{,}163 \cdot \Delta\vartheta} \; [m^3/h]$$

Q_{PU} = Flow rate of the pump in the design point in $[m^3/h]$
Q_N = Heat consumption of the area to be heated in [kW]
1.163 = Specific heat capacity in [Wh/kgK]
$\Delta\vartheta$ = Design temperature difference (spread) between heating system feed and return in [K]; here, 10 – 20 K can be assumed for standard systems.

Pump delivery head

To transport the fluids to every point of the heating system, the pump must overcome the sum of all resistances. As it is very difficult to determine the path of the pipework and the nominal diameters of the pipes used, the following formula can be used to roughly calculate the delivery head:

$$H_{PU} = \frac{R \cdot L \cdot ZF}{10.000} \; [m]$$

R = Pipe friction loss in straight pipe [Pa/m] Here, 50 Pa/m to 150 Pa/m can be assumed for standard systems (depending on the year the house was built; older homes have a smaller pressure drop of 50 Pa/m due to the use of pipes with larger nominal diameters).
L = Length of the least favourable (longest) heating line [m] for feed and return or: (length of the house + width of the house + height of the house) x 2
ZF = Addition factor for
moulded parts/fittings ≈ 1.3
Thermostatic radiator valve ≈ 1.7
If these installed parts, among others, are present, a ZF of **2.2** can be used.
Moulded parts/fittings ≈ 1.3
Thermostatic radiator valve ≈ 1.7
Mixing valve/gravity brake ≈ 1.2
If these installed parts, among others, are present, a ZF of **2.6** can be used.
10,000 = Conversion factor m in Pa

Application example

The heat generator in a multi-family home of an older type of construction has an output of 50 kW according to a calculation or document.

At a temperature differential $\Delta\vartheta$ of 20 K ($\vartheta_{feed} = 90°C / \vartheta_{return} = 70°C$), this results in the following equation:

$$Q_{PU} = \frac{50\ \text{kW}}{1{,}163 \cdot 20\ \text{K}} = 2{,}15\ \text{m}^3/\text{h}$$

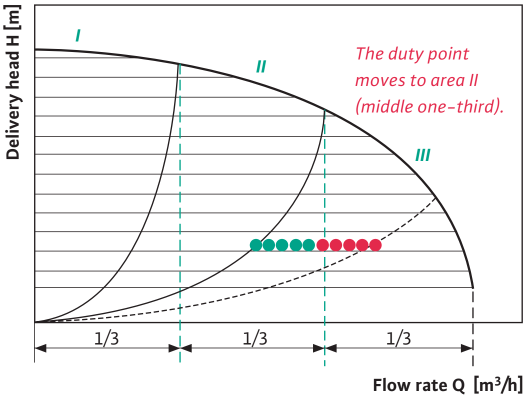
If the same building is to be heated with a smaller temperature differential, such as 10 K, the circulating pump has to pump at twice the volumetric flow rate, i.e. 4.3 m³/h, to transport the required heat energy from the heat generator to the heat consumers.

For our example, assume a pipe friction pressure loss of 50 Pa/m, a pipeline length for feed and return of 150 m and an addition factor of 2.2, since no mixing valve and no gravity brake have been installed in this case.
This results in delivery head H:

$$H_{PU} = \frac{50 \cdot 150 \cdot 2{,}2}{10.000} = 1{,}65\ \text{m}$$

Duty point in the pump curve field with variable volumetric flow

- *Area I (left one-third)*
  Select a smaller pump if the duty point is in this area.
- *Area II (middle one-third)*
  The pump will operate within the optimum range for 98 % of its operating time.
- *Area III (right one-third)*
  The controlled pump will be operated in the least favourable range only when at its design point (hottest/coldest day of the year), i.e. 2% of its operating time.



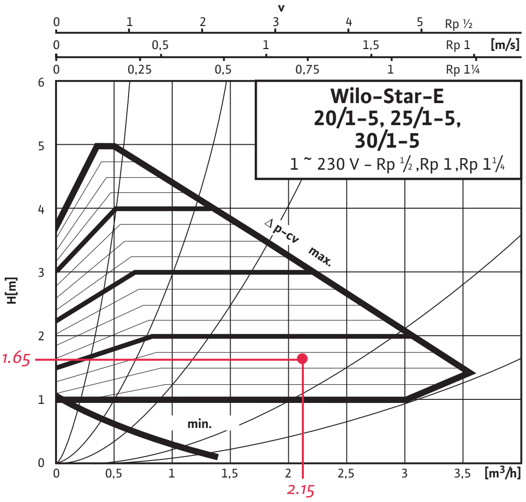
The duty point moves to area II (middle one-third).

In the chapter on "Design features," we have seen how the efficiency curve depends on the pump curve. If this efficiency curve is considered when selecting the pump, it is evident that in terms of energy, the middle one-third of the curve is the most favourable design range. Therefore, for systems with variable volumetric flow, the design point should be in the right one-third, as the duty point of the heating circulating pump drifts into the middle one-third and stays there for 98 % of its operating time.

The system curve becomes steeper as resistance increase, for example when the thermostatic radiator valves are closed.

This provides the following results from the data calculated for delivery head H and flow rate Q according to the catalogue for the rough pump design:

Wilo-EasyStar pump curves



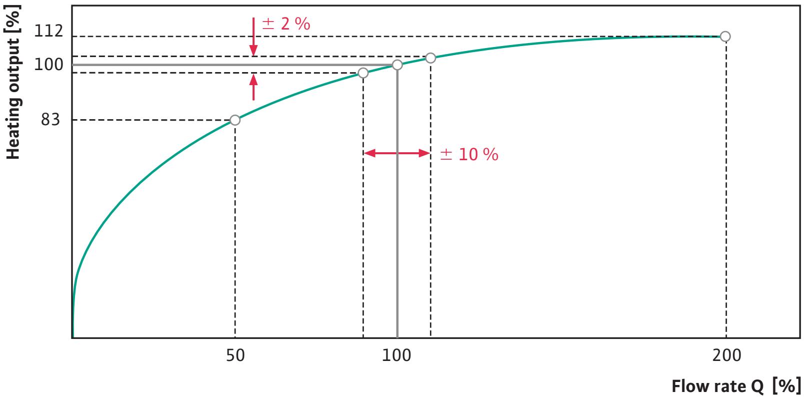
Effects of the rough pump design

If the building heat consumption in an unknown pipe system can only be determined using a rough calculation, one might ask what effect this has. The illustration to the right shows the typical output curve of a room radiator.

The following relationships can be seen: if flow rate Q is decreased by 10 %, the heat output of the radiator decreases by only 2 %. The same holds true if flow rate Q is increased by about 10 %. In that case, the radiators will be able to give off only about 2 % more heat energy. Even doubling the flow rate will only increase the heat output by about 12 %!

The reason for this is that the water velocities in the radiators are directly dependent on the flow rate. Higher flow velocities mean a shorter dwell time of the water in the radiator. At a lower flow speed, the fluid has more time to give off heat to the room.

Radiator operating diagram



Example of a radiator operating diagram 90/70°C, room temperature 20°C

Therefore, the practice of sizing pumps larger than necessary in order to allow a so-called "safety margin" is absolutely wrong.

Even significantly under-sizing the pump has only relatively minor consequences: at a flow rate of 50 %, the radiators will still be able to give off approx. 83 % heat energy to the room.

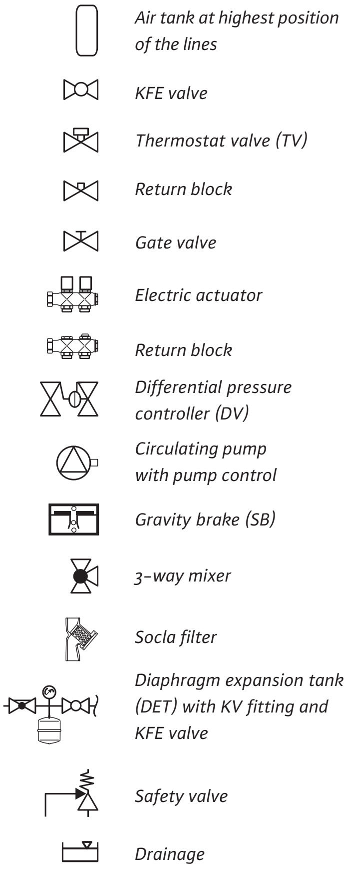
Pump planning software

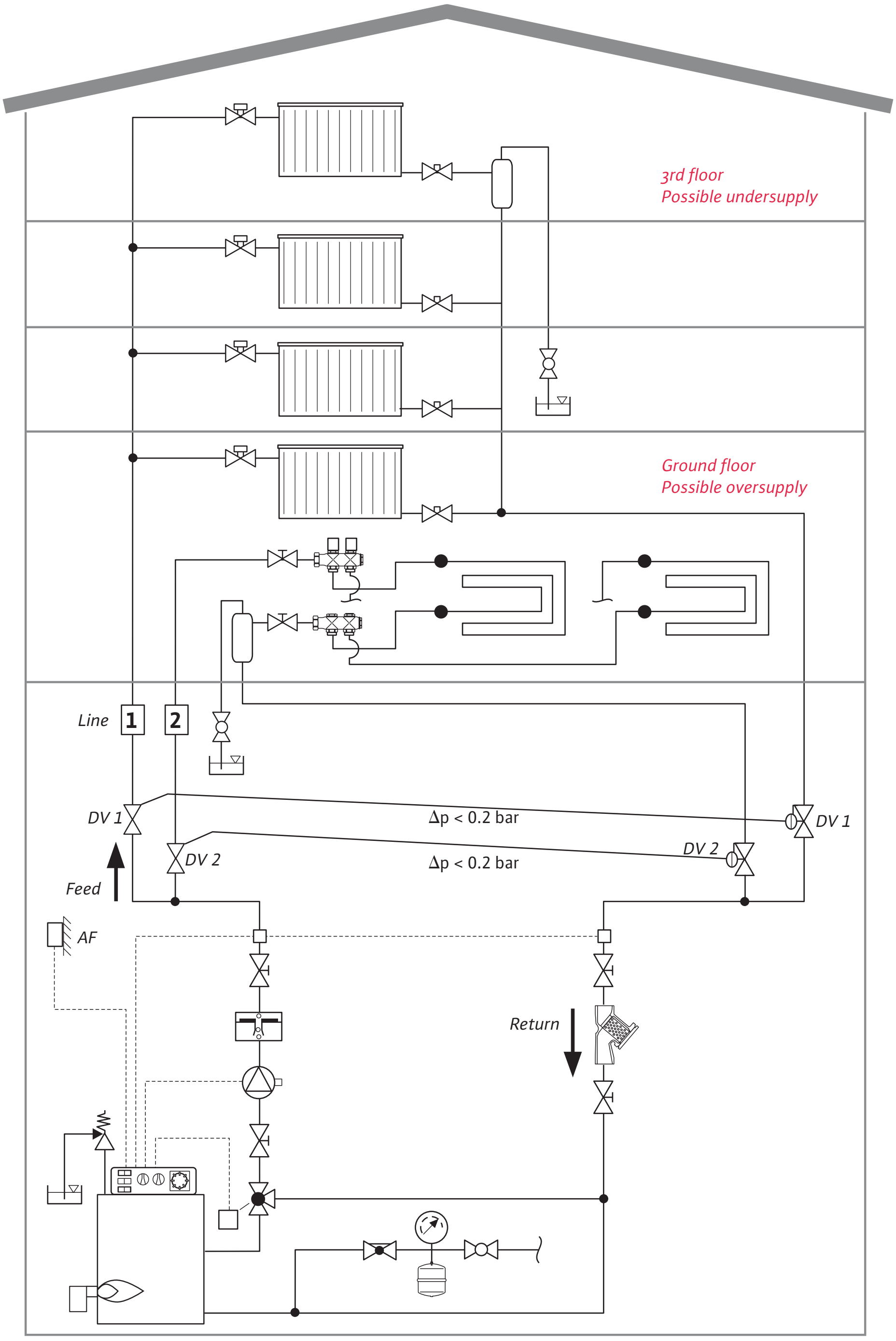
Pump planning software such as Wilo-Select provides a complete and effective planning service. For tasks ranging from calculation to design of pumps and the associated documentation, it provides all the data you need.

Wilo-Select Classic is a planning software program for pumps, systems and components. It can be used as an aid to professional work, broken down into these menu points:

- Calculation
- Design
- Catalogue and article research
- Pump replacement
- Documentation
- Electricity cost and amortisation calculations
- Lifecycle costs
- Data export to Acrobat PDF, DXF, GAEB, Datanorm, VDMA, VDI, CEF
- Automatic Internet update

Schematic diagram of a heating system with a facility for hydraulic calibration





For a pump to work efficiently, a hydraulic calibration is required.

Hydraulics from start to finish

To achieve optimum heat distribution and the lowest noise level possible, a hydraulic calibration is required.

Hydraulic calibration also serves to prevent the supply to the consumers from becoming too high or too low.

The nominal flow rate for supplying the lines is provided by the pump in the pipe system. The consumers (such as radiators) require only a portion of that output; the portion depends on the size and output of the radiator as well as the setting of the thermostat and control valve.

So that each individual consumer is supplied with the correct flow rate and pressure, differential pressure controllers, line regulating valves, preset thermostat and control valves or adjustable return pipe unions can be installed.

The settings for the consumers can be adjusted at the valves and controllers according to the manufacturer's specifications (design differential pressure 40 and 140 mbar). The consumers still need to be protected from excess pump pressure. The maximum pump pressure, for example ahead of thermostatic radiator valves, must not exceed 2 m. If the system necessitates that this pressure be exceeded, differential pressure controllers must be provided in the ascending pipes so that this limit value is maintained.

Refer to the chapter on the "Application example," page 42

Setting electronically controlled circulating pumps

Today's circulating pumps with electronic speed control provide a very simple option for setting the required delivery head for an unknown system:

- The prerequisite for this is that the pipelines have been carefully calibrated and that the system has been bled. Open all control valves.

- The electronics of the pump feature knobs or dials for setting the delivery head. Depending on the manufacturer, these knobs may or may not have scaling. Begin at the lowest head setting. Have a colleague, equipped with a mobile phone or two-way radio, stand at the most distant radiator of the entire heating system.

- After their initial report that no hot heating water is reaching this remote point, slowly increase the delivery head using the adjusting dial. While doing so, consider the inertia of the heating system.

- At the moment when even the most distant radiator is supplied with heat energy, the setting process is complete.

Connecting multiple pumps

Each of the previous designs was based on one centrifugal pump. In practice, however, there are operating situations in which a single-head pump cannot meet the requirements placed on it.

In such cases, two or more pumps are installed. Depending on the application, the pumps are installed in series or in parallel connection.

Before we begin our discussion of specific operating functions, let us point out a fundamental (though frequently heard) error. It is, generally speaking, not true that two identical pumps connected in series pump at twice the delivery head, and that two identical pumps connected in parallel pump at twice the flow rate.

Although this is theoretically possible, it is impossible to achieve in practice for reasons related to the design and the system.

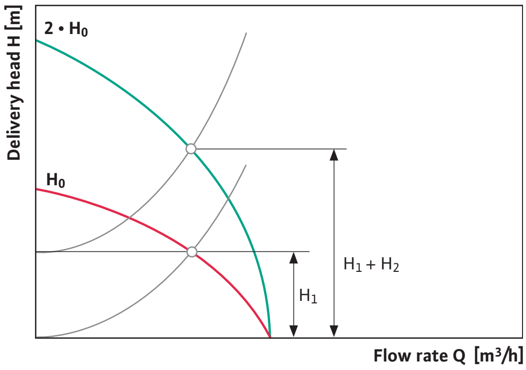
Pumps connected in series

If two pumps are connected in a row, the pump curves are added, meaning that if they work against a closed slide valve, the pressure generated is cumulative. Thus the delivery head when Q = 0 is doubled for two pumps of the same size.

At the other extreme, i.e. pumping without pressure, two pumps cannot transport a higher quantity of fluid than a single pump.

Series connection of two pumps installed in one housing with the same flow rate–delivery heads are added at points of equal flow rate

Pump curve for series operation



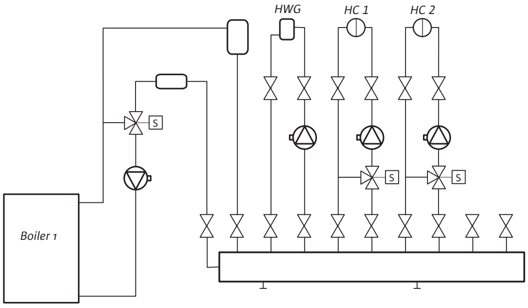
The practical meaning of this is that for both parts of the hydraulic work, proportionate increases result:

- For the vertical axis of the curve diagram, i.e. for delivery head H, this increase will be greater the further the system curve is to the left.
- For the horizontal axis, i.e. for the flow rate Q, the increase is extremely small.

Application example: multiple pump circuits (pumps in series connection)

For control technology reasons, large heating systems consist of multiple heating circuits. Sometimes, multiple boilers are also installed.

Example of a system with multiple heating circuits



The pumps for hot water generation (HWG) and those for heating circuits HC 1 and HC 2 work independently of each other. The circulating pumps are designed to overcome the respective system resistances. Each of these three pumps is in series with the boiler circulating pump BCP. The task of this pump is to overcome the resistance that already exists in the boiler circuit.

The theoretical considerations in the preceding section assumed pumps of the same size. However, the capacity data can differ for each pump, as in the diagram shown here.

Therefore, this kind of installation presents a great danger if the flow rates are not carefully matched to each other. If the pump pressure generated by the boiler circuit pump is too high, one or all distributor pumps can receive excessive residual inlet pressure at the suction port. This means that they are no longer working as pumps, but as turbines (generator operation). They are being pushed. This will very quickly lead to malfunctions and pump defects. (The solution for hydraulic decoupling is beyond the scope of this discussion.)

Pumps in parallel connection

If two pumps are installed in parallel, the pump curves are added to each other, meaning that when they operate without pressure, i.e. against an open pipe, the flow rate is cumulative. Thus the maximum delivery rate of two pumps of the same size doubles.

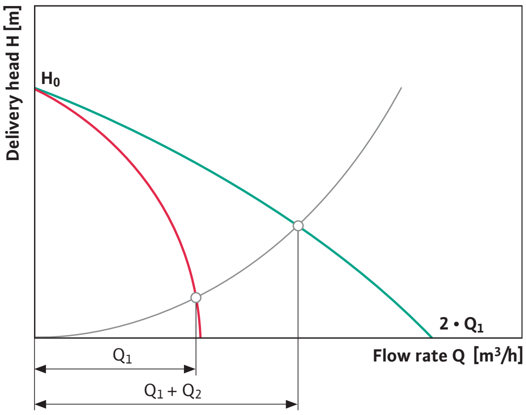
We have already pointed out that this pump curve point is only a theoretical limit value.

At the other extreme, i.e. the delivery head when Q = 0, two pumps in parallel connection cannot provide a higher delivery head than a single pump.

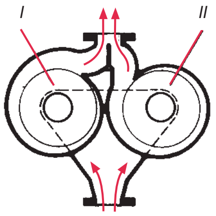
The practical meaning of this is that this also results in proportionate increases for both parts of the hydraulic work:

- For the horizontal axis of the curve diagram, i.e. for flow rate Q, this increase will be greater the further the system curve is to the right.
- For the vertical axis, i.e. for delivery head H, the increase is the greatest in the middle of the pump curves.

Curve for parallel connection



Parallel connection of two pumps with the same output



Both pumps operating

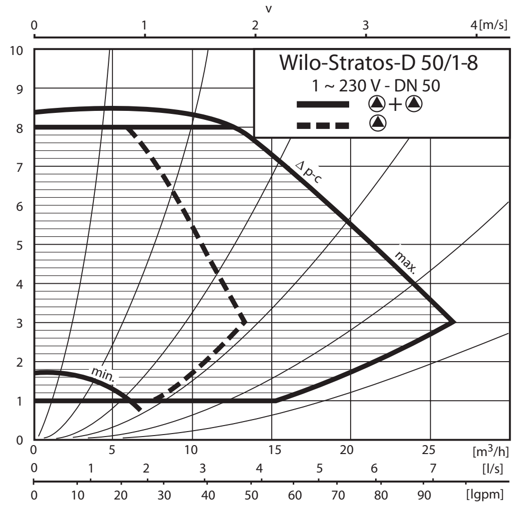
Application example: parallel operation

When the heating energy demand reaches its highest point, pumps I and II run together in parallel operation. In modern pumps, the control units required for this are contained in plug-in modules or in the electronic module with corresponding accessories.

Since each of the two single-head pumps built into the twin-head pump can, in turn, be adjusted in multiple steps, a wide spectrum of possibilities exists for adjusting the pump to the heat demand.

This is shown by the following curve. The dashed line is the pump curve for individual operation of one of the two pumps. The thick black line is the shared pump curve in duty/assist operation.

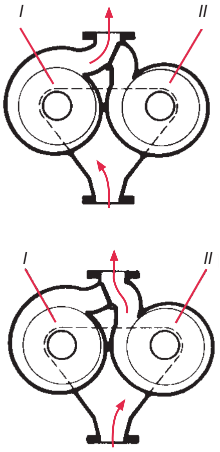
Wilo-Stratos D pump curve



Parallel connection of two pumps with the same output – actual increase of the flow rate

If one pump fails, over 50 % of the flow rate is still pumped. According to the radiator operating diagram, this still means a heat output of more than 83 % that can be given off by the radiator.

Refer to the chapter on "Effects of the rough pump design," page 43



Pump I or pump II operating

Application example: main and standby pump

The purpose of a heating system is to heat living spaces in the cold season. Therefore, the provision of a standby pump in each heating circuit is recommended in the event that the other pump breaks down. This is true, for example, for multi-family homes, hospitals and public institutions.

On the other hand, installing a second pump–along with the necessary fittings and controls–results in significantly higher installation costs. The industry offers a good compromise in the form of twin-head pumps. Two impellers and their drive motors are enclosed in one housing.

In duty/standby operation, pumps I and II run in alternation according to a timed schedule (for example, 24 hours each). While one pump is running, the other is idle. The butterfly valve, which is built in as standard equipment, prevents fluid from flowing back through the pump when it is at standstill.

As described at the beginning of this section, failure of one of the pumps triggers an automatic fault switchover to the pump that is ready for operation.

Peak-load operation with multiple pumps

Multiple, individual partial-load pumps are installed in systems that require a large flow rate. An example would be a hospital with 20 buildings and a centrally located boiler house.

In the following example, large glanded pumps with integrated electronics are installed parallel to each other. Depending on the requirements, such peak-load systems can consist of two or more pumps of equal size.

In conjunction with the signal transmitter, the control system maintains constant total pump pressure (Δp-c).

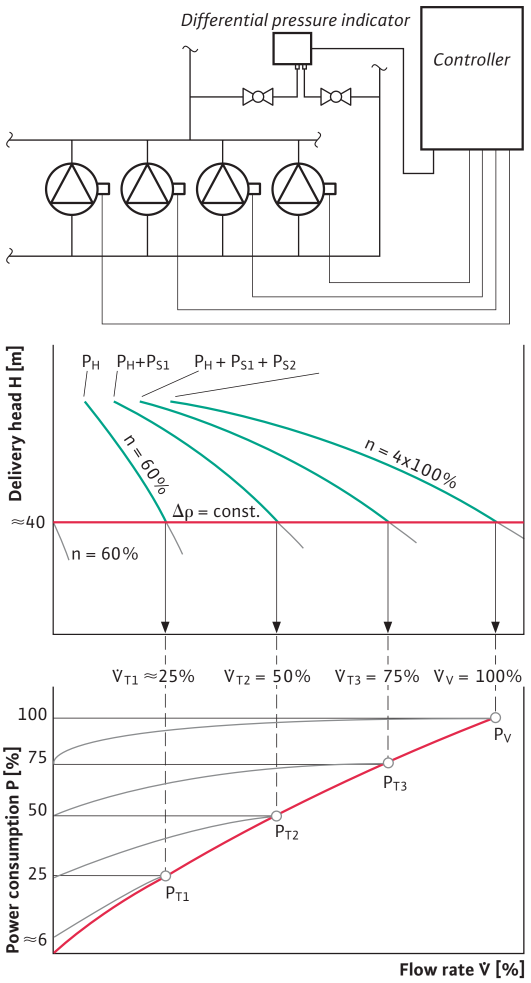
In this regard, the flow rates allowed through by the thermostatic radiator valves at all radiators, and how many of the four pumps are currently operating, are completely unimportant.

If a system of this sort is hydraulically calibrated, these circuits are also used to perform a remote point evaluation that ensures the proper supply. For this evaluation, the signal transmitter is installed at the point of the system that is most difficult to supply (at a distant, or remote point). The control signal from the signal transmitter is then sent to the control unit, where it is adjusted for the inertia and other characteristics of the system. The connected pumps are, in turn, activated by the control unit, for example via their integrated electronics.

The complete system shown in the example is controlled as follows:
The base duty or main pump P_H with integrated electronics is controlled continuously between its maximum speed of n = 100 % and a minimum speed of n = 40 %, triggered by the differential pressure signal transmitter. This causes the partial-load flow rate to move smoothly in the range of $Q_{T1} <= 25\,\%$. If a flow rate $Q_T > 25\,\%$ is required, the first peak-load pump P_{S1} is switched on, also by its integrated electronics. The control of the main pump P_H continues to be infinitely variable, so that its effect likewise adjusts the total flow rate between 25 % and 50 % according to the demand.

This process is repeated when the partial-load pumps with integrated electronics P_{S2} and P_{S3} are switched on, each at full speed. The maximum heat demand of the entire hospital is covered when all four pumps are working at their highest output, as they then provide the peak-load flow rate $\dot{V}_V$. Similarly, the peak-load pumps with integrated electronics, P_{S3} to P_{S1}, are switched off again when the heat demand decreases.

Multiple-pump system with infinitely variable control



Legend:
P_H = Main pump
P_S = Peak-load pump 1–3
$\dot{V}_V$ = Full-load flow rate
$\dot{V}_T$ = Partial-load flow rate
P_V = Full-load power consumption
P_T = Partial-load power consumption

To keep the operating times of the pumps as uniform as possible, the role of controlled main pump is assigned to different pump each day on a rolling basis.

The bottom diagram shows the great savings, including those of power consumption, that are possible depending on the type of each pump.

In large systems, the advantage of many years of low operating costs is more important than small initial investment costs. Four small pumps with built-in electronics and control units can cost more than one large pump without a control unit. However, if we take an operating time of ten years as an example, the investment costs for the control system and pumps with integrated electronics can be recouped several times over by the savings achieved. An additional side effect is better supply of the system, which is also quieter and more cost-effective, because of the improved supply to the consumers. This can even bring about a significant primary energy savings.

Conclusion

Beginning with early developments and the most basic context, and continuing with highly complex examples, the “Fundamental principles of pump technology” are intended to provide an overview of how and where pumps can and should be used.

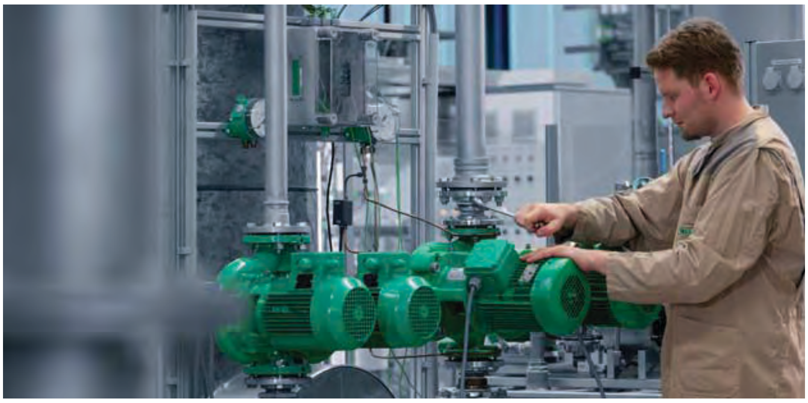
It illustrates the complex relationships and interconnections of pump operation, as well as the improvements in operation made possible by today's electronic control systems.

Compared to a building's heating system, the circulating pump is one of the smallest components of the overall system in terms of size and purchase price. It is the pump, however, that allows all the other components to function properly. If we compare the system to the human body, there can be no doubt: the pump is the heart of the system!

Did you know...

Test your knowledge of the "Fundamental principles of pump technology" by taking this short quiz.

History of pump technology



Questions on these topics:
- Water supply
- Wastewater disposal
- Heating technology

Question 1:
- Pumps existed as early as ancient times. (1)
- Pumps were invented for heating. (2)
- Pumps can be used to pump water only. (3)

Question 2:
- Archimedes invented the scoop wheel. (1)
- The Chinese invented the centrifugal pump. (2)
- The incline of Archimedes' screw determines the delivery quantity. (3)

Question 3:
- The first sewers were built in 1856. (1)
- The Cloaca Maxima was built in Rome. (2)
- Lifting plants must be installed at all drains. (3)

Question 4:
- The ancient German peoples already had central heating. (1)
- The Romans already built floor-heating systems. (2)
- Steam engines were used to heat homes in the 17th century. (3)

Question 5:
- The term "gravitational heating systems" refers to the heaviness of the powerful pumps they use. (1)
- Steam heating systems work at temperatures between 90°C and 100°C. (2)
- Low-temperature heating systems are possible only because of circulating pumps. (3)

Question 6:
For which application have pumps already been used for centuries?
- Water delivery (1)
- Steam heating systems (2)
- Gravitational heating systems (3)

Question 7:
- The circulation accelerator, which was patented in 1929, was a further development of a frequently used heating pump. (1)
- It was the first pump for pipe installation in heating systems. (2)

Question 8:
To which part of the human body can heating circulating pumps be compared?
- The arms (1)
- The heart (2)
- The head (3)

Question 9:
The advantage provided by the heating circulating pump is:
- Lower installation costs (1)
- Controlled operating costs (2)
- Adaptable control (3)
- All of the above (4)

Answers:
Question 1: No. 1
Question 2: No. 3
Question 3: No. 2
Question 4: No. 2
Question 5: No. 3
Question 6: No. 1
Question 7: No. 2
Question 8: No. 2
Question 9: No. 4

Water – our means of transport

Questions on these topics:
- Heat storage capacity
- Volume increase and decrease
- Pressure

Question 1:
When does water expand?
- When it is heated above 0°C. (1)
- When it is cooled below 0°C. (2)
- When it is heated or cooled from a temperature of +4°C. (3)

Question 2:
Which of the following are three equivalent terms?
- Work, output and efficiency (1)
- Work, energy and quantity of heat (2)
- Work, vim and vigour (3)

Question 3:
Which of the following is true of water when heated?
- It becomes specifically lighter. (1)
- It becomes specifically heavier. (2)
- Its density remains the same. (3)

Question 4:
What happens to the water temperature when it reaches the boiling point?
- It continues to increase. (1)
- It stays at the boiling point. (2)
- It begins to fall. (3)

Question 5:
How can cavitation be prevented?
- By selecting a pump with lower maintained pressure head. (1)
- By decreasing the static pressure. (2)
- By increasing the vapour pressure PD. (3)

Question 6:
Upon which of the following factors does the amount of heat energy available in the water depend?
- The storage capacity of the water. (1)
- The mass of the water being moved. (2)
- The difference in temperature between the feed and return (3)
- It depends on all three of the above variables. (4)

Question 7:
Which of the following makes gravitational heating systems work better?
- Smaller pipe resistances (1)
- Larger pipe resistances (2)

Question 8:
Which of the following is the role of the safety valve?
- It is used to ventilate and bleed the system. (1)
- It protects the system from an excessive pressure load. (2)
- None; it is useless when electronic pumps are installed. (3)

Answers:
Question 1: No. 3
Question 2: No. 2
Question 3: No. 1
Question 4: No. 2
Question 5: No. 1
Question 6: No. 4
Question 7: No. 1
Question 8: No. 2

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Design features

Questions on these topics:

- Self-priming and non-self-priming pumps
- Glandless pumps
- Glanded pumps

Question 1:
Which of the following statements are true of the suction head?

- It depends on the air pressure. (1)
- Theoretically, it is 10.33 m. (2)
- It has an effect on the delivery head. (3)
- Statements 1–3 are all true. (4)

Question 2:
Which of the following statements is true of self-priming pumps?

- They are conditionally able to bleed the suction line. (1)
- The suction line should be kept as short as possible. (2)
- They must be filled before commissioning. (3)
- All of the above are true. (4)

Question 3:
What function does the heating water inside the “can” of glandless pumps have?

- It cools and lubricates. (1)
- It supports the delivery head. (2)
- It has no real function. (3)

Question 4:
What are the benefits of a glandless pump?

- Good efficiency (1)
- High heating circuit temperatures (2)
- It runs smoothly and is maintenance-free. (3)

Question 5:
What is the recommended installation position for an inline glanded pump?

- Installed with the shaft arranged vertically. (1)
- Installed with the shaft arranged horizontally. (2)
- Other than the motor facing down, any installation position can be chosen. (3)

Question 6:
For which application are glanded pumps used?

- Low flow rates (1)
- High flow rates (2)
- No motor lubrication (3)

Question 7:
Which of the following ratios is equivalent to the efficiency of the pump?

- The ratio of the discharge port to the suction port (1)
- The ratio of the drive power to the output power (2)
- The ratio of its power intake to its power output (3)

Question 8:
Which area represents the highest efficiency of a centrifugal pump?

- The left one-third of the pump curve (1)
- The middle one-third of the pump curve (2)
- The right one-third of the pump curve (3)

Question 9:
Which of the following statements is true of mechanical seals?

- They consist of hemp or synthetic fibres. (1)
- They are shaft bearings. (2)
- They are used in glanded pumps. (3)

Answers:
Question 1: No. 4
Question 2: No. 4
Question 3: No. 1
Question 4: No. 3
Question 5: No. 3
Question 6: No. 2
Question 7: No. 3
Question 8: No. 2
Question 9: No. 3

Curves

Questions on these topics:
- Pump curve
- System curve/pipe system curve
- Duty point

Question 1:
Which of the following statements is true of electrical drive energy?
- It is converted into high pressure. (1)
- It is converted into pressure boost and motion. (2)
- It is gained from hydraulic energy. (3)

Question 2:
What is plotted on the axes of the curve diagram?
- The delivery head on the vertical axis and the flow rate on the horizontal axis. (1)
- The flow rate on the vertical axis and the delivery head on the horizontal axis. (2)
- The energy on the vertical axis and the medium on the horizontal axis. (3)

Question 3:
What does the system curve show?
- The increase in resistance over the flow rate (1)
- The increase in the flow rate over the pressure (2)
- The change in the flow rate with the water velocity (3)

Question 4:
How does pipe friction resistance change?
- In a linear fashion with the flow rate (1)
- Quadradically with the flow rate (2)
- Cubically with the flow rate (3)

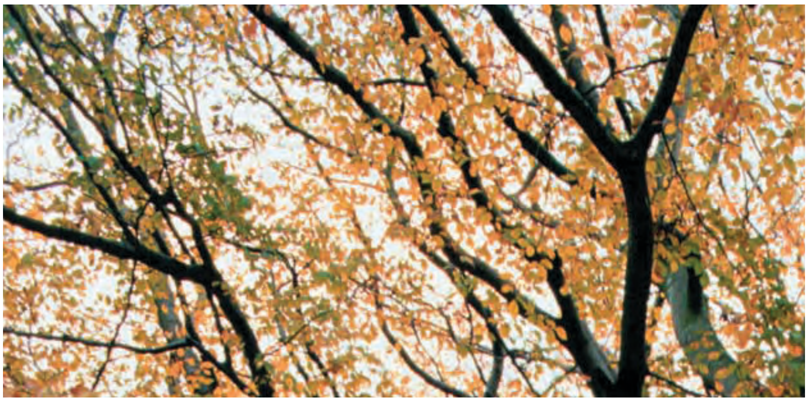
Question 5:
Which of these has to be considered in designing the delivery head that is supplied by a heating circulating pump?
- The height of the building (1)
- The pipe network resistance (2)
- Both of the above variables (3)

Question 6:
Which of these has to be considered in designing the flow rate that is supplied by a heating circulating pump?
- The average outside temperature (1)
- The desired inside temperature (2)
- The calculated heat demand (3)

Answers
Question 1: No. 2
Question 2: No. 1
Question 3: No. 1
Question 4: No. 2
Question 5: No. 2
Question 6: No. 3

Adjusting the pump to the heat demand

Questions on these topics:
- Weather fluctuations
- Pump speed control
- Infinitely variable speed control
- Control modes



Question 1:
Which of the following is true of the heat demand of a building?
- It always remains the same. (1)
- It changes with the season. (2)
- It increases from year to year. (3)

Question 2:
What happens when the heat demand changes?
- The thermostatic radiator valves are adjusted. (1)
- The windows are adjusted (= opened/closed). (2)
- The system pressure adjusts itself. (3)

Question 3:
Why is the speed of pumps changed?
- To adjust to the required flow rate. (1)
- To relieve the overflow valve. (2)
- To compensate for errors in the pump design. (3)

Question 4:
How is the pump speed changed?
- Always manually (1)
- Always automatically (2)
- Either manually or automatically depending on the equipment (3)

Question 5:
Which of the following are true of Infinitely variable speed control?
- It is better than step control. (1)
- It is worse than step control. (2)
- It provides the same results as step control. (3)

Question 6:
Which of the following can be adjusted with electronically controlled circulating pumps?
- The heat demand (1)
- The service life (2)
- The delivery head (3)

Question 7:
Which of the following is true of control mode Δp-c = differential pressure?
- The flow rate is increased by a constant speed. (1)
- The speed adjusts to the required flow rate. (2)
- The diaphragm expansion pressure tank inlet pressure remains constant at all times. (3)

Question 8:
Which of the following is true of automatic setback mode (autopilot)?
- It is controlled by a timer. (1)
- It depends on the room temperature. (2)
- It may be enabled only in hydraulically calibrated heating systems. (3)

Question 9:
Which of the following is true of the latest ECM pump technology (high-efficiency)?
- The rotor consists of a permanent magnet. (1)
- It provides up to an 80 % savings in operating costs compared to conventional pumps. (2)
- The rotation of the rotor is generated by an electronic commutation (frequency converter). (3)
- Points 1–3 mean that is the most cost-saving glandless pump currently available. (4)

Answers:
Question 1: No. 2
Question 2: No. 1
Question 3: No. 1
Question 4: No. 3
Question 5: No. 1
Question 6: No. 3
Question 7: No. 2
Question 8: No. 3
Question 9: No. 4

Rough pump design

Questions on these topics:
- Pump flow rate
- Pump delivery head
- Pump design
- Hydraulic calibration

Question 1:
How should a heating circulating pump be selected?
- According to the specified nominal diameter. (1)
- According to price considerations. (2)
- According to the capacity data. (3)

Question 2:
What happens when the flow rate is increased by 100 %?
- The heat output decreases by approx. 2 %. (1)
- The heat output increases by approx. 12 %. (2)
- The heat output remains the same. (3)

Question 3:
What should one do when in doubt as to which heating pump to select?
- Select the smaller pump. (1)
- Select the larger pump. (2)
- Select the less expensive pump. (3)

Question 4:
For which of the following variables should the pump in a water pumping system be designed?
- The geodetic head (1)
- The residual flow pressure (2)
- The pipe friction resistances (3)
- The sum of variables 1 to 3 (4)

Question 5:
In heating systems, for which of the following variables must the delivery head be designed?
- The geodetic head (1)
- The residual flow pressure (2)
- The pipe friction resistances (3)
- The sum of variables 1 to 3 (4)

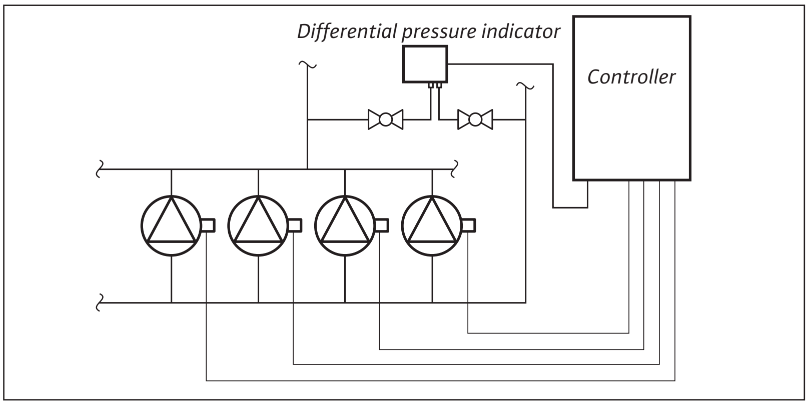
Question 6:
Why are heating systems calibrated?
- To achieve optimum heat distribution. (1)
- So that the system will operate as quietly as possible. (2)
- To protect the consumers are from undersupply or oversupply. (3)
- All three of the above points are correct and important. (4)

Question 7:
When the required delivery head is unknown, what is the correct procedure for adjusting an electronic pump?
- The best way is with the help of a colleague. (1)
- Adjustment is done after careful ventilation and hydraulic calibration of the system. (2)
- The adjustment process begins at the lowest setting of the pump. (3)
- It continues until there is an adequate supply of heat energy to the most distant radiator. (4)
- Adjustment is finished when all four of the above steps have been completed. (5)

Answers:
Question 1: No. 3
Question 2: No. 2
Question 3: No. 1
Question 4: No. 4
Question 5: No. 3
Question 6: No. 4
Question 7: No. 5

Connecting multiple pumps

Questions on these topics:
- Pumps in series connection
- Pumps in parallel connection
- Peak-load operation with multiple pumps



Question 1:
What happens when two pumps are connected in series?
- The delivery head doubles. (1)
- The flow rate doubles. (2)
- The change depends on the position of the system curves. (3)

Question 2:
What danger exists when pumps are connected in series?
- It will operate as a generator, and the pump will be “pushed.” (1)
- The pump outputs will be reduced to zero. (2)
- It will cause an undersupply of the system. (3)

Question 3:
What happens when two pumps are connected in parallel?
- The delivery head doubles. (1)
- The flow rate doubles. (2)
- The change depends on the system curves. (3)

Question 4:
In which mode can twin-head pumps be operated?
- Primarily in duty/standby operation (1)
- Primarily in duty/assist operation (2)
- It can be operated in both of these modes. (3)

Question 5:
In large systems, what benefit is provided by dividing the required pump output over multiple pumps?
- Lower operating costs (1)
- Longer service life of the pumps (2)
- Both statements 1 and 2 are true. (3)

Question 6:
What is the name of the control mode in which the signal transmitter is installed in the system at a great distance from the switching device?
- Centre of gravity control (1)
- Difficult control (2)
- Remote point control (3)

Question 7:
Which of the following should be considered when connecting pumps in parallel to one control unit?
- The pumps should be the same size. (1)
- They should all be low-speed pumps. (2)
- They should all be high-speed pumps. (3)

Answers:
Question 1: No. 3
Question 2: No. 1
Question 3: No. 3
Question 4: No. 3
Question 5: No. 3
Question 6: No. 3
Question 7: No. 1

Legal units of measure, partial listing for centrifugal pumps

Physical variable	Symbol	Legal units of measure			Units of measure no longer permitted	Recommended units	Remarks
		SI units		Other legal units of measure (incomplete listing)			
Length	l	m	Metre	km, dm, cm, mm, µm		m	Basic unit
Volume	V	m^3		dm^3, cm^3, mm^3, Litre (1 l = 1 dm^3)	cbm, cdm, …	m^3	
Flow rate, Volumetric flow rate	Q V	m^3/s		m^3/h, l/s		l/s and m^3/s	
Time	t	s	Second	s, ms, µs, ns, … min, h, d		s	Basic unit
Speed	n	rps		rpm		rpm	
Mass	m	kg	Kilogram	g, mg, µg, Ton (1 t = 1,000 kg)	Pound, Hundredweight	kg	Basic unit The mass of an item of merchandise is called its weight.
Density	ρ	kg/m^3		kg/dm^3		kg/dm^3 and kg/m^3	The designation “specific weight” should no longer be used because it is ambiguous (see DIN 1305).
Force	F	N	Newton (= kg m/s^2)	kN, mN, µN, …	kp, Mp, …	N	1 kp = 9.81 N. The gravitational force is the product of the mass m and the local acceleration of gravity g.
Pressure	P	Pa	Pascal (= N/m^2)	Bar (1 bar = 10^5 Pa)	kp/cm^2, at, m head of water, Torr, …	bar	1 at = 0.981 bar = 9.81 • 10^4 Pa 1 mm Hg = 1.333 mbar 1 mm head of water = 0.098 mbar
Energy, Work, Quantity of heat	W, Q	J	Joule (= Nm = Ws)	kJ, Ws, kWh, … 1 kW h = 3,600 kJ	kp m, kcal, cal WE	J and kJ	1 kp m = 9.81 J 1 kcal = 4.1868 kJ
Delivery head	H	m	Metre		M Fl. S.	m	The delivery head is the work performed on the unit of mass of the fluid in J = N m, expressed in terms of the gravitational force of this unit of mass in N.
Power	P	W	Watt (= J/s = N m/s)	MW, kW	kp m/s, horsepower	kW	1 kp m/s = 9.81 W 1 horsepower = 736 W
Temperature-difference	T	K	Kelvin	°C	°K, deg.	K	Basic unit