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Potential of condensing technology in steam and hot water systems

Many commercial and industrial applications with heat and process heat demands lose considerable amounts of heat via chimneys. One option for reducing flue losses from steam and hot water generators caused by physical processes is to use condensing technology. This technology, which has been standard in domestic heating systems for many years, is now starting to be adopted by industry. While it involves additional costs, they are often amortised within two to three years. Using condensing technology allows companies to improve their energy efficiency, conserve resources in their production processes and sustainably protect the environment.

Net and gross calorific values and condensation heat

A good analogy for explaining how condensing technology works is to imagine a cooking pot. If you pour boiling water into a pot without a lid, it takes a lot of time and energy to make the water completely evaporate and leave the pot empty. In contrast, with a lid placed on top, the water vapour will condense. This amount of energy is then released when the vapour changes back into a liquid.

The following brief explanations illustrate the distinction between the indicators of net calorific value and gross calorific value. The net calorific value ("lower heating value", H_i or H_u) is the maximum energy that can be used and which is released during complete combustion. During this process, the flue gas cools down to the reference temperature at a constant pressure. The water vapour created during combustion remains gaseous. The indicator of net calorific value therefore specifies the amount of heat contained in the flue gas (sensible heat).

The gross calorific value (“upper heating value”, H_S or H_O) contains the sensible heat and the condensation heat (or “latent heat”) in the flue gas. This means that the water vapour in the flue gas condenses and releases additional heat after combustion and cooling.

When calculating efficiencies, you should refer to a fuel’s net calorific value. Previously, it was essential to leave the water vapour in the flue gas in a gaseous state in order to prevent potential corrosion damage. Nowadays, a wide range of modern condensing systems that use flue gas condensation are available on the market. The net calorific value has remained as a reference value and results in condensing systems having efficiencies of over 100 %, i.e. gross calorific value = net calorific value + condensation heat. Nevertheless, it goes without saying that the “real” degree of primary energy efficiency can never be exceeded.

Basis for using condensing technology

Condensing technology harnesses the energy content in the water vapour of flue gases. In order to make full use of this potential, the flue gases from combustion must cooled below the dew point until the onset of condensation. This requires corrosion-resistant materials, such as heat exchangers made of stainless steel, and moisture-resistant flue systems and chimneys.

Which fuels are suitable for condensing technology?

When hydrocarbons are burnt, both the carbon and the hydrogen are combusted. The longer the chains are in the hydrocarbons, the higher the relative proportion of carbon will be. Natural gas largely consists of methane, which only contains one carbon atom in each molecule (CH4) and therefore forms the highest proportion of water in the flue gas and the least CO_2. Hydrogen is the only element that combusts without producing any CO_2.

When comparing the relevant key data for established fuels, natural gas currently offers the highest potential use for condensing technology (see table of key data for various fuels).
Natural gas has:

- The highest water content in the flue gas
- The highest flue gas dew point
- The highest pH value of the flue gas condensate

Compared to fuel oil EL, natural gas offers more condensation heat at a higher condensation temperature level. This means that flue gas condensation begins at higher flue gas temperatures. The flue gases produced by combustion are virtually free of soot and sulphur, making contaminated heating surfaces very easy to clean. This maintains the effectiveness of the condensing technology and prevents operating faults. Moreover, the pH value of the flue gas condensate is higher than for fuel oil EL, reducing the effort involved in disposing of the flue gas condensate. Nevertheless, fuel oil is also suitable for use with condensing technology and allows boilers to be operated more economically.

It is expected that alternative and carbon-neutral fuels, such as hydrogen, will be increasingly used in the future. The same established implementation rules and technologies for natural gas can be used for hydrogen combustion. In addition, the potential for using condensing technology with hydrogen is even higher than it is for natural gas.

Table: Characteristics of different fuels

Fuel	Net calorific value (H_i) [kWh/m³/kg]	Gross calorific value (H_S) [kWh/m³/kg]	Ratio H_S/H_i[%]	Flue gas dew point [°C]	Theor. condensate [kg/kWh]	pH value [–]
Hydrogen	3.00	3.54	118.0	71.8	0.27	4.3-4.9
Natural gas “H”	10.35	11.46	110.7	55.6	0.16	2.8–4.9
Natural gas “L”	8.83	9.78	110.8	55.1	0.16	2.8–4.9
Propane	25.89	28.12	108.6	51.4	0.13	2.8–4.9
Butane	34.39	37.24	108.3	50.7	0.12	2.8–4.9
EL fuel oil*	11.90	12.72	106.9	47.0	0.10	1.8–3.7**

* “Extra light” EL quality: Maximum sulphur content in the fuel 0.1 weight %
Low-sulphur fuel oil quality: Maximum sulphur content in the fuel 50 ppm = 0.005 weight %
** pH value of condensate from low-sulphur fuel oil: 2.3–4.5

Condensing technology achieves an efficiency of over 100 % in relation to net calorific value Hi

If suitable heat exchangers and the coldest possible circulating water are used, it is possible to cool the flue gas down to below its dew point. Figure 1 shows the influence of the flue gas dew point and the temperature of the return water on the quantity of condensing water vapour and the achievable boiler efficiency. Figure 2 illustrates examples of efficiency curves which show the potential of condensing technology. Using this technology considerably increases the operational and economic benefits in hot water and steam generation and achieves an efficiency of over 100 % in relation to the net calorific value Hi. Compared to using conventional systems with standard flue gas heat exchangers, condensing technology reduces the fuel quantity, fuel costs and emission of pollutants by over 8 %. This makes a significant contribution towards environmental protection and the sustainable reduction of CO_2 emissions.

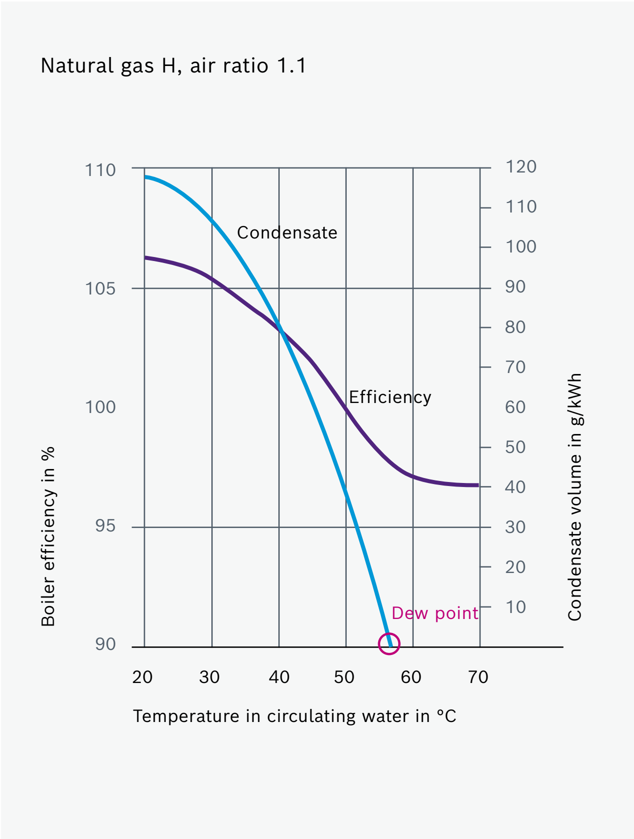

Figure 1: Influence of the circulating water temperature on the boiler efficiency and the condensate accumulation rate for natural gas.

Which systems are suitable for condensing technology?

Most condensing boilers and gas boilers with low outputs are made entirely out of stainless steel. For technical reasons and due to the high costs, hot water boilers with higher outputs for heating large buildings and building complexes are not made of stainless steel. These boilers are equipped with special stainless steel flue gas heat exchangers for

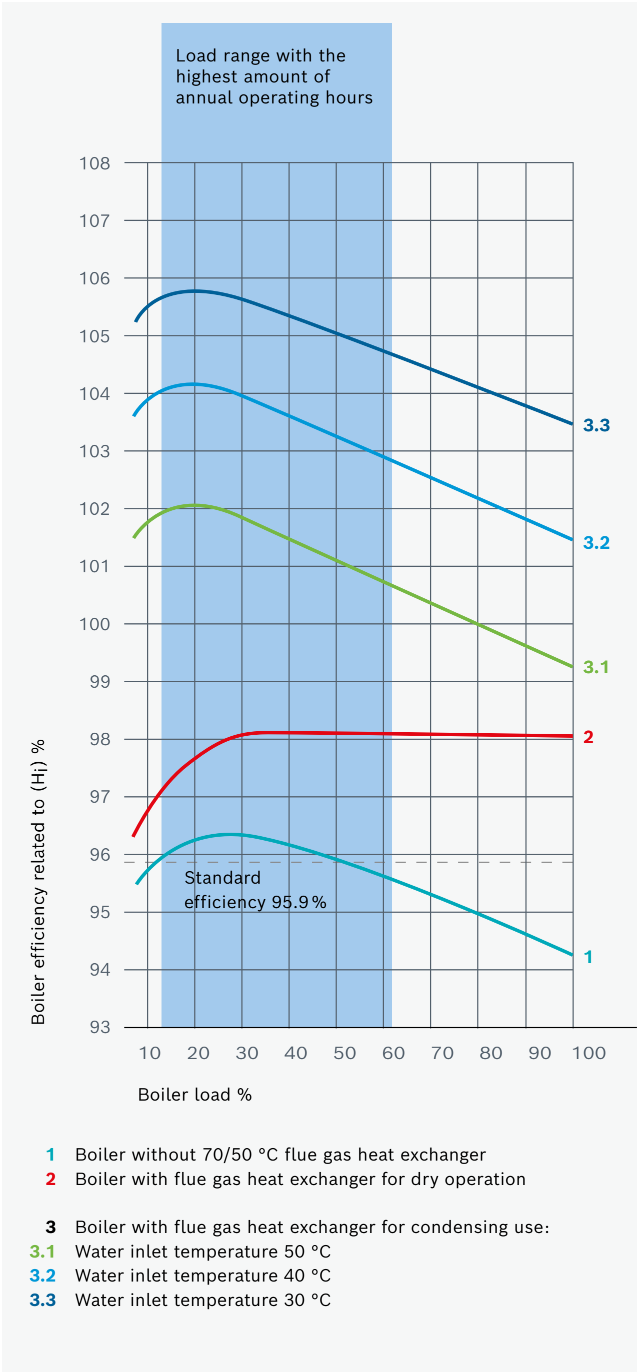

Figure 2: Efficiency curves for condensing technology (using a hot water boiler with gas combustion as an example).

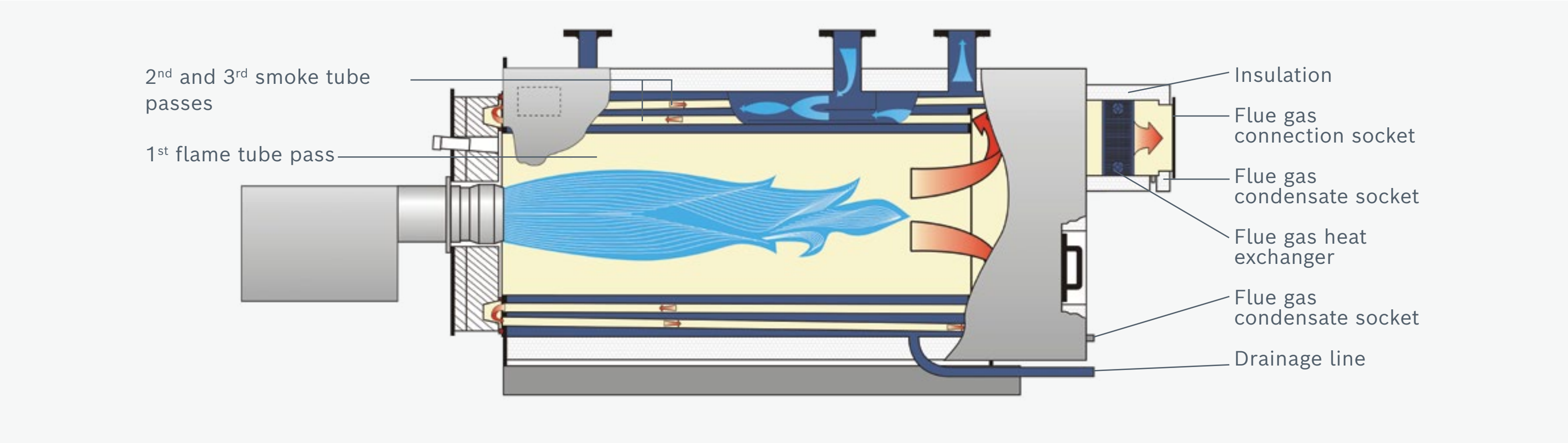

Figure 3: Cross-section of a Bosch heating boiler (UT-L) with an integrated flue gas heat exchanger.

condensing technology. These heat exchangers are already integrated on the boiler ex works or are installed as a separate module on-site (Figures 3 and 4).

In steam boiler systems, a two-stage flue gas heat recovery concept enables condensing technology to be used. Rather than having integrated systems, the stainless steel flue gas heat exchangers are only used as a separate module and connected downstream of the boiler on the flue gas side (title image). This topic is discussed in more detail below in “Areas of application for condensing technology in steam boiler systems”.

As a separate module, the flue gas heat exchanger is ideal for retrofitting existing systems. The hot water boiler shown (Figure 3) is designed as a flame-tube smoke-tube boiler in a three-pass system with a completely water-flushed rear flue-gas reversing chamber. Thanks to the large radiative heating surface of the flame tube and the large convection heating surface in the second and third flue gas passes, the flue pipes can reach an efficiency of 95% without the need for downstream heat exchangers or maintenance-intensive turbulators.

If a dual-fuel burner is used with natural gas and fuel oil, the heat exchanger for condensing must be equipped with a flue gas bypass in order to protect the system from unwanted condensation when operated with light fuel oil.

Areas of application for condensing technology in hot water systems

The use of condensing technology in homes has been commonplace since the early 1990s. However, this technology is also tried-and-tested commercial and industrial applications and often makes sense from an economic and environmental perspective. In particular, with a suitably low temperature level in the heating return – around 30 °C to 50 °C – condensing technology can be used for local heating supplies.

In contrast, the system return temperatures in high-pressure hot water generators for process and district heating are mostly above 100 °C – in other words, far higher than the flue gas dew point and therefore not suitable for condensing technology. In this case, flue gas heat exchangers for “dry” operation are an ideal solution and they can reach a boiler efficiency rate of up to 98%. It is possible to use condensing technology in these instances if there is a low-temperature secondary circuit in the system.

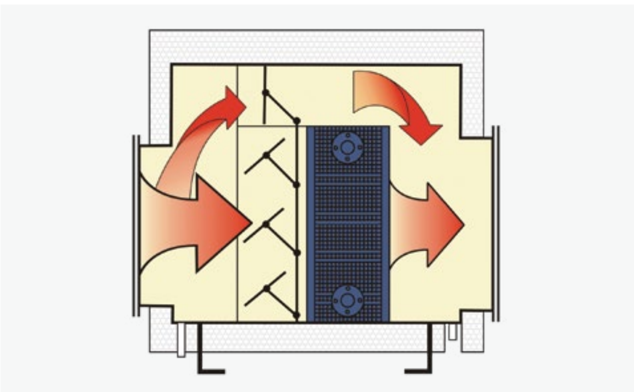

Figure 4: Flue gas heat exchanger for separate installation and retrofitting.

Hydraulic interconnection of condensation heat exchangers in hot water boiler systems

It is possible to make maximum use of condensing technology with the largest possible difference in temperature. The network return with the lowest temperatures (below the flue gas dew point for the fuel) flows through the condensation heat exchanger and this starts condensation at the heating surfaces of the heat exchanger. The flue gases cool, the low-temperature heating circuit heats up and is fed back to the hot water network.

The return flow temperature maintenance mixes the network return to the boiler with flow water before entering the boiler (Figure 5). This ensures compliance with the required minimum water inlet temperature of 50 °C in the boiler. A special injector on the top of the boiler means that there is an effective flow and mixing in the boiler across the entire control range of the modulating burner. Moreover, even

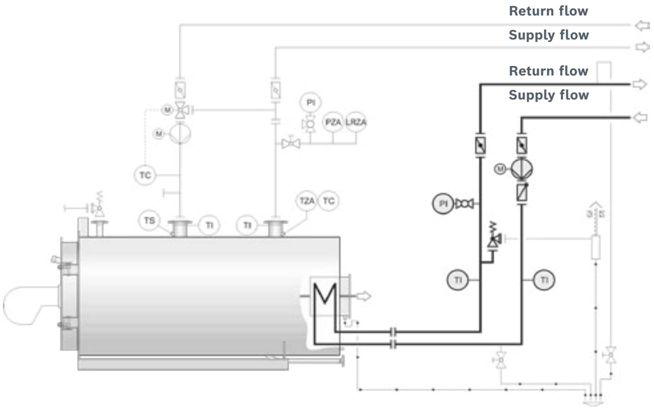

Figure 5: Hydraulic circuit for optimal use of condensing technology.

when the burner is in a low or small load range, this leads to long burner runtimes with low flue gas temperatures and optimal use of condensing technology. The return flow temperature maintenance prevents boiler temperatures from falling below the flue gas dew point for the fuel, which would otherwise cause corrosion in the boiler.

Areas of application for condensing technology in steam boiler systems

Steam generators with medium temperatures, typically between 150 °C and 200 °C, are supplied with deaerated feed water and temperatures of between 85 °C and 105 °C. Due to the physical processes, the flue gas temperatures for these steam boilers are approx. 80 °C higher than the boiler temperature. This is a considerable amount of heat and, if flue gas or condensing technology is not used, this energy is

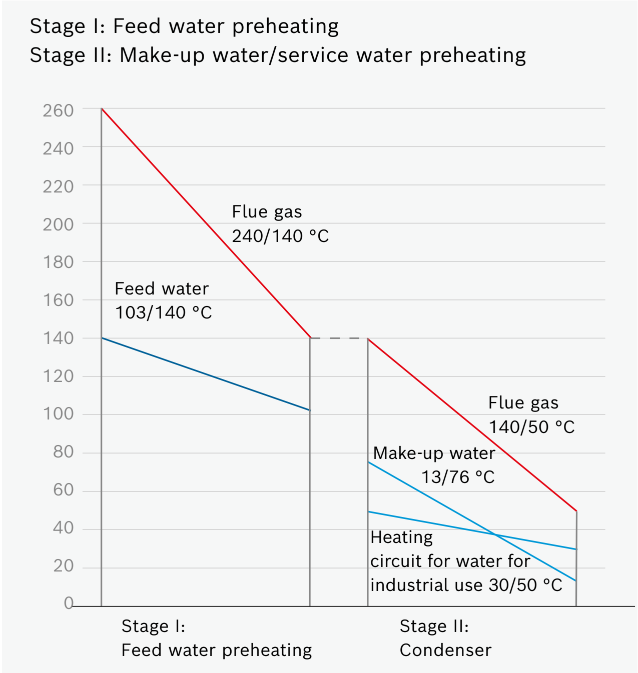

Figure 6: Two-stage flue gas heat recovery with flue gas/water temperature at 100 % load.

lost via the roof. A flue gas heat exchanger that uses the feed water as a heat sink (also known as an “economiser”) considerably reduces the flue gas losses. The flue gases cool down to around 130 °C, which is still in the “dry” range and is significantly higher than the dew point.

For high-pressure steam generators, adding a second heat exchanger stage with low-temperature consumers also allows condensing technology to be used (Figure 6). As with all downstream flue gas paths and drainage lines, this flue gas condenser is made of corrosion-resistant stainless steel.

Unlike building heating systems with clearly defined system and return flow temperatures, a wide range of steam application and heating systems are used in industry, meaning that there are various competing energy-saving and heat recovery systems. The basis for finding the most economical solution is to perform an up-front detailed analysis of all heat suppliers and heat consumers.

Interconnection of condensation heat exchangers in steam boiler systems

Steam supply systems must recover as much condensate as possible in order to supply this back to the boiler’s feed water supply. However, there are processes which rule out condensate recovery due to direct steam heating (e.g. polystyrene production, air humidification and processes in bread factories).

This is also applies to non-reusable condensate, which contains foreign substances. Moreover, there are losses due to blowdown, desalting, re-evaporation and leaks. The quantities of steam lost vary greatly depending on the system. These amounts can be much higher than half the amount of steam generated and must be replaced by make-up water. This water, which is usually available after water treatment with a maximum temperature of 15 °C, is ideally suited for preheating in the flue gas condenser. The low water inlet temperature results in extensive flue gas condensation and excellent use of condensing technology. This application produces the maximum utilisation factor between the availability of waste heat and the heat energy demand (see Figure 7 – variant A).

For example, Hans Henglein und Sohn GmbH in the Franconian village of Wassermungenau, Bavaria, uses a Bosch steam boiler with two flue gas heat exchanger stages (Figure 8) for processing its potatoes. First, the heating energy of the hot flue gases preheats the feed water. In the second step, the condensation heat is used to heat up cold make-up water. The components used are optimised for the customer's conditions and work together effectively. The flue gas temperature is ultimately reduced to a very low 55 °C. Compared to the previous system's efficiency of 85%, the new boiler system with flue gas and condensing technology achieves an efficiency of over 100%, thereby saving fuel costs and tonnes of CO_2.

Likewise, many industrial companies – particularly in the food industry – have high demands for service water. In these applications, service water that is free of hardness is an optimal medium as it can be preheated using a flue gas condenser, with water temperatures reaching between approx. 50 °C and 70 °C. The service water can be heated further to a higher extraction temperature using a downstream, steam-heated heat exchanger (see Figure 7 – variant B). Figure 9 shows the example of the heat balance for a high-pressure steam generator with an integrated flue gas heat exchanger for pre-heating feed water and a downstream flue gas condenser for pre-heating service or make-up water at a high utilisation factor. The remaining sources of fuel heat loss are conduction and exterior radiation losses from the boiler, the heat exchanger, the pipework and also the proportion of flue gas condensation that cannot be used due to the physical processes (limited size of the heating surfaces).

Suitable flue system for condensing technology

All of the housing components for flue gas condensers, flue gas lines and chimneys that come into contact with condensing flue gases must be made from corrosion-resistant material, which is generally stainless steel. Using condensing technology results in very low flue gas temperatures which can reach approx. 50 °C. Unlike as is usually the case, the natural chimney draught is not sufficient for economically discharging the flue gases into the flue gas paths with negative pressure. The burner or combus-

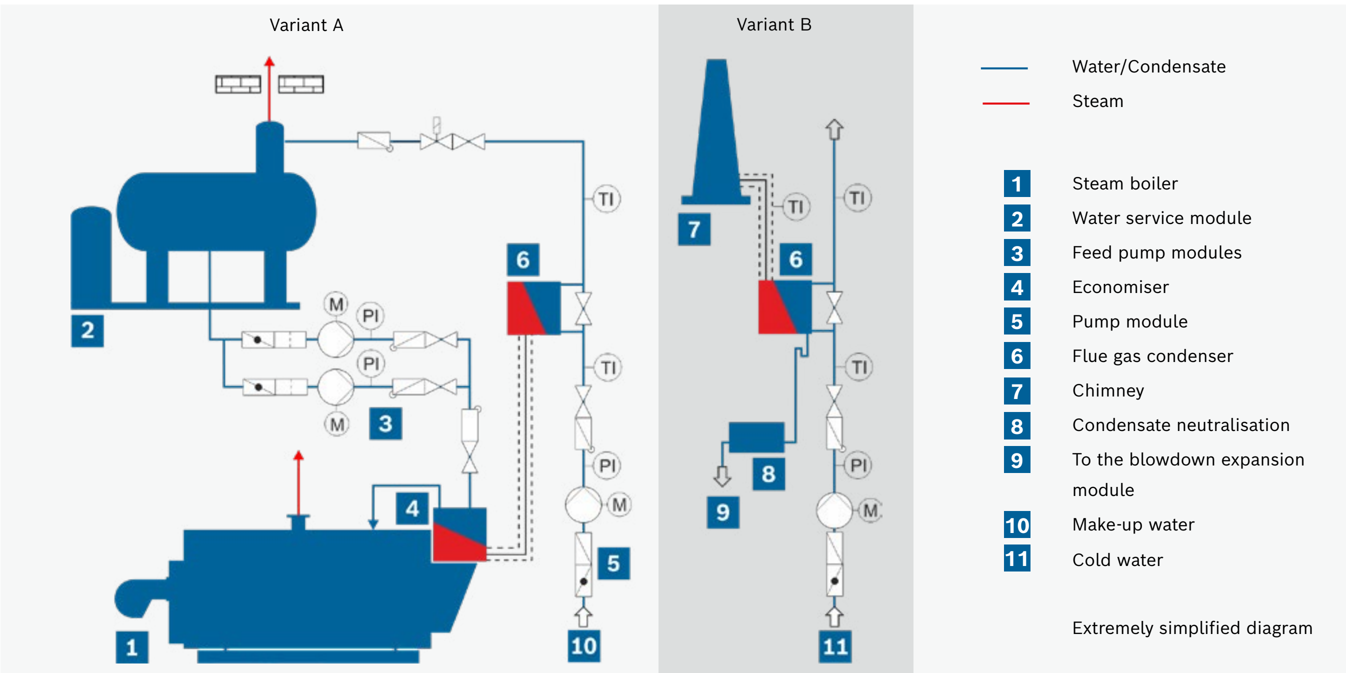

Figure 7: Simplified diagram of a high-pressure boiler system with two flue gas heat exchanger stages (economiser/flue gas condenser).

Figure 8: Hans Heinglein und Sohn GmbH's particularly efficient steam boiler system with an integrated economiser and downsteam flue gas condenser.

tion air fan for the boiler combustion must extend up to the chimney in order to overcome all of the resistance on the flue gas side. This requires comprehensive project planning, checking and coordination.

Discharge and neutralisation of the condensate

The greater the use of condensing technology, the more condensate will be produced. The flue gas condenser, flue gas lines and chimney should therefore be fitted with suitable drainage systems for discharging the acidic waste water. The theoretical condensate volumes are shown on page 2 in the "Key data for various fuels" table. However, the condensate volumes that are actually produced depend on the degree of condensation and are usually between 40% and 60% of the theoretical condensation volume specified in this table. Measured with the pH value as the acidity level for liquids, the flue gas condensate from the combustion of natural gas has a pH value of between 2.8 and 4.9, and a pH value of between 2.3 and 4.5 from the combustion of low-sulphur fuel oil. The condensate temperatures are in a temperature range of between 25 °C and 55 °C. The local authority waste water treatment regulations must be followed when discharging the water into the public sewage system. The German Association for Water, Wastewater and Waste (DWA) has produced a data sheet which recommends using a condensate neutraliser and keeping to a pH value >6.5 for combustion with condensing technology for heating capacities from 200 kW. However, practices vary greatly in different countries and municipalities. For neutralisation, filters filled with replaceable dolomite (granule boxes) are suitable for small systems. They are also suitable for containers in large systems with dosing equipment for sodium hydroxide (liquid condensate neutralisers), which increase the pH value accordingly.

Consideration of economic efficiency

In order to determine the fuel savings and amortisation time, a sensible approach is to calculate each individual case according to familiar methods. When comparing the investment in a conventional hot water boiler to investment in a hot water boiler with an integrated condensation heat exchanger, the following aspects should be considered:

- Costs for the integrated stainless steel flue gas heat exchanger – for dual-fuel burners, including the bypass – and hydraulic connection
- Costs of condensate draining and neutralisation from 200 kW
- Where applicable, costs for stainless steel flue gas lines – chimneys are usually made of stainless steel in any case

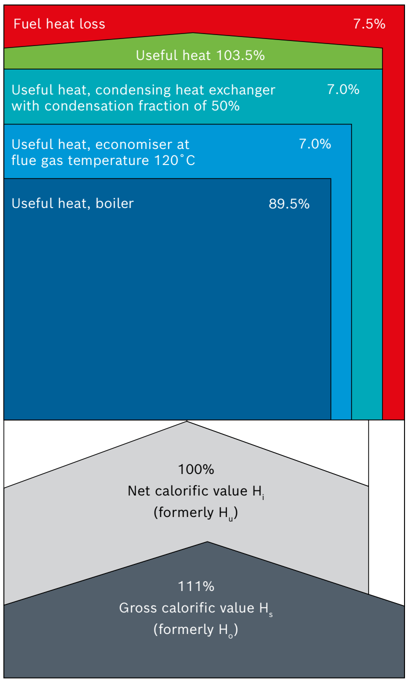

Figure 9: Heat balance of a steam generator with condensing technology.

- Generally speaking, there are no additional costs incurred during combustion. The increased flue gas resistance is compensated for by the reduced flue gas flow related to the savings in fuel quantities

Taking account of these elements, the additional investment for a 2.5 MW hot water boiler with integrated condensation heat exchanger compared to a conventional hot water boiler with flue gas heat exchanger without flue gas condensation, each without a chimney, is approx. €25,000. Using a typical German heating load over the course of a year, the costs are recouped in less than three years. This is based on the condensing system being 8% more efficient and a natural gas composite price of 40 cent/m^3.

Potential of condensing technology

There is a high, untapped potential for condensing technology in local heating supplies with a direct connection to all heat consumers. An increasing number of economic analyses and application studies for flue gas condensation in existing local heating systems conclude that such technology often supplies the required amount of heat for the majority of the heating period and at a lower temperature level. It is therefore possible to use condensing technology in many instances. This technology allows a large number of heat suppliers to improve their cost effectiveness, increase their competitiveness and sustainably reduce their carbon footprints. Likewise, condensing technology can also be used in high-pressure steam generators and this tried-and-tested and sophisticated technology has been available for a long time. Prerequisites are that the heat consumers are analysed in detail during the planning phase and graduated heating with low-temperature heating circuits are considered. Modified heating concepts could enable condensing technology to be used in many areas of industrial steam generation.

The additional investment in condensing technology can be recouped in both hot water systems and steam boiler systems thanks to the high fuel savings of up to 8% and often pays for itself within two to three years. In addition, the decreased pollutant emissions considerably reduces industry’s impact on the environment and is another step towards sustainably protecting the climate. Last but not least, this technology also allows businesses to reduce their bill for the CO_2 emission tax introduced in many countries.

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