Expert report

www.bosch-industrial.com

A comparison of steam and hot water

Dipl.-Ing. (FH) Daniel Gosse MBA, Head of Marketing Bosch Thermotechnology Industrial

Process heat in the form of steam or high-pressure hot water plays an important role in production and heat supply. Which of the two heat transfer media is used for industrial plants, processes, mechanical drive applications and heat networks depends on a number of factors. The following technical report describes the basic principles for the differentiated consideration of steam and hot water, the physical bases of these media and their technical requirements.

Processes with steam

Steam is an indispensable energy source in many industrial sectors. It meets the high requirements of temperature stability, offers rapid process times and enables direct medium contact. The required temperature level is generally between 100 and 300 °C. To ensure quality, safety and efficiency in processes, steam is one of the preferred media for:

- The food industry, including for cooking, sterilising, drying and pasteurising
- Paper manufacturing, e.g. for drying paper rolls
- The chemical and pharmaceutical sector, e.g. for distillation, pressing and drying
- Power plants, to help start steam turbines
- The hospital sector, to supply pure steam generators for sterilisation purposes

In the food industry, filtered steam, also known as culinary steam, is particularly necessary.

Hot water ideal for heat networks

In applications such as district heating and the heating of buildings, warm/hot water is now an economic standard. It can store large quantities of heat and transport it to the relevant consumer with a high level of efficiency. The temperature level in heat networks is between 45 and 100 °C, depending on their generation. When using steam systems in the district heating sector, there is an option of superheating to overcome longer transport routes. However, the high temperature level is rarely questioned from an energy point of view. One exception to the use of steam is for high-rise buildings several 100 metres high, if the hydraulic heat transportation is pushed to its technical and economic limitations. If consumers with a steam demand are connected to the district heating grid, using hot water supply with steam extraction is an option, if local steam generation is not possible.

Planning approaches for new or existing plants

In many applications and processes, there is no doubt over whether steam or hot water is to be used as the energy source. However, there are areas such as in the food industry and in breweries which are encountering this issue when planning new process heat supply systems or when modernising existing plants. The entire site needs to be considered in order to assess the investments and the running costs in full. In practice, the following approaches can often be found:

- **Replacement of existing steam boiler systems:** Here the infrastructure for heat distribution and consumers generally predefines whether steam or hot water is used. Steam pipes are not generally suitable for hot water, for example because of their small diameter, the lack of suitable hydraulic design, lack of pumps and suitable heat exchangers. In general, the consumers are limited to steam and cannot be readily adapted.
- **Redesign with mixed energy requirements:** A differentiated consideration of the requirements for steam, hot water and domestic hot water is worthwhile. For particularly high mixed energy requirements, systems with different energy generators are often installed. However, these each require a dedicated infrastructure for the distribution of steam and water as well as more extensive maintenance concepts.
- **One medium dominates:** If one type of energy dominates on the consumer side, e.g. steam, the main energy generator can be used to cover the lower energy requirements. One typical example is a steam boiler with hot water extraction and/or additional domestic hot water heating via waste heat usage or a steam/water heat exchanger.
- **Multivalent systems:** If available, decentralised power generators can also be taken into consideration in the overall concept. Thus, for example, the waste heat of a combined heat and power unit can be integrated into the domestic hot water base load or the flue gas from CHPs/gas turbines can be used to generate steam.

Nowadays, district heating networks use hot water as heat transfer medium.

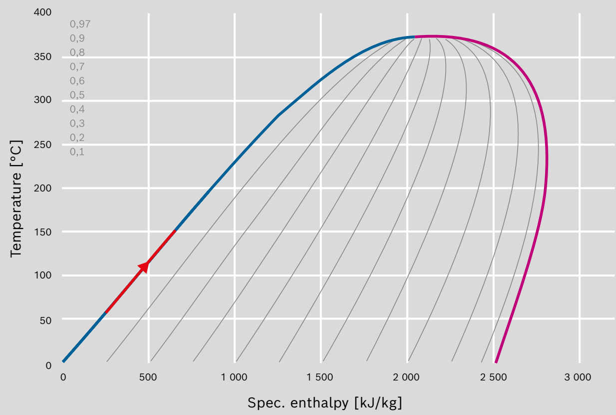
Physical principles of steam and hot water

The major difference between steam and hot water at the same pressure is the density. This is based on the different aggregate states of the two media. 1 kg of steam or hot water will be used below for the energy comparison. The supply flow temperature is 180 °C in each case when it arrives at the consumer. The return flow temperature or condensate temperature ranges from 130 °C to 165 °C (temperature difference 50–15K). In this case, 1 kg of steam has transferred 10 to 34 times the amount of energy. For processes with a narrow temperature window, this implies that when using hot water, a significantly higher recirculation volume of water is required. This must, in turn, be transported using electric pumps, which need to be taken into consideration in the review of energy costs.

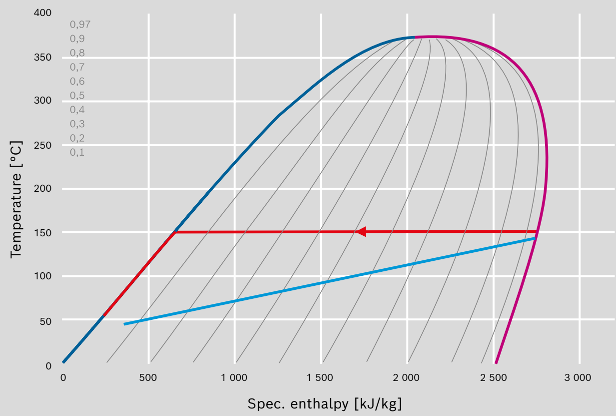
Key indicators	Hot water	Steam
Density	1000–841 kg/m³ (20–220 °C)	0.7–15.5 kg/m³ (0.2–30 bar)
Aggregate state	Liquid	Gaseous
Energy density per ton	17.5–59 kWh (ΔT 15–50 °C)	610–640 kWh (120 °C T_{steam})
Mass flow rate, example 7 MW, 180 °C	116–382 t/h (ΔT 15–50 °C)	11 t/h → 10–34 times lower
Heat transfer area 7 MW	220 m²	67 m² → >3 times smaller

In contrast to hot water, steam emits the largest proportion of the energy released by enthalpy of condensation. This means not only that the mass flow rate required is significantly lower, but also that the transfer of energy will be faster and over a significantly smaller area. With an output of 7 MW, a plate heat exchanger only requires an area three times smaller, for example. Furthermore, the energy transfer for steam takes place at a virtually constant temperature, which enables extremely high process accuracy and short process times. This is shown clearly in the enthalpy diagram: Here the enthalpy change on the red line can be read on the x-axis. Purely heating the water (top diagram) only causes a slight increase in enthalpy and is accompanied by a change in temperature. As a result, the energy transfer always takes place within a defined temperature range – at a temperature that is not constant. The flow rate thereby determines the thermal output. With steam, on the other hand, the energy transfer takes place during the phase change to a gaseous state at a constant temperature. This is shown by the horizontal section of the red line (middle diagram). The further enthalpy change caused by the steam overheating visible in the bottom diagram is extremely small – this is also caused by a pure temperature change.

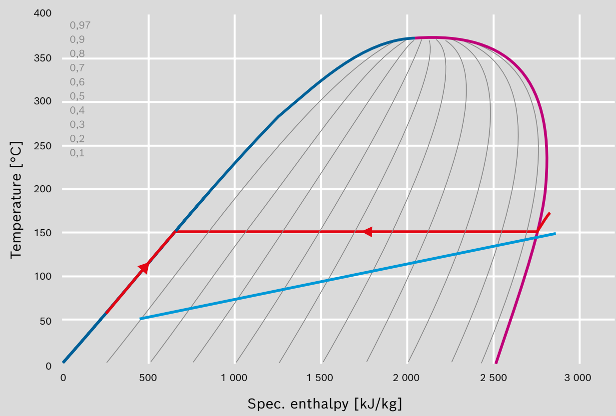
Hot water



Saturated steam



Superheated steam



The decisive advantage to hot water is that the medium can transport large thermal quantities. Over long distances, the low temperature level and the large pipe cross-section in particular lead to lower losses. In addition, no drainage is needed for any condensate that accrues and condensate management is not required. Since the hot water system is closed, less energy escapes from the system. As a result, virtually no fresh water needs to be heated. The actual heat transfer always takes place via a heat exchanger, which does not allow direct media contact.

To summarise: Warm and hot water are ideal for indirect heating, particularly at temperatures up to 100 °C. Steam, on the other hand, is suitable for both direct heating (contact with the product to be heated) but also for indirect heating at temperatures above 100 °C. One exception is vacuum steam – a technology not very widespread outside China.

Overview: Comparison of steam and hot water

Warm and hot water	Steam
Ideal for indirect heating with a temperature level up to 100 °C	Ideal for indirect heating and direct heating with a temperature level over 100 °C (exception – vacuum steam)
Can be used up to approx. 220 °C	Saturated steam up to approx. 220 °C Superheated steam up to 300 °C
Evaporation is not permitted	Evaporation intended → Evaporation heat transferred to the product to be heated up
1 t of hot water emits 48 kWh heat when cooled from 160 °C to approx. 120 °C	1 t of steam at 160 °C (5.2 bar) emits 626 kWh during condensation and cooling down to 120 °C (13 times more!)
Volume change approx. x1.04	Volume change x289
Mostly longer process times	Fast, even heating up is possible
Much slower	Fast, precise temperature control
Medium transport via circulation pump, higher power consumption	Medium transport via inherent pressure, condensate trap, condensate and feed pump
Expansion vessel and generally a separate pressure-monitoring unit	Condensate/feed water vessel, expansion via inherent pressure
Suitable for long transport routes	Transport routes as short as possible with drainage
Large pipe cross-sections required	Smaller mass flow rate at the same transferred thermal quantity (by factor 10–50), therefore small pipe cross-sections are possible
Closed, low-loss systems	Open systems experience more losses; closed condensate systems for reduced losses

Investment comparison between steam and hot water systems

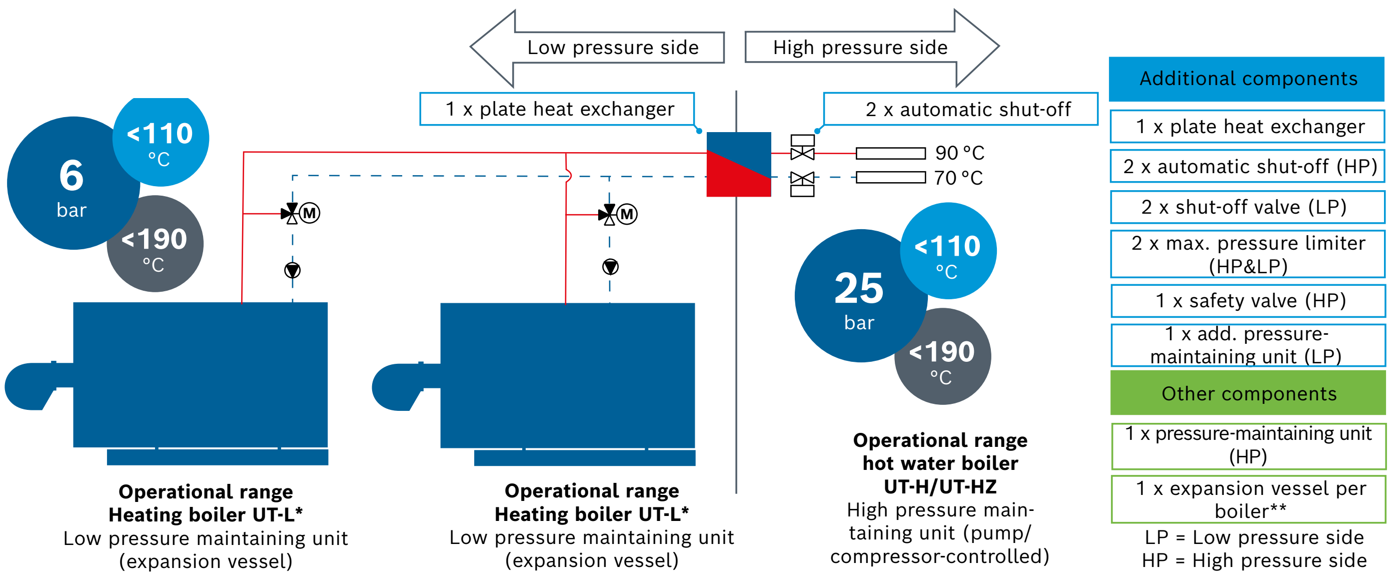
As already mentioned, it is recommended when planning new systems and when overhauling existing systems that an extensive review is carried out. It is sensible to assess both the initial investment and the ongoing costs over a defined review period. As an example, below is a comparison of a 10 t/h steam system and a 7 MW high-pressure hot water system. The purchase price for the boilers with same performance level is comparable. Even though different components are needed in the peripherals, these are also virtually identical in terms of price: The steam system includes water treatment comprising softening and deaerator as well as a condensate module, where necessary. The total investment for the components is currently around EUR 60,000. System components including a pressure-maintaining unit, a heating circuit distributor, the hydraulic system and a dirt and sludge separator are required for the hot water system – likewise totalling around EUR 60,000. However, there are cost differences if we look at the entire thermotechnical system. The largest proportion of costs here is in heat distribution and the consumers. The larger pipe cross-sections in hot water systems in conjunction with the large circulation pumps play an important role here. In existing systems, this is even more important if additional pipe routing work and, potentially, ground work is necessary. Consumers for hot water and suitable heat exchangers must also use the significantly higher volume flow and are, accordingly, larger (more expensive). However, what appears to be feasible for new systems has its limitations when retrofitting existing ones. If the replacement of production facilities that consume steam is required, conversion to hot water is in many cases not profitable.

Heating systems: Cost-efficient alternatives with circuit separation

One particular feature in the media transport of hot water used for heating purposes is circuit separation using plate heat exchangers. If, for example, a district heating supply has a pressure requirement of above 16 bar, e.g. in order to overcome a great height in a building, but only needs temperatures below 110 °C, the boiler circuit and the heating circuit can be hydraulically separated. As a result, the temperature spread on the secondary side can be freely selected in a very large range and the loss of efficiency by the heat exchanger is generally almost negligible, at around 0.3 %.

The decisive advantage of circuit separation is that it enables a more cost-effective, more compact and more lightweight heating boiler with attractively priced boiler equipment to be used. Compared to a hot water boiler (Pressure Equipment Directive), the heating boiler is not subject to the constant monitoring obligation, which makes operation simpler and thus also reduces the running costs. Another advantage is the chemical separation from the heating circuit. On multivalent systems with differing manufacturer requirements in particular, these systems can be kept separate from one another. This prevents any dirt from the network from entering the heat exchanger. The additional hydraulic costs are relatively low: In addition to the plate heat exchanger, only additional shut-off and safety valves, a pressure limiter and pressure-maintaining units for the low and high pressure range are needed. In the high pressure range of the heat network, the pressure-maintaining unit is normally controlled via a pump or compressor.

Concept for cost reduction



*With UT-M also possible in a higher temperature band
**If the boiler can be hydraulically blocked off

Practical examples

At the Hungarian Haribo site of Nemesvamos, originally one steam boiler supplied the processes in production and heated the building. As part of a capacity expansion, the company decided to **separate its heat and steam supply**. For the additional process heat requirements in sweets production, a new UL-S steam boiler was integrated into the existing infrastructure. The heating energy supply was separated and is now provided via an 800 kW heating boiler. In addition, a downstream condensing heat exchanger of the steam boiler system helps to heat the building.

Traunstein hospital features a **multivalent system comprising a steam and heating boiler plant as well as a CHP.** Via its motor waste heat, the CHP supplies the base load to heat the helicopter platform and the buildings. At max. 85 °C, the heat enters the hospital's low-temperature network. A UT-L heating boiler with 1.9 MW together with an existing boiler ensure the peak load heat demand. For particularly ecological steam generation, a heat recovery steam boiler with a fourth pass (UL-S type) uses the residual heat of the CHP and generates saturated steam. Combined with its own firing system, this boiler supplies up to 1,600 kg of steam per hour. For additional requirements and as a back-up, a three-pass UL-S type steam boiler with the same output is integrated. The steam generated is used, for example, to heat pure steam generators for sterilisation purposes.

KSB Pumps decided on a holistic **conversion from steam mode to DHW mode.** The required temperature level has changed over the decades, partly due to efficiency measures, and is now max. 100 °C. A CHP with a thermal output of 400 kW for the base load and two 8.4 MW UT-L heating boilers replaced the old steam boiler system from the 1970s. The existing wood-burning boiler was retained and was also converted to DWH mode. The conversion resulted in both easier setup conditions and a reduced monitoring obligation. In addition, the fuel costs were greatly reduced with up to 1 GWh/year less natural gas.

A UT-M **hot water boiler system for district heating supply** is used at RWTH Aachen University. The expansive network system at RWTH university's Melaten campus covering around 500,000 m² requires transport distances to be overcome efficiently. The hot water generated can store large thermal quantities and transport these to the consumer with a high level of efficiency. The heat for the different heating and process heat applications leaves the hot water boilers with a flow temperature level of 150 °C and returns from the network with around 83 °C. Around 50 large buildings with various requirements depend on the heat network, including the university hospital Aachen. There, steam extraction takes place (e.g. for sterilisation processes) to satisfy their steam demands.

Summary

In many places, more efficient machines, optimised processes and a reduction in heating requirements are, overall, leading to a drop in energy requirements at the low temperature level. This means it is sensible to compare hot water and steam in advance when redesigning energy supply systems. In many cases, steam remains the most effective solution due to temperature stability and other process parameters.

In a comparison of system costs it is important to consider the entire system including distribution and consumers, likewise the influence on ongoing costs and the implications for process times. For existing systems in particular, e.g. in breweries, huge expenses are often incurred in the entire production system in order to convert existing infrastructures with steam to hot water. By contrast, on many new systems, it is possible to provide the steam and domestic hot water/hot water as separate networks. If one of these requirements is significantly larger than the other, there is an option to separate small quantities of steam from hot water or vice versa. In individual cases, it is also possible to convert steam boilers to hot water boilers at a later time. This should, however, be taken into consideration as early as possible in the planning stages.

Bosch Industriekessel GmbH

Nuernberger Strasse 73
91710 Gunzenhausen
Germany
Tel. +49 9831 56253
Fax +49 9831 5692253
sales@bosch-industrial.com
Service hotline +49 180 5667468*
Spare parts hotline +49 180 5010540*

Bosch Industriekessel Austria GmbH

Haldenweg 7
5500 Bischofshofen
Austria
Tel. +43 6462 2527300
Fax +43 6462 252766300
sales-at@bosch-industrial.com
Service hotline +43 810 810300**
Spare parts hotline +49 180 5010540**

info@bosch-industrial.com
www.bosch-industrial.com
www.bosch-industrial.com/YouTube

*€0.14 per minute inside Germany on a landline; maximum charge on mobile devices €0.42 per minute
**Max. €0.10 per minute inside Austria on a landline
Costs for calls from mobile networks and international calls may vary.