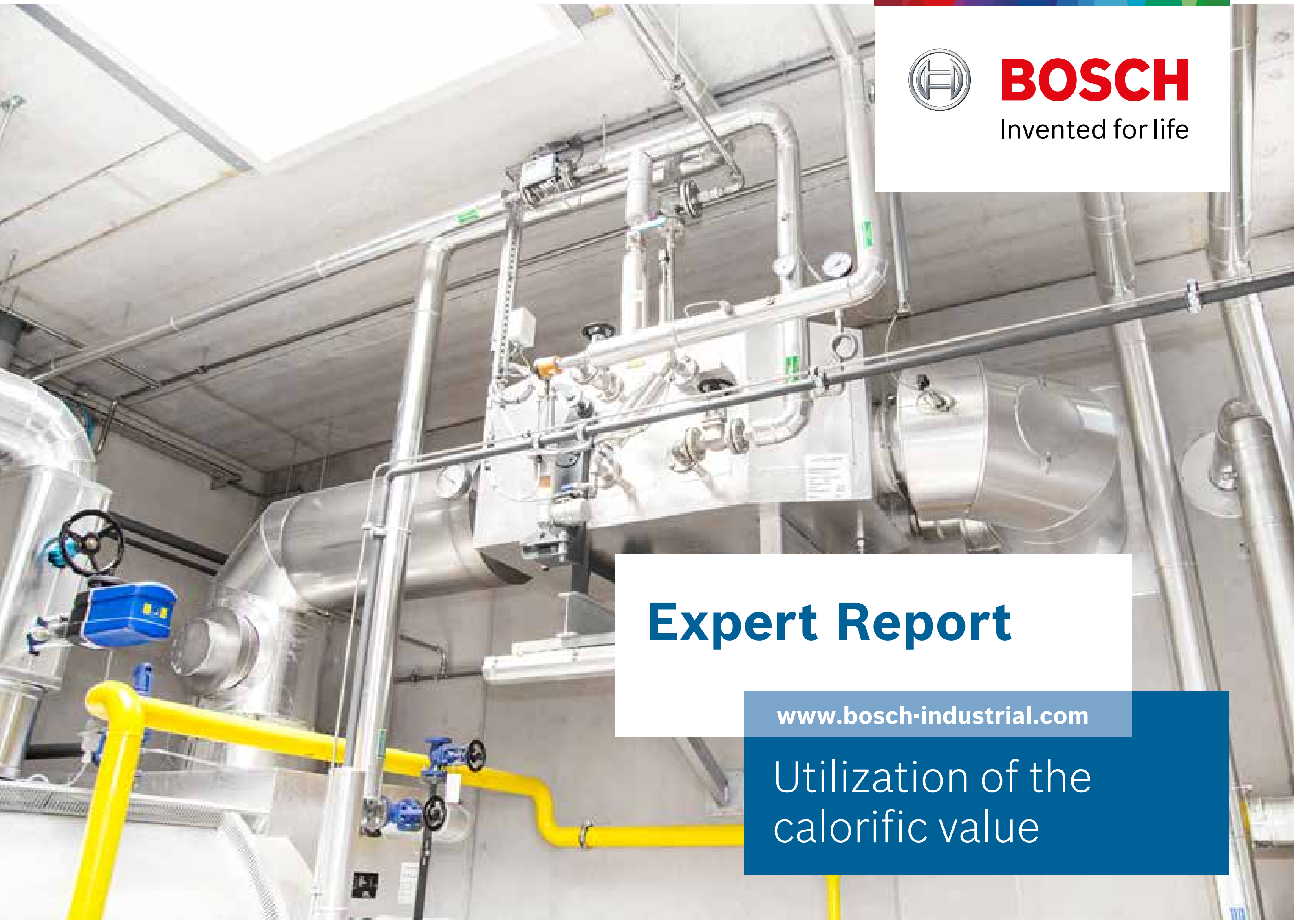

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Utilization of the calorific value

Dipl.-Ing. Matthias Raisch, Bosch Industriekessel GmbH

The utilization of existing tried and tested calorific value technology enables operators of steam or hot water boiler systems to reduce their running costs and to make an additional contribution to CO_2 reduction as well as climate protection. Consistent use of the calorific value technology amortizes the additional costs within less than 2 years.

Net calorific value, gross calorific value and condensation heat

The net calorific value (‘net calorific value’, H_u or H_i) is the energy released during a complete combustion when the flue gas is cooled back to the reference temperature with constant pressure. However, the water vapour originating from the combustion remains gaseous during the process. Thus, the calorific value only indicates the amount of sensible heat in the flue gases but not the latent amount of heat in the water vapour.
Efficiency is calculated on the basis of the calorific value of a fuel as in former times it was essential to leave the water vapour in the flue gas in a gaseous way by means of high flue gas temperatures in order to prevent flue gas condensation and corrosion of the boiler or the flue gas system as well as chimney sooting.

The gross calorific value (‘gross calorific value’, H_o or H_s) is the energy released during a complete combustion when the flue gas is cooled back to the reference temperature with constant pressure. The gross calorific value additionally contains the energy released by condensation of the water vapour contained in the flue gas, i.e. the heat of condensation.

Basic principles of the utilization of the calorific value

Nowadays, the water vapour of flue gases can be exploited with calorific value technology. Corrosion-resisting materials in heat exchangers as well as flue gas systems and chimneys insensitive to moisture facilitate this without any damage in the long run. For the utilization of the calorific value it is necessary not only to withdraw the sensible heat from the flue gas but also part of the condensation heat bound in the water vapour.

Calorific value technology profits from turnaround of the fuel trend

The use of heavy fuel oils has been decreasing more and more in Europe in the past years (e.g. in Germany, the use of heavy fuel oil as fuel is prohibited since 1986 due to the German clean air regulations for burner outputs < 5 MW).

25 % of all shell boilers up to 20 MW installed in Germany in the past 2 years are equipped with gas firing systems, 40 % are equipped with natural gas/light fuel oil firing systems primarily using gas and 35 % are equipped with light fuel oil firing systems.

Active environmental protection and technological solutions for improving the utilization of the calorific value are today's main reasons for the increased use of natural gas.

When comparing the characteristics of customary fuels relevant for the utilization of the calorific value, natural gas provides the highest utilization potential (see table 1).

Natural gas offers:
- ▶ The highest water content in flue gas
- ▶ The highest flue gas dew point
- ▶ The highest pH value of the flue gas condensate

Compared to EL fuel oil, more condensation heat is available on a higher condensation temperature level, i.e. the flue gas condensation already starts at higher flue gas temperatures. The flue gases generated during combustion are almost free from soot and sulphur. Thus, very little expenditure is necessary for cleaning soiled heating surfaces in order to maintain effectiveness and avoid operating faults. As the pH value of the flue gas condensate is also higher compared to EL fuel oil, less expenditure is necessary for disposing of the flue gas condensate.

The suitability of low-sulphur fuel oil for the utilization of the calorific value has been proven

Due to the growing market penetration of low-sulphur fuel oil, the demand of calorific value systems for this fuel is also increasing.

The low sulphur content in the fuel (max. 50 ppm = 0.005 weight % compared to 0.1 weight % of sulphur when using EL fuel oil) supports soot-free combustion free from residues. Thus, flue gas condensation can also be utilized with low-sulphur fuel oil.

Tests on the test station have demonstrated that the use of low-sulphur fuel oil can bring about an availability similar to the utilization of the calorific value of gaseous fuel oils if the prescribed cleaning intervals at the heat exchanger are adhered to.

Desulphurization as additional process step makes low-sulphur fuel oil slightly more expensive. However, the higher fuel costs are more than compensated by the gain in efficiency and the connected fuel saving (plus the fact that as of 2009, the tax rate will be determined acc. to the sulphur content which will bring about a tax privilege compared to EL fuel oil).

Table 1: Characteristics of different fuels

Fuel	Net calorific value (H_u) [kWh/m³/kg]	Gross calorific value (H_o) [kWh/m³/kg]	Ratio H_o/H_u[%]	Flue gas dew point [°C]	Theor. codensate [kg/kWh]	pH value [–]
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

If boilers are equipped with dual firing systems for optional heating with natural gas or EL fuel oil (e.g. in connection with gas switch-off contracts where the operator must provide for temporary boiler operation with EL fuel oil as substitute fuel in case of severe frost), a condensation heat exchanger with flue gas bypass is used.

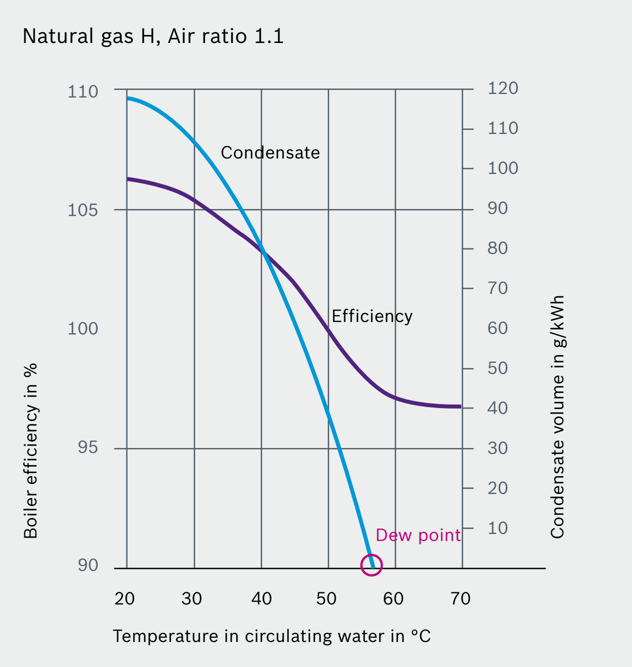
The utilization of the calorific value facilitates efficiencies of more than 100 % related to the net calorific value H_u

For utilization of the calorific value, the flue gases generated during combustion must be condensed below the flue gas dew point by cooling. If this potential is going to be used, the heating surfaces and discharge systems touched by wet flue gases must be made of corrosion-resisting stainless steel.

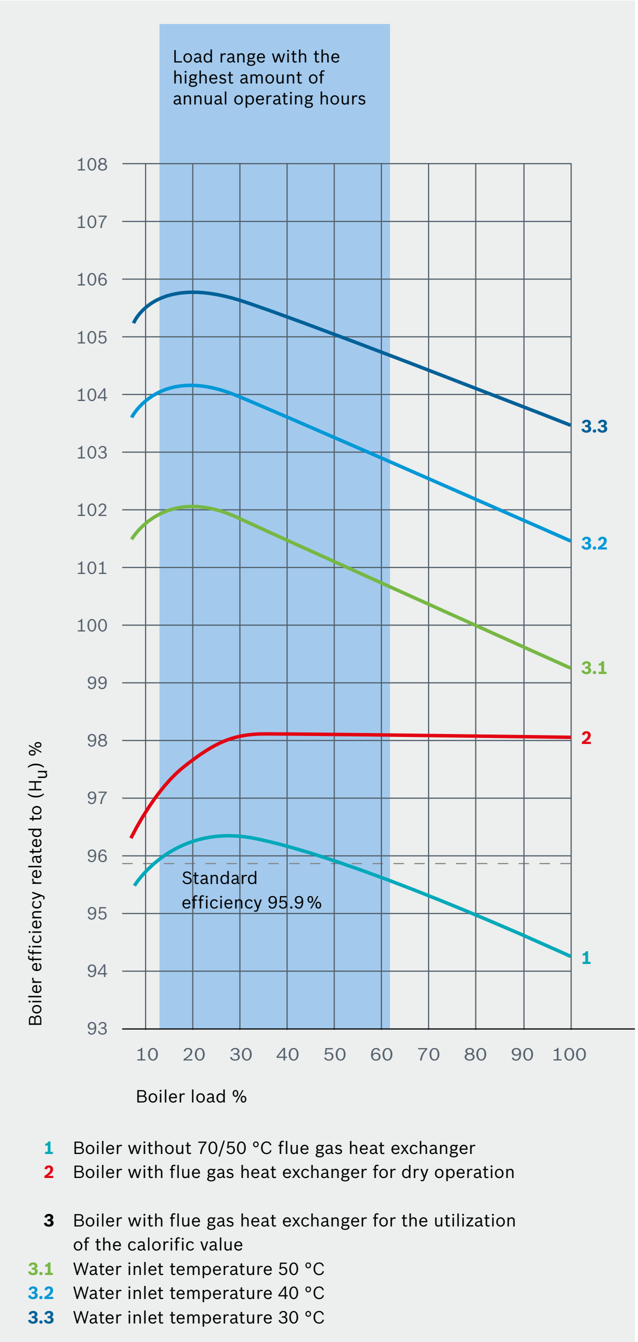
The flue gas must be cooled below its dew point with suitable heat exchangers and circulating water which is as cool as possible.

Graphic 1 shows the influence the flue gas dew point and the temperature of the return-circuit water exert on the condensing amount of water vapour and the attainable boiler efficiency.

Graphic 2 shows efficiency curves which indicate the potential of the utilization of the calorific value as an example. The operational and economic use for the generation of hot water/vapour can be increased considerably by the utilization of the calorific value. Compared to conventional systems with the usual flue gas heat exchangers, the utilization of the calorific value makes it possible to reduce the fuel amount (i.e. also the fuel costs) and the discharge of harmful substances for more than 10%. Therefore, the utilization of the calorific value makes a contribution to climate protection and provides an opportunity to reduce CO_2 emissions.



Graphic 1: Influence of the temperature of circulating water on boiler efficiency and condensate volume for natural gas (Ruhrgas)



Graphic 2: Efficiency curves for the utilization of the calorific value (example hot water boiler with gas firing system)

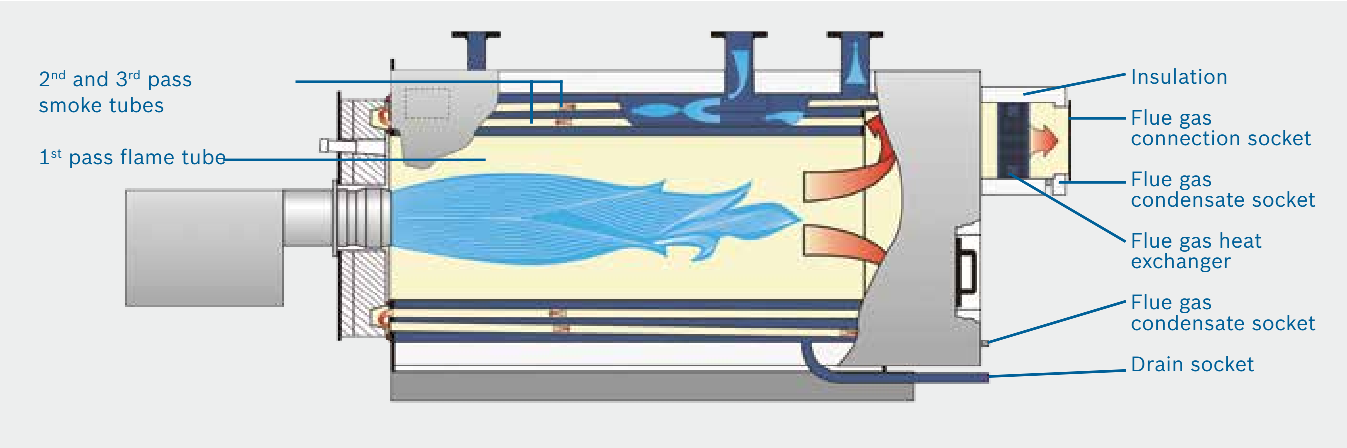


Figure 1: Sectional drawing of the UNIMAT heating boiler with integrated flue gas heat exchanger

Systems for the utilization of the calorific value

Condensing boilers and gas boilers for comparatively small ratings usually completely consist of stainless steel. Due to technical reasons and high costs, hot water boilers with high capacities for heating large buildings and blocks of buildings are not made of stainless steel. For the utilization of the calorific value, they are equipped with special stainless steel flue gas heat exchangers integrated in the boiler or as separate module (figure 1 and 2).

Due to the use of the two-stage flue gas heat recovery concept (see chapter ‘Areas of application for the utilization of the calorific value in steam boiler systems’), steam boiler systems are not equipped with integrated systems but with stainless steel flue gas heat exchangers as separate modules down-line on the flue gas side (figure 2).

The flue gas heat exchanger as separate module is particularly suitable for retrofitting. The hot water boiler in figure 1 is designed as three-pass flame-tube smoke-tube boiler with the rear flue gas reversing chamber completely washed around with water. Due to the round design for convenient functioning, a large amount of convective heating surfaces can be installed down-line from the large radiation heating surface in the 2nd and 3rd flue gas pass. This already brings about standard degrees of utilization of more than 95 % without torsion bodies in the smoke tubes and without down-line heating surfaces.

Areas of application for the utilization of the calorific value in hot water systems

Until a few years ago, the application of the utilization of the calorific value was focused on small condensing boilers and gas boilers for the central heating and the generation of process water for small flats and dwellings. Meanwhile, the use of the gas calorific value has also found its way into larger systems.

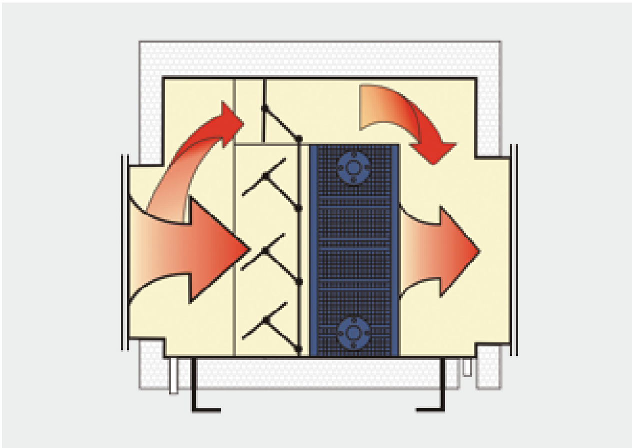


Figure 2: Flue gas heat exchanger for separate installation and retrofitting

Now oil calorific value systems are gaining in popularity in smaller systems (due to the availability of low-sulphur fuel oil). It is merely a matter of time until the use of the oil calorific value will also be established in a larger range of performance.

The attainable amount of utilization of the calorific value depends on the heating system and the actual operating temperatures. Heating systems with direct circulation of the heating water through boiler and heating element are a basic precondition. Furthermore, the boiler control should be based on control by atmospheric conditions for variable boiler water control. Newly planned floor heating systems and large-surface low-temperature heating elements are particularly suitable for condensing boilers and all-season condensation operation. As many old systems are equipped with oversized heating elements and render sufficient heating capacity with lower operating temperatures in the majority of the heating period they are also suitable for applications in condensing boilers. The utilization of the calorific value is also worthwhile for the low-temperature range of heating systems with different temperature zones. Many buildings were equipped with subsequent heat insulation, so they can be heated sufficiently with low system temperatures. During most of the year, the utilization of the calorific value can be operated with return flow temperatures.

High-pressure hot water generators for process or long-distance heating systems with primary heating circuits for heating house substations and connected secondary heating circuits for the heating of buildings are mostly operated with system return flow temperatures above 100 °C, i.e. far above the flue gas dew point. Therefore, the calorific value technology cannot be applied. However, due to the use of flue gas heat exchangers for 'dry' operation a boiler efficiency of up to 98 % can be achieved. In that case the use of calorific value is only possible if the system is equipped with a low-temperature secondary circuit.

Hydraulic sheeting of calorific value heat exchangers in hot water boiler systems

Highest utilization of the calorific value is achieved when return flow temperatures are as low as possible. The network return flow with the lowest temperatures (below the flue gas due point of the fuel) flows through the condensation heat exchanger and brings about condensation at the heating surfaces of the heat exchanger. The flue gases are cooled down, the low temperature heating circuit is heated up and again supplied to the hot water network.

Before entering the boiler, the return flow temperature maintenance module mixes the network return flow to the boiler with supply flow water to the necessary minimum water inlet temperature of 50 °C in the boiler (see figure 3). A special injector in the boiler top provides an effective mix and flow through the boiler. The turn down ratio of allocated boilers, also modulating ones, can be used to the full extent. This also brings about long burner running times with low flue gas temperatures and optimum utilization of the calorific value in the low load range of the burner. The return flow temperature maintenance prevents boiler water temperatures below the flue gas dew point of the fuel which might cause corrosion in the boiler.

Areas of application for the utilization of the calorific value in steam boiler systems

Steam generators with medium temperatures mainly between 150 and 200 °C are fed with deaerated feed water and temperatures between 85 and 105 °C. Due to physical reasons, the flue gas temperatures of these steam boilers are between 230 and 280 °C. In order to reduce flue gas losses, flue gas heat exchangers are used for feed water heating. During this process, the flue gases are cooled down to approx. 130 °C which is still located in the 'dry' range above the dew point.

The utilization of the calorific value is not possible with these energy concepts. If a second heat exchanger stage is used with low temperature consumers, the utilization of the calorific value is also possible with high-pressure steam generators (see graphic 3). This flue gas condenser is made of corrosion-resistant stainless steel like all other down-line flue gas and drainage lines.

In contrast to heating systems for buildings with clearly definable system and return flow temperatures, many different kinds of steam utilization and heating systems are used in industry. Thus, various energy saving and heat recovery systems are competing with each other. An overall view combined with a thorough analysis of all waste heat suppliers and heat consumers is necessary for finding the most economic solution. Close cooperation between operator, planner and boiler manufacturer is essential for finding the most efficient measures in the abundance of opportunities.

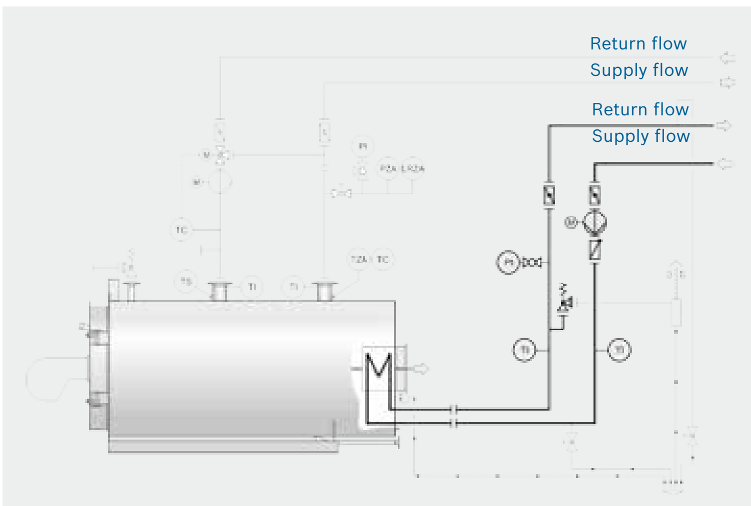


Figure 3: Hydraulic circuit for optimum utilization of the calorific value

The sheeting of calorific value heat exchangers in steam boiler systems

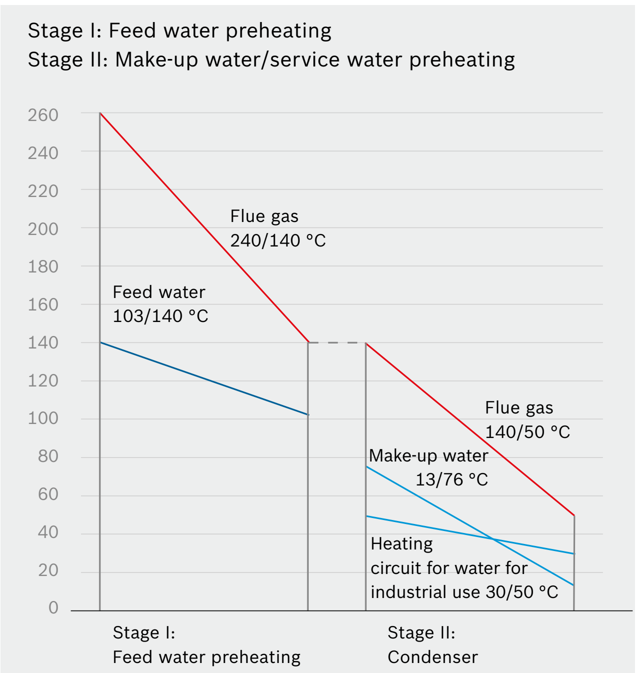
Steam supply systems recover as much condensate as possible in order to supply this condensate again to the feed water supply of the boiler. However, there are systems that do not recover condensate by direct steam heating (e.g. Styrofoam production, air humidification, bread factories) or condensate loaded with foreign substances which cannot be reused is generated. Additionally, there are losses by desalting, blow-off, re-evaporation and leakage. The loss volumes vary extensively. Far more than half of the generated amount of steam can be lost and must be replaced by make-up water. After water treatment, the make-up water is mostly provided with a max. temperature of 15 °C that is perfectly suitable for preheating in the flue gas condenser. The low water inlet temperature facilitates extensive flue gas condensation and maximum utilization of the calorific value. This method provides the highest simultaneity factor between waste heat availability and heat demand (see figure 4 – variant A).

Many industrial plants have a high demand of service water. This particularly applies to the food processing industry. In these cases, the hardness-free service water can be preheated with a flue gas condenser. The water reaches temperatures between approx. 50 and 70 °C. Further heating of the service water to higher extraction temperatures is possible by means of a down-line steam-heated heat exchanger (see figure 4 – variant B).

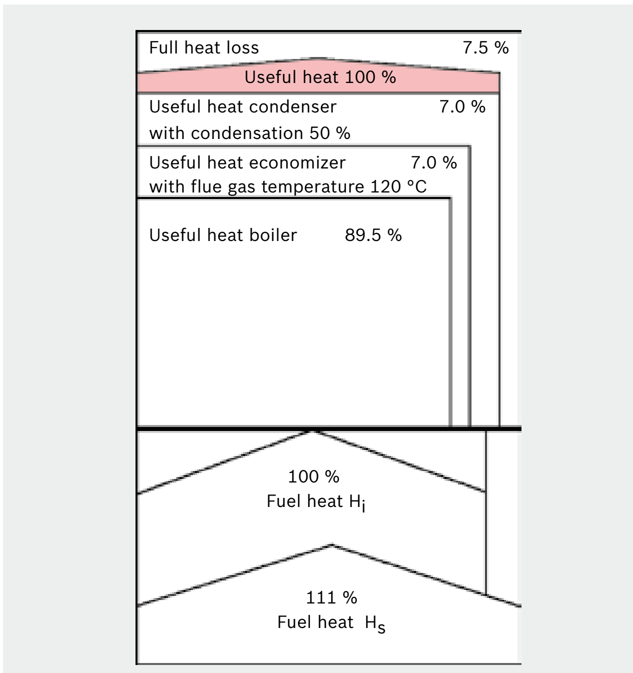
Graphic 4 shows an example of the thermal balance of a high-pressure steam generator with integrated flue gas heat exchanger for feed water preheating and a down-line flue gas condenser for service water or make-up water preheating with a high simultaneity factor. Conduction loss and radiation losses of the boiler, the heat exchanger and the piping as well as the part of the flue gas condensation which cannot be used for physical reasons (related to the size of the heating surfaces) remain fuel heat loss factors.

Utilization of the calorific value and the flue gas system

All flue gas tracts in contact with condensation flue gases must be impermeable to water and flue gases and made of corrosion-resistant material. The parts of the housing for the flue gas condenser as well as flue gas lines and chimneys endangered by corrosion are mostly made of stainless steel. Due to the utilization of the calorific value the flue gas temperatures are very low down to approx. 50 °C. The natural chimney pass does not have sufficient capacity for the customary discharge of flue gases with negative pressure in the flue gas tract. Therefore, the flue gas system incl. chimney should be designed for overpressure operation on the flue gas side in order to facilitate reduced cross sections. The burner or the combustion air fan of the boiler firing system respectively must be designed for negotiating all resistances of the flue gas side up to the chimney. This requires integral project planning, monitoring and coordination.



Graphic 3: Two-stage waste gas heat recovery
Flue gas/water temperature with 100 % load



Graphic 4: Thermal balance of a steam generator with calorific value technology

Drain-off and neutralization of the condensate

Flue gas condenser, flue gas lines and chimney must be equipped with drainage systems for draining the condensate. The theoretical amounts of condensate can be gathered from table 1. The amounts of condensate actually accruing depend on the degree of condensation and mostly range from 40 to 60 % of the theoretical amount of condensation acc. to table 1. When taking the pH value as acid value for liquids as a basis, the pH value of flue gas condensate from natural gas combustion is between 2.8 and 4.9 and the pH value from the combustion of low-sulphur fuel oil is between 2.8 and 4.5. The condensate temperatures range from 20 to 55 °C. The municipal sewage regulations must be observed for discharge into the public sewage network. The German Waste Water Technology Association (ATV) issued a technical bulletin which recommends a neutralization unit and the adherence to a pH value > 6 for firing systems with utilization of the calorific value from 200 kW heating capacity upward. The individual states and communes use very different methods. For neutralization purposes, small plants can use filters with renewable dolomite filling (granulate boxes) and large plants can use containers with dosing devices for caustic soda (liquid neutralization devices) which lift the pH value correspondingly.

Assessment of the economic efficiency

For determining the fuel cost savings and amortization period, each individual case should be calculated acc. to established methods. A general statement would not make much sense. The following aspects should be taken into account when comparing the investments for a customary hot water boiler to a hot water boiler with integrated condensation heat exchanger:

- Costs for the integrated stainless steel flue gas heat exchanger, for dual burners incl. bypass and the hydraulic connection.
- Costs for the condensate drain-off and neutralization from 200 kW upwards.
- Costs for stainless steel gas drain-off systems if necessary; however, the chimney is made of stainless steel in most cases anyway.
- Usually, additional costs for firing do not accrue. The increase of resistances on the flue gas side is compensated by the decrease of the flue gas flow due to the saving of fuel quantities.

Considering these facts, the additional investment of approx. 20,000€ for a 2.5 MW hot water boiler with integrated flue gas condenser is worthwhile compared to a customary hot water boiler (without chimney respectively). These costs will be paid off after approx. 4,200 operating hours with an average load of 60%. This calculation is based on a higher degree of efficiency of the calorific value system of just 7.5% and a mixed price of 40 cent/m³ for natural gas.

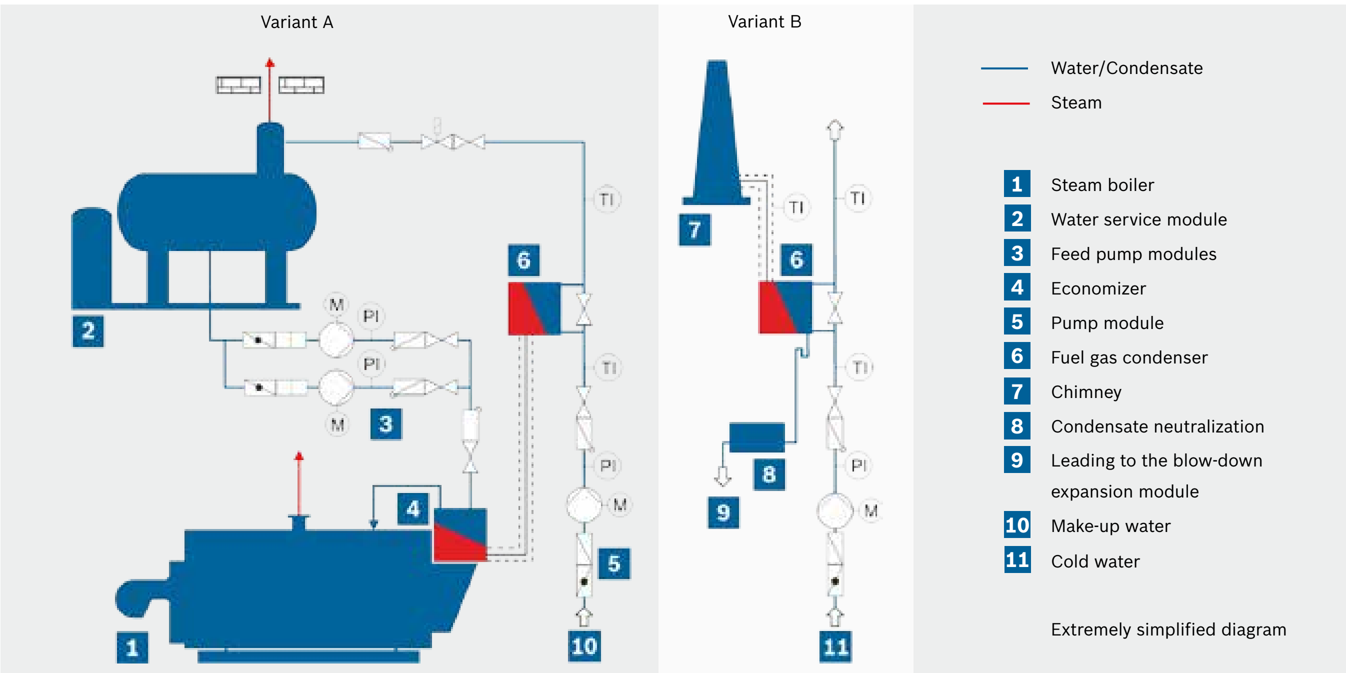


Figure 4: Block diagram of a high-pressure steam boiler system with two flue gas heat exchanger stages (economizer/flue gas condenser)

Potential of the utilization of the calorific value

Local heat supply with direct connection to all heat consumers has a high potential for the utilization of the calorific value which has not been developed by far until now. More analyses of the economic efficiency and applicability studies for flue gas condensation in existing local heating systems would often lead to the conclusion that the necessary amount of heat is also supplied on a low temperature level during most of the heating period. Utilization of the calorific value would be possible in many cases. Heat suppliers can increase their competitiveness and make an additional contribution to environmental protection.

According to the state of knowledge, the utilization of the calorific value is also possible with high-pressure steam generators. Tried and tested technology is available. An extended application in industry is possible, if the planner analyses the heat consumers thoroughly and pays more attention to progressive heating-up with low-temperature heating circuits. Changed heating concepts can facilitate the application of calorific value technology in wide ranges of industrial steam supply.

Additional investment by reduced amounts of fuel is financed in hot water systems as well as steam boiler systems. Low emissions relieve the strain on the environment. The CO_2 reduction makes a contribution to climate protection.

Bosch Industriekessel GmbH

Nuernberger Strasse 73
91710 Gunzenhausen
Germany
Phone +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
Phone +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
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