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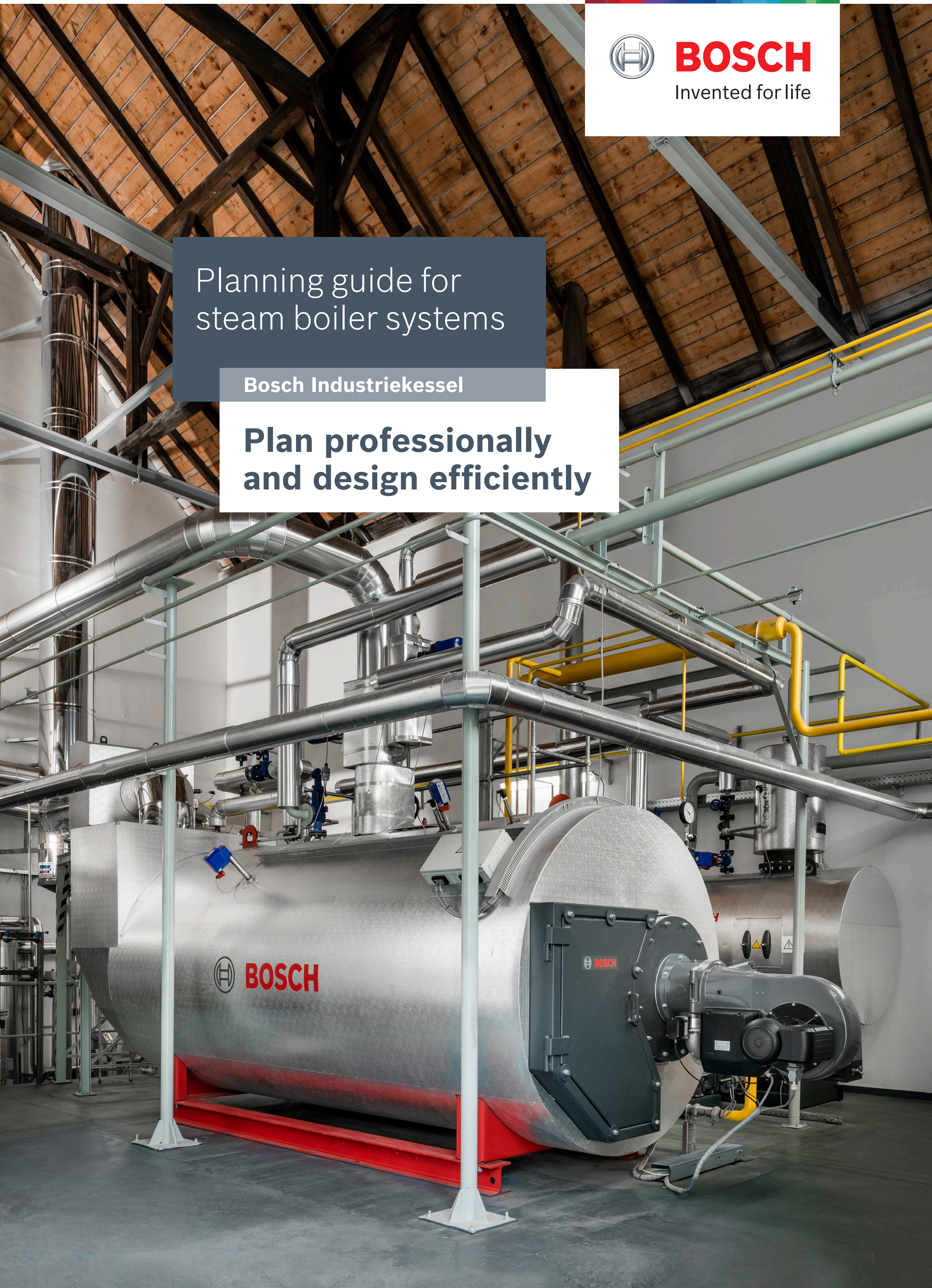
Planning guide for steam boiler systems

Bosch Industriekessel

Plan professionally and design efficiently



Preface

Beverages, food, car tyres, paper, district heating or medicines – nearly every product we use in modern day-to-day life is manufactured using process heat. The heat in many cases is provided in the form of steam from boilers by Bosch[1] – Invented for life. High reliability and longevity of our boiler systems are the essential core of our production philosophy and are achieved due to our very high quality standards.

In times of global warming and increasing scarcity of resources, it is our demand to produce highly efficient process heat systems in collaboration with our valued partners – together with planners, plant engineers and installation firms. Together, using system components for heat recovery, automation and integration of renewable energy, we protect the environment and valuable resources. Due to the resulting energy savings, additional components pay for themselves within a very short time and the cost savings achieved from this point on motivates both operators and investors alike.

Planning and exact design of the more and more complex systems is challenging and must be perfectly tailored to the connected processes, load curves and steam consumers. This planning guide communicates the fundamentals of steam boiler system planning. But it also goes further by acting as an interactive planning tool that can facilitate planning and help avoid planning errors. The document also provides information for operators on how to ensure safe, efficient operation and a long service life.

Special thanks to Tobias Lüpfert and Sebastian Weeger for technical elaboration and to Lutz Ehemann and Kristin Heininger for implementation.

Dipl.-Ing. (FH) Daniel Gosse MBA
Head of Marketing and Academy

Bosch Thermotechnology
Commercial and Industrial Heat and Power

1 Formerly Loos International

Content

Introduction

Navigation

To make navigation through the main chapters and subchapters easier and faster at the click of a mouse, buttons are provided on every page. When the main chapter is clicked, the subchapters appear.

By referring to the clear table of contents at the start of the page, users of the print version can quickly look up the chapters which are preceded in each case by a detailed overview of the corresponding subchapters.

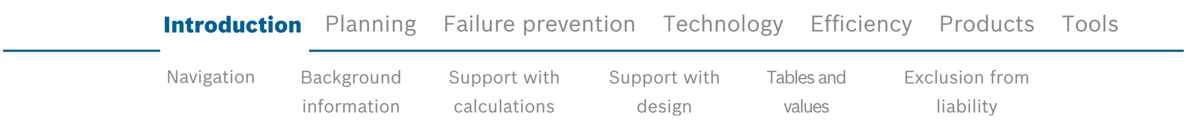


Fig. 1 *Main chapter and subchapter*

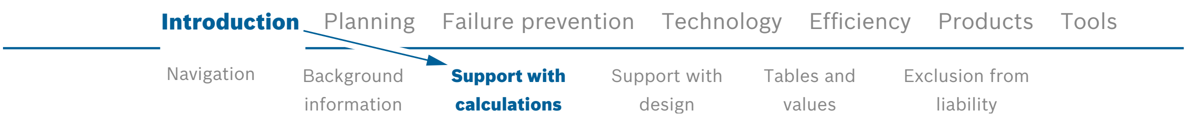
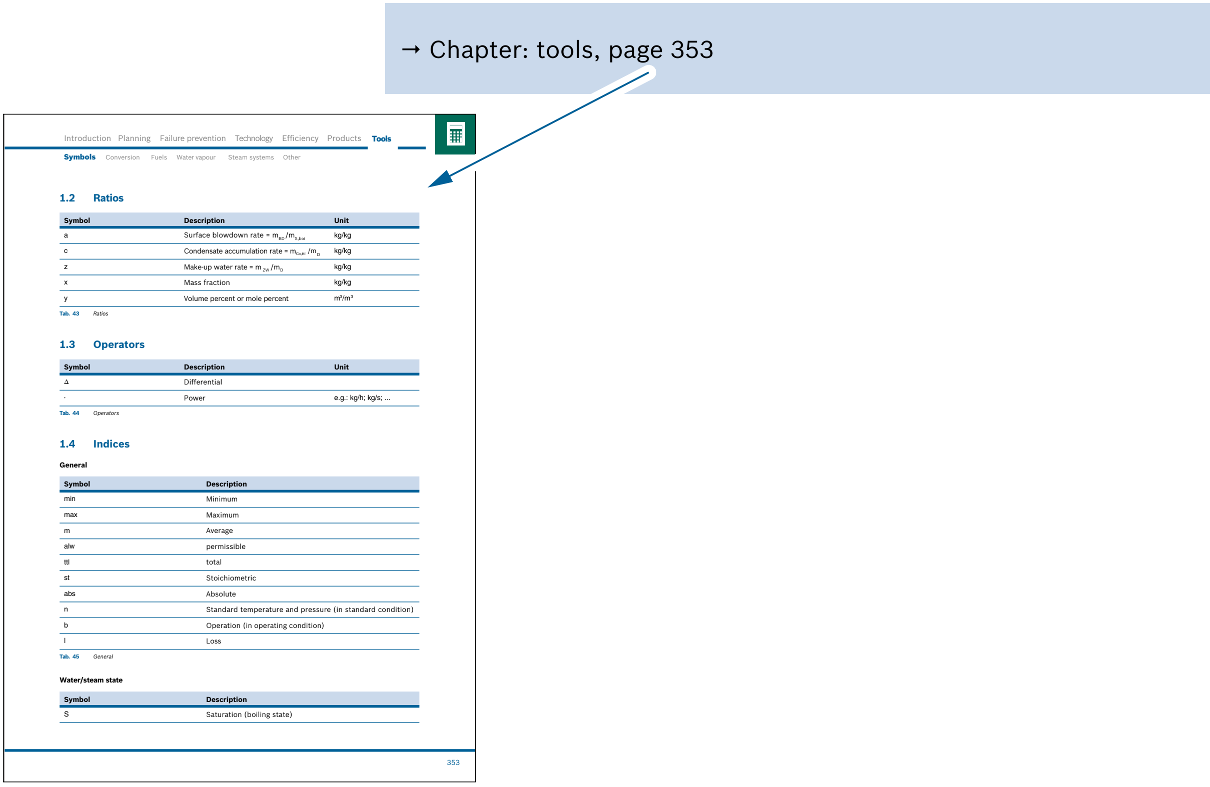


Fig. 2 *Main chapter and subchapter navigation*

Background information

References to further information or explanations of the terms used are provided in the side margin throughout the document. The information can be accessed in the digital version by clicking on it – users of the print version can find the page number in the reference.



Introduction Planning Failure prevention Technology Efficiency Products Tools

Symbols Conversion Fuels Water vapour Steam systems Other

1.2 Ratios

Symbol	Description	Unit
a	Surface blowdown rate = $m_{BD}/m_{S,boi}$	kg/kg
c	Condensate accumulation rate = $m_{Co,ttl}/m_D$	kg/kg
z	Make-up water rate = m_{ZW}/m_D	kg/kg
x	Mass fraction	kg/kg
y	Volume percent or mole percent	m^3/m^3

Tab. 43 *Ratios*

1.3 Operators

Symbol	Description	Unit
Δ	Differential	
·	Power	e.g.: kg/h; kg/s; ...

Tab. 44 *Operators*

1.4 Indices

General

Symbol	Description
min	Minimum
max	Maximum
m	Average
alw	permissible
ttl	total
st	Stoichiometric
abs	Absolute
n	Standard temperature and pressure (in standard condition)
b	Operation (in operating condition)
l	Loss

Tab. 45 *General*

Water/steam state

Symbol	Description
S	Saturation (boiling state)

353

Fig. 3 *Reference box*

References to technical reports are provided at several points – you can find these online at:

www.bosch-industrial.com/technicalreports

You can find the relevant technical information online at:

www.bosch-industrial.com/technicalguides

Support with calculations

The required formulas for the design in the digital version are interactive. When the values of your system are entered, the result is calculated and displayed immediately. This means you do not have to write them down; a time-consuming process which is also prone to errors.

$$p_m = 9.0 + 1.2 + 1.5 \text{ [bar]} \cdot \frac{83\,\%}{(75\,\%)} = 12.95 \text{ [bar]} \quad 13 \text{ [bar]}$$

Fig. 4 *Interactive formula*

Support with design by Bosch experts

Forms are provided at the start of the chapter Planning – one for fast enquiries using basic data and one for advanced expert enquiries, where detailed technical and cost information can be readily provided. By clicking on the relevant button, you can send the forms by e-mail, print them or save them as a PDF file. Once we have received the form, you will promptly receive a binding offer or the required technical information from our boiler experts.

→ Planning – Chapter 1: Basic data planning and questions planning process, page 17

Tables and values

The chapter Tools of the planning guide contains many useful tables and diagrams comprising values that are frequently required during planning. For convenience, they are interlinked in the relevant chapter or formula.

→ Tools, page 377

Exemption from liability

A great deal of care has been taken to ensure the technical information provided in this document is accurate. However, if you notice an error or have any comments on the contents, we would welcome your feedback. Bosch cannot assume liability for the accuracy of the contents in the document and for damage arising from their use. In case of doubt, always refer to the operating instructions of the boiler manufacturer as these are definitive. If you no longer have the operating instructions for your Bosch/Loos boiler system, we can provide you with a replacement from our archive:

info@bosch-industrial.com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Planning

Planning

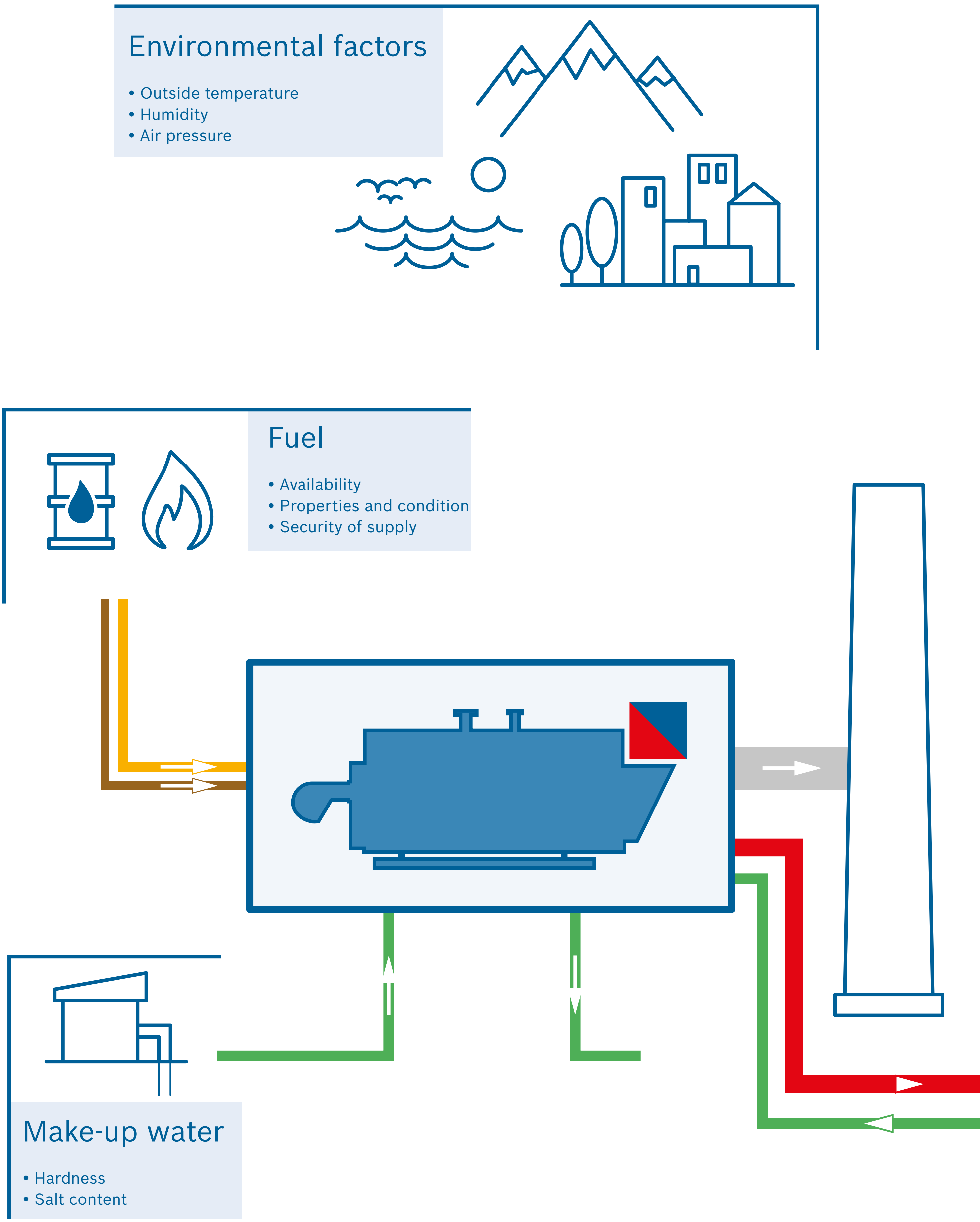
The most important prerequisite for design and sizing of a steam boiler system is that the maximum and minimum values of all relevant parameters have been recorded, documented and evaluated. In addition to the logging and evaluation of existing system data, forecast planning is equally important. This future-oriented task which should be performed jointly with the operator of the system, the planner, the plant engineer and boiler manufacturer is the foundation for long-term, successful operation of steam boiler systems. The individual boiler house components chosen at this stage should reflect an appropriate balance between the investment costs and subsequent operating costs of a steam boiler system.
In this case, it is particularly important to ensure that operational changes in the future can also be covered by the system components of a boiler house available at the time and that new components can be integrated as easily as possible into the existing parts of the system.

This chapter explains the most important general parameters for a steam boiler system in relation to steam pressure, steam output, fuel and legal framework conditions.

In addition to these technical framework conditions, economic and environmentally compatible operation of the boiler system is of course the decisive criterion for selection and installation. The available boiler and system components for improving efficiency are dealt with in the chapter Efficiency.

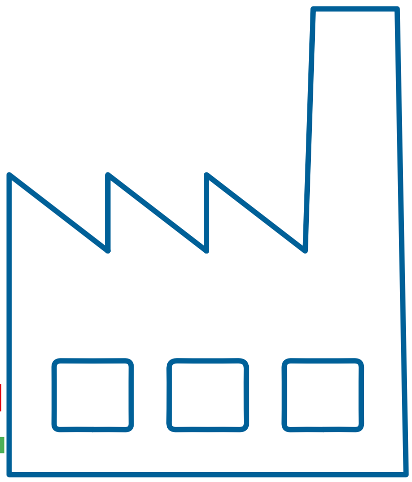
Factors influencing the planning

- Water
- Condensate
- Fuel
- Consumers
- Operator
- Environment
- Installation
- Legal regulations


Environmental factors
• Outside temperature
• Humidity
• Air pressure
Fuel
• Availability
• Properties and condition
• Security of supply
Make-up water
• Hardness
• Salt content

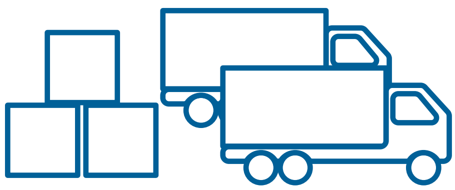
Legal regulations

- Country of installation
- Approval
- Operation
- Emissions
  - Nitrogen oxide
  - Sound



Consumer

- Operating pressure
- Steam output
  - Minimum load
  - Normal load
  - Peak load
  - Load change
- Steam quality
  - Residual moisture
  - Superheat



Condensate

- Quantity
- Temperature
- Pressure
- pH value
- Contamination

Customer/Operator

- Security of supply
- Extendibility
- Energy efficiency
- Emissions requirement
- Ease of maintenance
- Process control
  - Interfacing with automation system
  - Remote monitoring
  - Measured-value acquisition
  - System check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1 Basic data planning and questions planning process

1.1 Questions during planning

The overview of questions below is designed to assist with the planning and design of the steam supply. It serves as orientation at the start of the planning process and as a basis for reflection prior to the conclusion of planning. Although the list is by no means exhaustive, frequently recurring faults can be avoided by answering the questions consistently and systematically.

If one or more of the questions on inter-related themes have not been clarified at the end of planning, references to chapters containing relevant information are inserted after the questions for assistance.

1.1.1 Steam pressure

- Have unnecessarily high safety margins been used when defining the average operating pressure? Larger pressure safety margins should only be used when defining the maximum permissible operating pressure.

→ Planning – Chapter 2: Pressure, page 27

1.1.2 Steam demand

- Have all consumers (existing consumers and consumers planned in the medium term, internal consumption of boiler system) been taken into consideration and the heat losses (pipework, valves, containers) estimated or calculated?
- Are the planned safety margins for the steam output transparent? Multiplications of safety margins at different points must be avoided!
- Has a consumption analysis been carried out? Is the simultaneity of the steam consumption known? What is the actual maximum steam output simultaneously required by the consumers?
- Is it evident from the consumption analysis how and why the distribution among the generator units takes place?
- Does the configured boiler system have a sufficiently large control range to serve all frequently occurring loading conditions, without cycling the combustion system?
- What is the load profile or annual steam consumption (in order to precisely calculate the amortisation of additional heat recovery measures)?

→ Planning – Chapter 3: Steam output, page 35

1.1.3 Steam quality

- Does the steam have to meet specific requirements (e.g. residual moisture content, contact with food, superheated steam)?

→ Technology – Chapter 1: Steam, page 103

1.1.4 Water and condensate

- Is a water analysis available? Do seasonal fluctuations in the water quality have to be taken into account, for example?
- Has an analysis been carried out to determine which water treatment is the most sensible? In terms of cost-effectiveness, has a water softener unit been compared with osmosis water treatment? Does it make sense to use an automatic water analyser?
- Is a partial or full deaeration system more suitable?
- How much condensate can be returned, and under what conditions in relation to pressure/ temperature?
- Is there a risk of the condensate becoming contaminated with grease/oil or other media which is harmful to the boiler system (e.g. due to leaking heat exchanger)? If the answer is yes, a condensate monitoring system is required.

→ Technology – Chapter 4: Boiler house, page 175

1.1.5 Fuel

- Which fuels can be used at the location?
- Is the fuel quality and its fluctuation range known?
- Has the gas flow pressure been ensured? If the gas flow pressure drops when the gas consumption is high, this can cause problems. Deviations from the design value and actual gas flow pressure could lead to consequential costs.
- Should heavy fuel oil, other highly viscous or sulphurous fuels be used? Special equipment may be required for this (e.g. oil preheating or economiser supplied as stand-alone version with exhaust gas bypass).

→ Planning – Chapter 4: Fuel, page 53

1.1.6 Efficiency

- How important is energy efficiency and what is the maximum length of amortisation time for which energy saving measures are feasible?
- Are efficiency measures planned and has waste heat recovery been integrated in a sensible manner? Has their efficiency and savings of resources been verified?

→ Efficiency – Chapter 1: Basics, page 243

1.1.7 Operator

- How rigorous are the requirements for security of supply? Is either a partially or fully redundant boiler configuration required? Should it be possible to burn a substitute fuel via a multi-fuel combustion system?
- Is it likely that the steam supply will be extended in the coming years? If the answer is yes, the capacity of the feed water supply should, for example, be designed with future requirements in mind and sufficient space provided in the boiler house.
- What is the degree of availability and level of qualifications of the operating personnel? Which automation applications would make sense?
- Should there be a connection to a centralised automation system?

→ Planning – Chapter 3: Steam output, page 35

1.1.8 Installation location

- Is the installation location in a coastal region?
- Is the boiler installed in a seismological zone and does it have to be specially anchored/secured?
- Do special requirements exist regarding sound or pollutant emissions (e.g. due to proximity to a residential area or siting in an air or water protection area)?

→ Planning – Chapter 5: Installation, page 59

1.1.9 Boiler house

- Are the available openings sufficiently large for inward transportation?
- Is the load-bearing capacity of the foundation sufficient for the water-filled system?
- Have a suitable number of supply and extract air apertures been provided at suitable locations?
- Have the required emergency stop buttons been provided inside and outside the boiler house?
- Has sufficient space been provided? For access to inspection apertures (on the water and flue gas side), access to boiler, removal of components (burner), for example?

→ Planning – Chapter 5: Installation, page 59

1.1.10 Pipework

- Is the load-bearing capacity of walls and ceilings sufficient to absorb the pressure of the pipe?
- Has all pipework been planned with sufficient sizes? This particularly applies for safety valve blow-off pipes, air vent lines, exhaust vapour lines and condensate pipes.
- Are prohibited combinations being avoided?
- Are the steam pipes laid with a slope and drained correctly?
- Is the use of acoustic isolation elements feasible?

→ Technology – Chapter 5: Peripherals, page 211

1.1.11 Legislation

- Have the relevant rules and regulations been fully taken into account during planning?
  - In relation to emissions and environmental protection laws, especially flue gas and water.
  - In relation to approval regulations or the operating permit. Is the approval authority being consulted at an early stage and the application for approval submitted on time? Are the relvant authorities being informed?
  - In relation to the obligations of operators, especially occupational health and safety and operational safety. Has a risk assessment for the boiler system been performed?
  - In relation to timely involvement of approved notified bodies.

→ Planning – Chapter 6: Legislation, page 63

1.2 Recording of basic data for steam boiler system

During practical system planning, a rough cost indication or 3D models are frequently required quickly before working out a detailed solution. We provide you with a form for this which you can use to submit a request to our sales engineers in a fast and uncomplicated process.

Simply complete the form and send it to us:

- by e-mail to **sales@bosch-industrial.com** or
- by fax to **+49 9831 56 929 57**.

Boiler system planning – Basic

The most important parameters at a glance

Steam output: indicates how many kilograms or tons of steam are required per hour. Attention: When calculating the steam required, the internal steam consumption should be considered.

System output = boiler output – own use

Required system output: ______ kg/hour

The own use by the feed water treatment is usually between 5 and 20%. It can be greatly reduced by waste heat recovery.

Do peak loads occur only occasionally or is the system operated with full loads over long periods of time?
If necessary, the boiler size can be reduced by a steam accumulator (cost saving).

- ☐ Rarely peak load
- ☐ Longer full load times

Pressure: the most important criterion is the average operating pressure. The safety pressure of the boiler is always higher than the operating pressure.

Average operating pressure: ______ bar

Fuel: Depending on the fuel and boundary conditions, different burner/combustion chamber combinations are suitable. Multi-fuel burners are an advantage when high demands are placed on plant availability or when, for example, biogas is available.

Main fuel:

- ☐ Natural gas (☐ H ☐ L)
- ☐ Light oil
- ☐ Ethanol
- ☐ Heavy oil
- ☐ Animal fats
- ☐ Biogas
- ☐ Diesel

External waste heat sources

- ☐ yes
- ☐ no

Send enquiry

Print

1.3 Recording of additional data for steam boiler system

With a more detailed description of the required system, accurate pricing and technical scope can be determined. We have therefore provided a more comprehensive version of the form for experts, in addition to the simplified version. Using the information provided in this form, we can provide extended documentation and 3D data directly with the offer.

Simply complete the form and send it to us:

- by e-mail to **sales@bosch-industrial.com** or
- by fax to **+49 9831 56 929 57**.

Extended boiler system planning I

The periphery of the steam generator has a decisive influence on the energy, freshwater, system, chemical and maintenance costs.

Steam quantity: the quantity of steam required by the boiler for feed water heating and deaeration must be taken into consideration when sizing the steam boiler, in order to deliver sufficient steam to the system(s). However, in most cases the boilers are oversized – this results in unnecessary costs. In some cases, a significantly smaller boiler (one which is more favourably priced) will suffice when using steam accumulators.

Maximum steam quantity required: ______ kg/hour

alternative: ______ BTU

Optional: steam quantity incl. own use: ______ kg/hour

Short-term peak loads that a steam accumulator can compensate for? ☐ Yes, Details: ______ ☐ No

Steam: there are many different types of steam. Depending on the application, the steam must comply with certain chemical requirements or have a defined residual moisture content.

Characteristics of steam:

☐ Saturated steam
☐ Demister required (from residual moisture content < 3%)
☐ Superheated steam

Average operating pressure: ______ bar

Residual moisture content: ______ %

Temperature: ______ °C

Steam comes into contact with e.g. food? ☐ Yes, Details: ______ ☐ No

Installation and operating conditions: local regulations in the country of installation and the ambient conditions when the boiler is in operation influence the design of the boiler and combustion system.
Do you know the details?

Country of installation: ______ Height above sea level: ______ m

Temperature min. (winter): ______ °C max. (summer): ______ °C

Outdoor installation? ☐ Yes ☐ No ☐ Installation in container
(water and weatherproof insulation required)

Voltage ☐ Phases ☐ Frequency ☐ Hz

Extended boiler system planning II

Lower procurement costs, higher efficiency and higher reliability are only a few of the benefits of a detailed design.

Flue gas: Permissible NO_x value: ____ mg/mn³ ☐ Value not known

Fuel:

Natural gas

☐ Natural gas H ☐ Natural gas L

☐ LPG, Gas number: ____

☐ Propane ☐ Butane

☐ Propane-Butane

Gas flow pressure ____ mbar

Net calorific value: ____ kWh/mn³

Gas price: ____ €/m³

Oil

☐ Fuel oil, extra light (EL)

☐ Fuel oil, low-sulphur (SA)

☐ Medium/heavy fuel oil

Sulphur ____ %

Net calorific value: ____ kWh/kg

☐ Oil preheating available

Viscosity of oil: ____ mm²/s

At temperature: ____ °C

Oil price: ____ €/kg

Others

☐ Animal fat

☐ Fish oil

☐ Ethanol

☐ Biogas

☐ Sewage gas

☐ Other

Multifuel combustion systems: additional fuel as admixture

☐ Biogas Hydrogen sulphide: ____ mg/mn³ Methane: ____ %

☐ Sewage gas

☐ Other combustion gases Properties: ____

☐ Other oils/greases/... Description: ____

☐ Continuously available Quantity: ____ ☐ Available all year round

Waste heat utilisation: from CHP module flue gases, gas turbines, waste heat from external sources, e.g. industrial processes, etc.

☐ CHP module flue gases ☐ Gas turbine flue gases ☐ Other flue gases

Mass flow rate: ____ Kg/h Temperature: ____ °C

Permissible pressure loss: ____ mbar

Condensate utilisation at full load (rated output)

☐ Oxygen-free			☐ Oxygenic			☐ High-pressure condensate		
Quantity:		Kg/h	Quantity:		Kg/h	Quantity:		Kg/h
Pressure:		bar	Pressure:		bar	Pressure:		bar
Temperature:		°C	Temperature:		°C	Temperature:		°C

Extended boiler system planning III

Reduction of internal consumption by recovering waste heat.

Waste heat recovery: large quantities of heat can be recovered. The mass flows that give off heat are normally flue gas, hot waste water and exhaust vapour. The heat is absorbed by the feed water, make-up water, process water or combustion air.
The following measures are available for this:

- ☐ Economiser (flue gas heat exchanger)
- ☐ Condensing heat exchanger
- ☐ Feed water cooler (increases the efficiency of the economiser)
- ☐ Air preheater system (preheats combustion air)
- ☐ Surface blowdown water heat exchanger
- ☐ Exhaust vapour cooler
- ☐ Combustion control O_2/CO (reduces flue gas losses)

Reduce power costs: in older systems, the burner fan and pumps are often operated continuously at both partial and full load.
Up to 75% of the power consumption can be avoided using speed controls.

Speed-controlled combustion air fan: ☐ Yes ☐ No

Speed-controlled pumps: ☐ Yes ☐ No

Property and condition of fresh water: the property and condition of the freshwater decides the surface blowdown rate of a steam boiler. Reducing the surface blowdown rate to the required technical minimum can make a significant contribution to lower energy costs.

Silicic acid:		mg/l
Conductivity:		µS/cm
Carbonate hardness:		°dH

Send enquiry

Print

0
5
10
15
20
25
EN 837-1
bar

2 Pressure

Excess pressure and absolute pressure

In steam boiler technology, it is routine for all pressures to be stated as excess pressure relative to an atmospheric pressure of 1 bar.

The unit [bar] or [barg] is used at these points.

The excess pressure is therefore converted to absolute pressure as follows:

$$p_{absolute} = p + 1.01325 \text{ bar}$$

F1. *Conversion from excess pressure to absolute pressure*

Normal temperature and pressure and standard temperature and pressure

Normal temperature and pressure (according to DIN 1343):
p_n = 101,325 Pa = 1.01325 bar = 1 atm
T_n = 273.15K = 0°C

Standard temperature and pressure (STP, IUPAC):
p° = 100,000 Pa = 1.0 bar
T° = 273.15K = 0°C

Standard ambient temperature and pressure (SATP, IUPAC):
p° = 100,000 Pa = 1.0 bar
T° = 298.15K = 25°C

F2. *Normal temperature and pressure and standard temperature and pressure*

2.1 Average operating pressure

The operating pressure of a boiler system is not a constant value, but instead fluctuates around the average operating pressure p_{avg}. The reason for this is that the operating pressure in the steam boiler is used as the input variable for the output regulation of the steam boiler system and therefore fluctuates in a range of roughly ±10% of the average operating pressure used as the set value.

Fig. 5 *Illustration of pressure curve over time (boiler control BCO)*

Prerequisites for determining the average operating pressure

To determine the necessary average operating pressure p_{avg} the following aspects must be taken into account:

- **Required pressure/temperature level at the steam consumers**

  To define the average operating pressure p_{avg}, the required pressure or temperature level of the steam consumers must be determined. The maximum pressure level $p_{max,C}$ of the consumers must be used to design the average operating pressure of the steam boiler system.

  The required pressure level of the consumers at a known heating temperature can be determined from the steam table by linking the boiling pressure to the temperature.

→ Fig. 37, page 109

$$p_{max,C} = p_s\,(T_{max,C})$$

F3. *Maximum pressure and temperature required at the consumer*

$p_{max,C}$	Maximum pressure required at the consumer
$p_s(T_{max,C})$	Boiling pressure at the maximum temperature required
$T_{max,C}$	Maximum temperature required at the consumer

- **Pressure losses**
  In addition, the pressure losses in the steam pipe between the steam boiler and consumer, the pressure losses of valves in the steam pipe and the pressure losses of any existing pressure reducing stations must be taken into consideration.

→ Tools – Chapter 5.4.4: Pressure loss – guide values for the pressure loss coefficient ζ, page 411

If the pressure levels of the consumers are far apart (> 3 bar) or if a constant steam pressure is required with smaller fluctuation range than can be performed by the output control of the steam boiler, the steam pressure at the consumers should be set via pressure reducing stations between the steam boilers and consumers. The control circuits for the load control at the steam boiler and pressure regulation at the consumer are separated by installing pressure reducing stations.

Determining the average operating pressure

The average operating pressure p_{avg} of the steam boiler is determined taking the maximum control deviation into account as follows:

$$p_{avg} = (p_{max,C} + \Delta_{p_P} + \Delta_{p_{valves}}) \cdot \frac{83\%}{(75\%)}$$

F4. *Formula for determining the average operating pressure*

p_{avg}	Average operating pressure [bar]
$p_{max, C}$	Maximum pressure required at the consumer [bar]
Δp_P	Pressure losses in the pipework [bar]
Δp_{valves}	Pressure losses of valves and reducing stations [bar]
75% points	Lower control level for the output regulation based on the maximum permissible pressure of the boiler
83% points	Average control level for the output regulation based on the maximum permissible pressure of the boiler

$$p_{avg} = (9.0 + 1.2 + 1.5)\ [bar] \cdot \frac{83\%}{(75\%)} = 12.95\ [bar] \approx 13\ [bar]$$

B1. *Example calculation for determining the average operating pressure*

Setting and modifying the average operating pressure

The average operating pressure p_{avg} of the steam boiler system can be set at the control unit of the boiler control cabinet during commissioning and operation of the system or specified by the automation system.

Safety margins during design

At this point in the design process, it is advised to work without safety margins in order to reflect the actual operating conditions.

If the average operating pressures specified are too high, this may lead, among other things, to the steam valves and steam pipes being sized too small due to the higher density of the saturated steam.

If safety margins are to be taken into account for pressure in the design, this can be done when defining the maximum permissible operating pressure.

Reduced operating pressure

For energy efficiency reasons, the operating pressure should not be set any higher than what is necessary. A typical application for reduced operating pressure can be carried out during the weekend, this enables reduction in radiation losses of the boiler.

However, the operating pressure must not be reduced. If the operating pressure is reduced too much, it can have the following negative effects:

- Cavitation can occur in the pumps if throttling is insufficient.
- The pumps can run in an unstable range of the characteristic map.
- The pumps can run with a lower pump efficiency.

High steam velocities arising from reduced density can also lead to negative effects:

- Erosion at valves and elbows
- Loud flow noises
- Increased rate of droplet entrainment from the steam boiler

The minimum permissible operating pressure is therefore limited to half of the configured operating pressure as the default setting.

The minimum average operating pressure of a high-pressure steam boiler system should not fall below 5 bar as the steam feed valves and steam pipes must be sized very large due to the larger specific volume of the steam at a lower pressure.

2.2 Maximum permissible operating pressure

The maximum permissible operating pressure of a boiler is the excess pressure arising as a result of the construction and strength of the materials used.

This information is provided on the boiler manufacturer's data plate, in the documentation provided and in the acceptance documents. The excess pressure must be limited by a safety valve on the steam boiler. The safety valve opens when the maximum permissible pressure is reached to prevent the pressure in the boiler shell from rising any further. Once the safety valve has responded, it closes again when the pressure in the boiler has reduced.

For the safety valve to function reliably, the valve does not respond or start leaking during operation, the pressures in the steam boiler are graded as follows.

Type of pressure	Formula	Value	Unit
Maximum permissible operating pressure (safety pressure/safety valve triggering pressure)	$p_{max,perm} = p_{SV} \triangleq 100\%$	≥ 16.0	[bar]
Pressure limiter	$p_{PL} \triangleq p_{max,perm} \cdot 95\%$	= 15.2	[bar]
Combustion system switch-off point	$p_{bu,off} \triangleq p_{max,perm} \cdot 91\%$	= 14.6	[bar]
Average operating pressure	$p_{avg} \triangleq p_{max,perm} \cdot 86\%$	= 13.8	[bar]
Combustion system switch-on point	$p_{bu,on} \triangleq p_{max,perm} \cdot 75\%$	= 12.0	[bar]
Standard value for heat maintenance via heating coil = average operating pressure / 2	$p_{HMS} \triangleq p_{avg} \cdot \sim 50\% \cong 42\%$	= 6.7	[bar]

Tab. 1 *Grading of operating pressures (as a percentage of maximum permissible operating pressure)*

This results in:

- The lowest maximum permissible operating pressure $p_{max,perm}$ of the boiler required based on the average operating pressure p_{avg} which has been derived from the operational requirements.

$$p_{max,perm} = p_{SV} \geq \frac{p_{avg}}{86\%}$$

F5. *Formula for determining the smallest maximum permissible operating pressure required*

$$p_{max,perm} = p_{SV} \geq \frac{13.8\ [bar]}{86\%} = 16.0\ [bar]$$

B2. *Example calculation for determining the smallest maximum permissible operating pressure required*

- The highest average operating pressure $p_{avg,max}$ of the boiler based on the maximum permissible operating pressure $p_{max,perm}$ of the boiler:

$$p_{avg,max} \leq p_{max,perm} \cdot 86\% = p_{SV} \cdot 86\%$$

F6. *Formula for determining the highest average operating pressure*

$$p_{avg,max} \leq 16.0 \text{ [bar]} \cdot 86\% = 13.8 \text{ [bar]}$$

B3. *Example calculation for determining the highest average operating pressure*

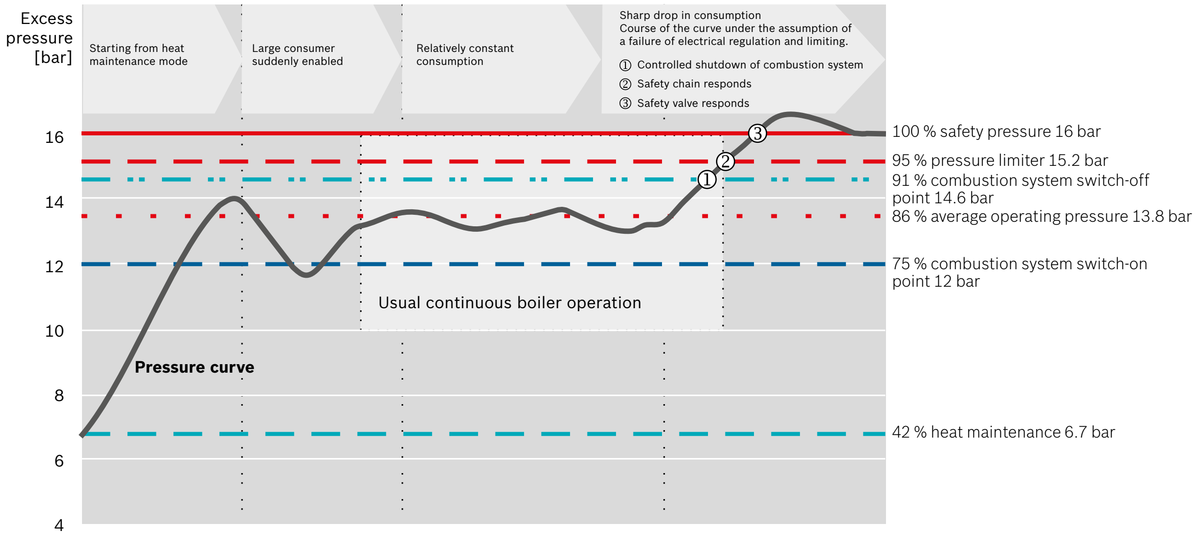

Fig. 6 *Diagram of pressure curve with switching points when using steam boilers with an average operating pressure of 13.3 bar*

Other gradings for the average operating pressure can also be selected in the boiler control, subject to certain limits.

Other system components

In addition to the boiler shell itself, the maximum permissible operating pressure and maximum permissible temperature of all components and assemblies directly connected to the boiler (e.g. valves, sensors, pipework, gaskets, apparatuses) must be taken into account.

→ Pressure/temperature curve for flange according to EN 1092-1

Safety margins during design

In reference, to the difference between the excess pressure determined $p_{max,perm}$ and the maximum permissible excess pressure of the next higher boiler pressure stage, a design safety margin may effectively already exist. If an additional design safety margin is required for the pressure range, an appropriate higher boiler pressure stage can be selected.

If consumers with a lower permissible operating pressure than the steam boiler are connected in the steam system, they must be equipped with their own safety valves or pressure reducing stations with safety valves connected in-between them.


Gas
Dampf

3 Steam output

The most important data is obtained from the performance of the individual steam consumers. However, the internal consumption of the steam boiler system must also be taken into consideration, especially for heating up and deaerating the make-up water and condensate, surface blowdown and heat losses in the pipework.

When determining the necessary steam output of the boiler system, additional factors such as the simultaneity of the maximum outputs of individual consumers, the maximum loading rate and purely technical aspects that can often only be measured with difficulty (for example, security of supply or possible extensions) must also be considered.

The typical steam output distribution is shown below. The calculation of the precise project-specific consumption is described in the following chapter.

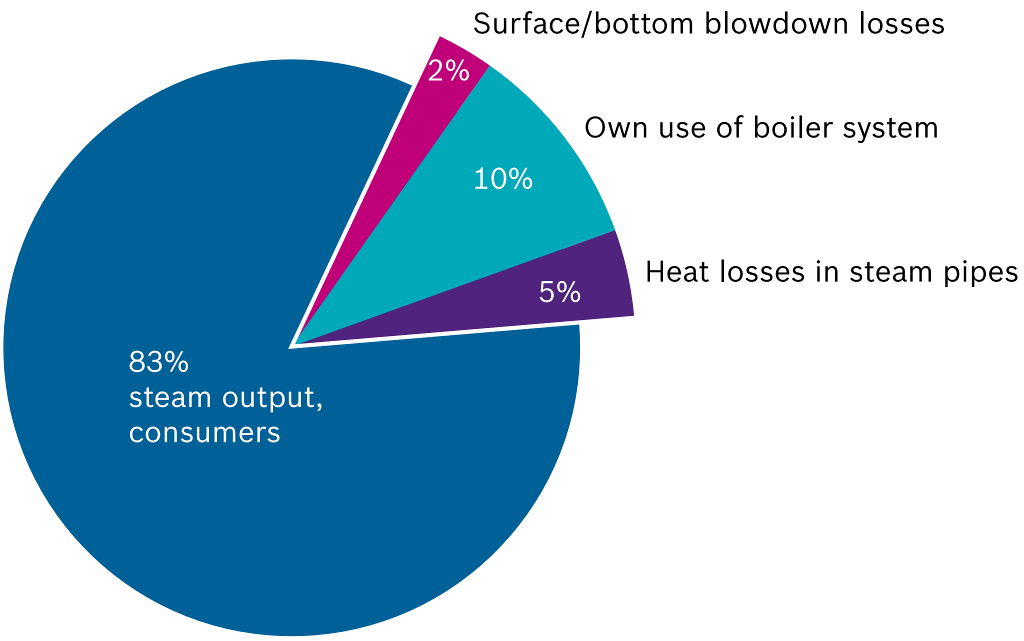

Fig. 7 *Illustration of the correlation between the nominal steam output of the boiler and the steam output at the consumers (values shown are examples)*

List of symbols

Symbol	Unit	Meaning
$\dot{m}_S$	[kg/h]	Steam output; quantity of steam
$\dot{m}_{S,dC}$	[kg/h]	Quantity of steam for direct consumers
$\dot{m}_{S,iC}$	[kg/h]	Quantity of steam for indirect consumers
$\dot{m}_{S,IP}$	[kg/h]	Quantity of steam due to expansion steam
$\dot{m}_{S,OU}$	[kg/h]	Own use of boiler system
$\dot{m}_{S,boi}$	[kg/h]	Steam output of boiler
$\dot{Q}$	[kW]; [MW]	Heating output
$\dot{Q}_{HX}$	[kW]; [MW]	Thermal output of heat exchanger
r	[kJ/kg]	Evaporator enthalpy at corresponding pressure
c_p	[kJ/kgK]	Specific thermal capacity of water (up to 250°C can be calculated with minimum error with constant c_p = 4.19kJ/kgK)
ΔT	[K]	Temperature difference

Tab. 2 *List of symbols*

3.1 Calculation of consumption

When determining the necessary steam output of a steam boiler system, all steam consumers in the steam network must ideally be recorded in a table with their minimum and maximum output and then the output of all consumers must be added up.

In doing so, a distinction should be made between the following consumers:

- Direct consumer (e.g. autoclave)
- Indirect consumer (e.g. heat exchanger)
- Expansion steam losses (e.g. at unpressurised condensate tank)
- Heat losses in the steam pipes
- Own use of boiler system (e.g. heat-up steam for feed water vessel)

Direct consumer

$\dot{m}_{S,dC}$ [kg/h] = quantity of steam for direct consumer

With direct steam consumers, the steam comes into direct contact with the medium (not via a heat exchanger), where it leaves the system as condensate.. The condensate produced is removed with the product (or remains in the product) and is no longer available to the steam circuit. This water consumed must be replaced once again as make-up water by the water treatment system in the steam circuit.

→ Technology – Chapter 4.1: Water treatment, page 177

The make-up water must be deaerated by heating it in the feed water vessel. This increases own use required by the steam boiler system.

Direct consumers can, for example, be found in drying processes during humidification, when heating up boiling baths or during sterilisation.

The steam output required at direct steam consumers is stated in the necessary form as mass flow rate $\dot{m}_{S,dC}$ (quantity of steam for direct consumers) in [kg/h]. If a heat output is specified for these steam consumers, the same formulas used with indirect consumers for conversion of thermal output to steam output also apply here.

Indirect consumer

Indirect steam consumers are all types of heat exchanger, in which steam condenses while releasing thermal energy (which heats a medium, e.g. water). The boiling point of the condensate produced during this process initially corresponds to the steam pressure at the inlet to the heat exchanger, but can also be cooled further to below the boiling point, depending on the temperature level of the medium being heated. This is then referred to as supercooled condensate. The condensate is transported via the deaerator back to the feed water vessel.

The thermal output of a heat exchanger is normally specified in [kW] or [MW]. To determine the required steam output in [kg/h] of saturated steam, the thermal output of the heat exchanger must be converted to a saturated steam output.

The saturated steam requirement at a heat exchanger can initially be calculated using the following simple formula:

$$\dot{m}_{S,iC} = \dot{Q}_{HX} \cdot 1.8$$

F7. *Formula for rough calculation of the saturated steam requirement of indirect consumers*

$\dot{m}_{S,iC}$	Quantity of steam for indirect consumers [kg/h]
$\dot{Q}_{HX}$	Thermal output of heat exchanger [kW]
1.8	Estimation factor for the conversion

$$\dot{m}_{S,iC} = 1{,}000\ [kW] \cdot 1.8 = 1{,}800\ [kg/h]$$

B4. *Example calculation for rough calculation of the saturated steam requirement of indirect consumers*

For a steam pressure of 5 – 18 bar, the difference compared to the actual steam output is <5%. Possible supercooling of the condensate is not taken into account in this case.

To precisely determine the steam output based on the thermal output of a heat exchanger, the evaporation enthalpy must be determined from the saturated steam table with the actual operating pressure of the heat exchanger.

→ Tools – Chapter 4.2: Water vapour table, page 398

The thermal output of the heat exchanger can be subsequently converted into a saturated steam output as follows:

$$\dot{m}_{S,iC} = \dot{Q}_{HX} \cdot \frac{3{,}600}{r}$$

F8. *Formula for conversion of thermal output to saturated steam output*

$\dot{m}_{S,iC}$	Quantity of steam for indirect consumers [kg/h]
$\dot{Q}_{HX}$	Thermal output of heat exchanger [kW]
r	Evaporation enthalpy with corresponding pressure [kJ/kg]

$$\dot{m}_{S,iC} = 1{,}000\ [kW] \cdot \frac{3{,}600\ [\frac{s}{h}]}{1{,}959\ [\frac{kJ}{kg}]} = 1{,}838\ [\frac{kg}{h}]$$

B5. *Example calculation for conversion of thermal output to saturated steam output*

If the condensate produced is supercooled, i.e. to below the boiling point, under all operating conditions the steam output can be calculated using the following formula, taking the thermal output for supercooling of the condensate into account:

$$\dot{m}_{S,iC} = \dot{Q}_{HX} \cdot \frac{3{,}600}{r + c_p \cdot \Delta T} = \dot{Q}_{HX} \cdot \frac{3{,}600}{h'' - h_{Co,outside}}$$

F9. *Formula for calculating the quantity of steam for indirect consumers incl. condensate supercooling*

$\dot{m}_{S,iC}$	Quantity of steam for indirect consumers [kg/h]
$\dot{Q}_{HX}$	Thermal output of heat exchanger [kW]
r	Evaporation enthalpy with corresponding pressure [kJ/kg]
c_p	Specific thermal capacity of water [kJ/kgK] (up to 250°C can be calculated with minimum error with a constant c_p = 4.19 [kJ/kgK])
ΔT	Supercooling of condensate, temperature difference $T_{S - TCo,outside}$ [K]
h"	Saturated steam enthalpy [kJ/kg]
$h_{Co,outside}$	Enthalpy of the condensate directly upstream of the outlet at the heat exchanger

Expansion steam losses

$\dot{m}_{S,ES}$ [kg/h] = quantity of expansion steam

Expansion steam occurs when hot pressurised condensate expands at the pressure below the boiling pressure. This happens, for example, when condensate flows through condensate drains or valves or when it flows into an open condensate tank at atmospheric pressure. The higher the temperature of the condensate, the more expansion steam is produced.

The quantity of the expansion steam produced can be read off from the diagram or calculated from the water vapour table.

→ Tools – Chapter 4.2: Water vapour table, page 398

It has to be considered in this case that the quantity of expansion steam may already be reduced due to supercooling of condensate. If the expansion steam is released into the surroundings, the steam lost from the boiler system must be reintroduced as make-up water, along the same lines as when water is lost from direct consumers.

The expansion steam can also be utilised through heat recovery measures and reintroduced directly into the water circuit.

→ Technology – Chapter 3.3: Economiser, page 148

Heat losses in steam pipes

$\dot{m}_{S,IP}$ [kg/h] = quantity of steam for equalisation of heat losses in the steam pipes

The heat loss in the pipework must also be taken into account in the steam output design. If the pipework is well insulated, a heat energy demand of roughly 10kg steam per hour and in each pipe ($10kg_S$ / (h · 100m)) can be assumed.

To calculate heat losses more accurately, a separate calculation must be carried out for every pipe run based on the nominal diameter, length of the pipe and insulation thickness.

The heat losses at valves, flange connections and containers must also be taken into account accordingly. Corresponding guide values can be found in the chapter Efficiency.

→ Efficiency – Chapter 4.1: Insulation, page 287

Unfortunately the heat loss via poorly or only partially insulated pipework, containers and valves is still underestimated. This is mainly the case because during the service life of the system, the insulation is removed for inspection or maintenance and not reinstalled afterwards. The insulation of pipework (both in the steam and also the condensate system) represents one of the most economical cost-saving measures in existing systems.

If the heat loss in the pipework is precisely calculated, the steam demand for these losses must be determined in the same manner as the heat demand for an indirect consumer.

$$\dot{m}_{S,IP} = \dot{Q}_{IP} \cdot 1.8 = \dot{Q}_{IP} \cdot \frac{3,600}{r}$$

F10. *Formula for calculating the quantity of steam for heat losses in pipework*

$\dot{m}_{S,IP}$	Quantity of steam for heat losses in pipework [kg/h]
$\dot{Q}_{IP}$	Thermal output of pipework losses [kW]
1.8	Estimation factor for conversion
r	Evaporation enthalpy with corresponding pressure [kJ/kg]

$$\dot{m}_{S,IP} = 20\ [kW] \cdot 1.8\ [\frac{kJ}{kg}] = 36\ [\frac{kg}{h}]$$

$$\dot{m}_{S,IP} = 20\ [kW] \cdot \frac{3,600\ [\frac{s}{h}]}{1,959\ [\frac{kJ}{kgK}]} = 36.8\ [\frac{kg}{h}]$$

B6. *Example for calculation of the quantity of steam for heat losses in pipework*

→ Tools – Chapter 4: Basic principles of water vapour, page 397

→ Tools – Chapter 4.2: Water vapour table, page 398

Own use of steam boiler system

In order to operate, the steam boiler system also requires some of the steam output for its own use. The actual steam output required for own use can only be determined based on in-depth knowledge of the mode of operation of the overall steam boiler system. The heat-up steam quantity for the feed water vessel is decisive for the internal steam consumption.

→ Technology – Chapter 4.1: Water treatment, page 177

The heat-up steam at the feed water vessel depends in turn on the condensate return flow from the steam consumers with the relevant condensate temperatures, make-up water demand and water losses from the boiler for surface blowdown and bottom blowdown.

The quantity of steam for own use is required to operate the following heat consumers. To obtain a rough guide value to initially design the necessary steam output, the steam demand for own use can be estimated as follows:

$\dot{m}_{OU}$ [kg/h] = own use of boiler system:

- Heating of make-up water (~5 – ~15% of system steam output)
- Heating of oxygenic condensate (~1 – ~3% of system steam output)
- Exhaust vapours during deaeration (~0.5% of the system steam output)

Roughly 6 .– 16% of the total steam output is therefore required by the boiler for own use.

To precisely calculate the steam required for own use, the precise data for the make-up water demand, type of water treatment and chemical mode of operation of the boiler, condensate return with condensate temperatures and, if necessary, the fuel preheating must be available.

The steam required for own use can however be significantly reduced by heat recovery measures such as exhaust vapour coolers, flash tanks, brine coolers and feed water coolers or condensation economisers and a salt-free mode of operation with osmosis water treatment.

→ Technology – Chapter 3.3: Economiser, page 148

To precisely calculate the quantity of steam required for own use, the following heat-up steam quantities must be calculated. Together they represent the heat-up steam quantity for the feed water vessel.

Heating up make-up water

In order to compensate for the steam losses in the steam circuit, e.g. due to the direct consumers, treated make-up water must be fed into it.

→ Technology – Chapter 4.1: Water treatment, page 177

During deaeration, the cold make-up water must be heated from roughly 10°C to 103°C. The required thermal output is obtained as internal steam consumption directly from the steam output of the boiler.

$$\dot{m}_{OU,MW} = \frac{\dot{m}_{MW} \cdot c_p \cdot \Delta T \cdot \frac{3{,}600\ s}{h}}{r}$$

F11. *Formula for calculation of steam required for own use to heat up make-up water*

$\dot{m}_{OU,MW}$ Steam required for own use to heat up make-up water [kg/h]

$\dot{m}_{MW}$ Make-up water demand for feed water treatment [kg/h]

r Evaporation enthalpy with corresponding pressure [kJ/kg]

c_p Specific thermal capacity of water [kJ/kgK] (up to 250°C can be calculated with minimum error with a constant c_p = 4.19 [kJ/kgK])

ΔT Temperature difference between feed water temperature and make-up water temperature $T_{dea} - T_{MW}$ [K]

The make-up water demand can therefore be calculated from the steam output, surface blowdown, exhaust vapours and the condensate return flow:

$$\dot{m}_{MW} = \dot{m}_{S,sys} + \dot{m}_{BD} + \dot{m}_{VS} - \dot{m}_{Co,ttl}$$

$$\dot{m}_{MW} = \dot{m}_{S,sys} \cdot z$$

$$\dot{m}_{MW} \approx \dot{m}_{S,sys} \cdot (1 + a + 0.5\% - c)$$

F12. *Formula for calculation of make-up water demand*

$\dot{m}_{MW}$	Make-up water demand [kg/h]
$\dot{m}_{S,sys}$	System steam output [kg/h]
$\dot{m}_{BD}$	Mass flow rate, surface blowdown [kg/h]
$\dot{m}_{VS}$	Mass flow rate, exhaust vapours [kg/h]
$\dot{m}_{Co,ttl}$	Mass flow rate, total condensate [kg/h]
a	Surface blowdown rate = $\dot{m}_{BD} / \dot{m}_{S,boi}$ [kg/kg]
c	Condensate accumulation rate = $\dot{m}_{Co,ttl} / \dot{m}_{S,sys}$ [kg/kg]
z	Make-up water rate = $\dot{m}_{MW} / \dot{m}_{S,sys}$ [kg/kg]

Heat-up of oxygenic condensate

In addition to heating up make-up water, the oxygenic condensate which is collected in open condensate tanks and is therefore colder than 103°C must also be heated back up to feed water temperature. The temperature of oxygenic condensate is frequently between 50 – 90°C.

The required thermal output is obtained as own steam consumption directly from the steam output of the boiler.

$$\dot{m}_{OU,hCo} = \frac{\dot{m}_{hCo} \cdot c_p \cdot \Delta T \cdot \frac{3{,}600\ s}{h}}{r}$$

F13. *Formula for calculation of the steam required for own use to heat up condensate*

$\dot{m}_{OU,hCo}$	Steam required for own use to heat up condensate [kg/h]
$\dot{m}_{hCo}$	Quantity of condensate, oxygenic [kg/h]
r	Evaporation enthalpy with corresponding pressure [kJ/kg]
c_p	Specific thermal capacity of water [kJ/kgK] (up to 250°C can be calculated with minimum error with a constant c_p = 4.19 [kJ/kgK])
ΔT	Temperature difference between feed water temperature and condensate temperature $T_{dea} - T_{hCo}$ [K]

Exhaust vapours during deaeration

So the gases such as oxygen and CO_2 dissolved in the make-up water and oxygenic condensate can also be removed from the deaerator, a proportion of roughly 0.5% of the mass flow rate consisting of make-up water and oxygenic condensate must be discharged as exhaust vapours to the atmosphere. During this process, the oxygen, nitrogen and expelled carbon dioxide are transported in the exhaust vapours out of the water into the atmosphere.

$$\dot{m}_{VS} \approx (\dot{m}_{hCo} + \dot{m}_{MW}) \cdot 0.5\%$$

$\dot{m}_{VS}$ Mass flow rate, exhaust vapours [kg/h]
$\dot{m}_{hCo}$ Quantity of condensate, oxygenic [kg/h]
$\dot{m}_{MW}$ Make-up water demand [kg/h]

As a heat recovery measure, the heat in the exhaust vapours can be condensed in an exhaust vapour cooler and accumulated thermal energy used to heat up the make-up water.

→ Efficiency – Chapter 3.2: Exhaust vapour, page 280

Heat-up steam quantity for feed water vessel

The steam required for own use to heat up the feed water vessel can be summarised by the following formula:

$$\dot{m}_{HS} = \dot{m}_{OU} = \dot{m}_{OU,MW} + \dot{m}_{hCo} + \dot{m}_{VS}$$

F14. *Formula for calculation of the steam required for own use to heat up the feed water vessel*

$\dot{m}_{HS}$ Heat-up steam quantity [kg/h]
$\dot{m}_{OU}$ Steam required for own use [kg/h]
$\dot{m}_{OU,MW}$ Steam required for own use to heat up make-up water [kg/h]
$\dot{m}_{hCo}$ Quantity of condensate, oxygenic [kg/h]
$\dot{m}_{VS}$ Mass flow rate, exhaust vapours [kg/h]

Nominal design steam demand of the boiler system

To determine the overall steam demand of the system, all steam consumers must be added up:

$$\dot{m}_{S,boi} = \dot{m}_{S,sys} + \dot{m}_{OU} = \dot{m}_{S,dC} + \dot{m}_{S,iC} + \dot{m}_{S,IP} + \dot{m}_{OU}$$

F15. *Formula for calculating the total steam demand of the system*

$\dot{m}_{S,boi}$ Boiler steam output [kg/h]

$\dot{m}_{S,sys}$ System steam output [kg/h]

$\dot{m}_{S,dC}$ Quantity of steam for direct consumers [kg/h]

$\dot{m}_{S,iC}$ Quantity of steam for indirect consumers [kg/h]

$\dot{m}_{S,IP}$ Quantity of steam required to compensate for heat losses in pipework [kg/h]

$\dot{m}_{OU}$ Own use of boiler system [kg/h]

Example calculations of mass and energy balances

The simple example below illustrates the mass and energy balances of a steam boiler system with a small number of components.

For the sake of clarity, the comparison is limited to the change in quantity of recirculated condensate and the type of water treatment. The thermal efficiency in all three cases is around 95%.

Example B1	Example B2	Example B3
Steam system consisting mainly of **indirect consumers** (c = 90%) and a small number of direct consumers (10%). The make-up water is replenished from an osmosis water treatment unit and the boiler has a low salt mode of operation.	Steam system consisting mainly of **direct consumers** (90%) and a small number of indirect consumers (c = 10%) so that hardly any oxygenic condensate returns. Just as in example 1, the make-up water is replenished from an osmosis water treatment unit and the boiler therefore has a low salt mode of operation.	Steam system with **direct** (60%) and **indirect** consumers (c = 40%). The make-up water is replenished from a water softener unit and the boiler has a saline mode of operation.
In systems, for example, where the steam is used in heat exchangers but only some of the condensate is returned (e.g. due to very long distances to the consumers).	In systems, for example, where the steam is only used for direct consumers, such as those used in the manufacturing of animal feed or in autoclaves. Condensate is only recirculated when using pipework drainage systems and a number of ancillary units.	In systems, for example, where only some of the condensate is or can be returned, such as those with direct consumers used in the beverage industry (bottle cleaning).
Summary		
Very little heat-up steam is required due to the high-quality water treatment and high condensate accumulation rate. This means that almost all of the steam produced by the boiler can be used in the consumers. The specific fuel demand is low.	Due to the high-quality water treatment, the surface blowdown rate remains very low despite the low quantity of condensate. However, as the quantity of make-up water that must be heated up is very large, the specific fuel demand is significantly higher.	The higher surface blowdown rate and high heat losses (without surface blowdown heat recovery) in addition to the significant quantity of make-up water also result in a higher specific fuel demand.
Required fuel energy per kg of steam to the consumer:		
0.724 [kWh/kg]	**0.793 [kWh/kg] (+ 9.5%)**	**0.755 [kWh/kg] (+ 4.3%)**

Tab. 3 *Example calculations of mass and energy balances for various steam systems*

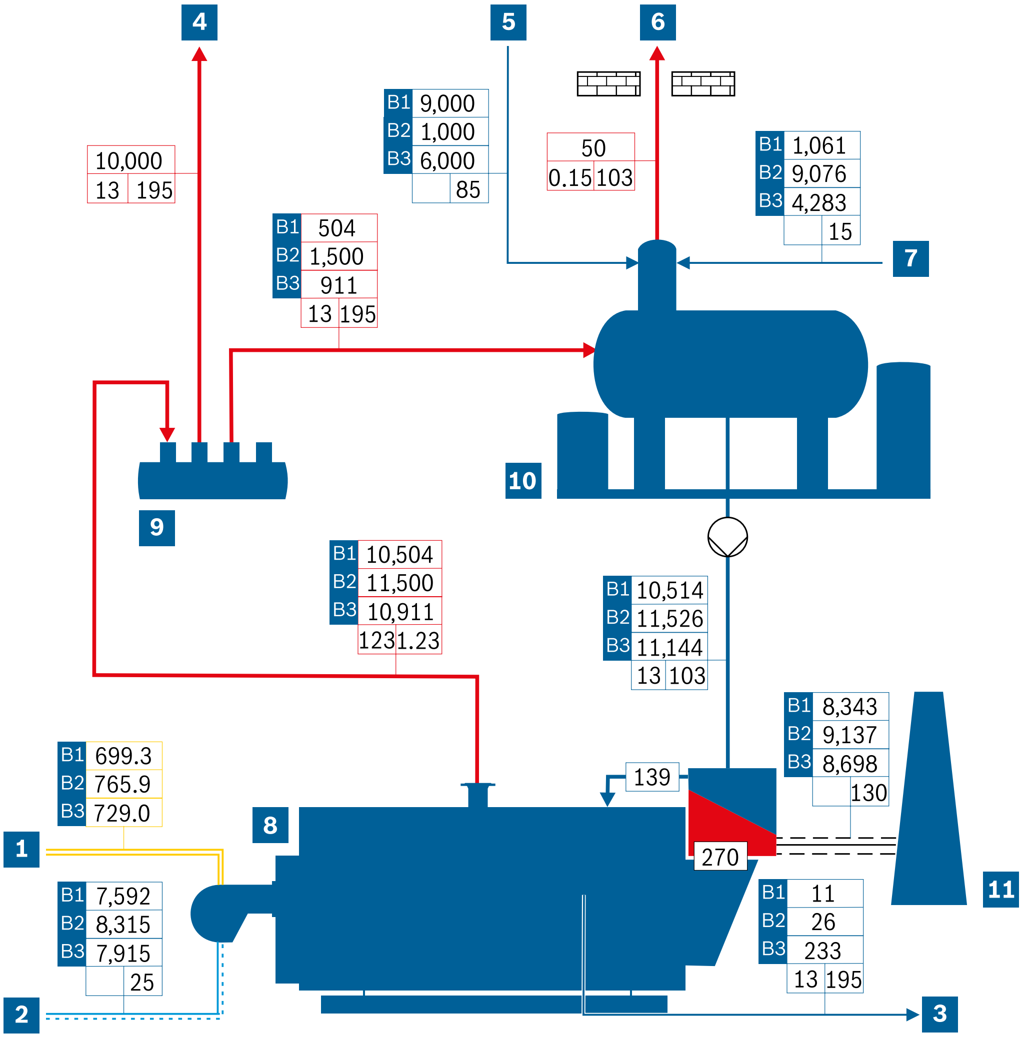

Fig. 8 *Illustration of mass and energy balance in simplified flow chart (highly-simplified representation)*

1 Fuel
2 Air
3 Surface blowdown
4 Saturated steam
5 Oxygenic condensate
6 Exhaust vapour

7 Make-up water
8 Steam boiler
9 Steam distributor
10 Water service module
11 Chimney

Water
Steam
Fuel
Air
Flue gas

Mass flow	
Pressure	Temperature

3.2 Consumption analysis

If the nominal design steam quantity is known, the planning must include a step for defining the steam output of the individual boilers in the system. The aim of this is to determine the maximum steam demand arising during operation, as well as the minimum steam demand. Any design safety margins or expansion of the boiler system must also be taken into consideration.

3.2.1 Maximum steam output

The maximum load or nominal load corresponds to the total number of individual consumers that could be in operation at the same time.

To ensure that the chosen maximum steam output is not too high, a check should be carried out to verify whether all heat consumers are or need to be operating at their maximum output at the same time. This is normally not the case, or can be avoided by in-house processes. The required maximum load can therefore be reduced, for example, so that start-up processes of system components and heat exchangers can be staggered, which completely eliminates or at least reduces problems arising during light load phases due to oversizing of the system.

Safety margins during design

Of course with the maximum steam output it also makes sense to factor in an appropriate safety margin.

To avoid excessive oversizing, the following aspects should be considered when defining the safety margins:

- Collaboration with the operator of the system
- Incorporation of future operational developments
- Explicit demonstration of the safety margins during conception of the system:
  - Multiplication of safety margins at different points must be avoided
  - As a rule, safety margins have already been included at the heat exchangers and steam consumers

Problems due to oversizing

- Increased investment costs
- Increased operating costs, especially due to burner cycles and heat losses
- Reduced service life of the boiler and other components of the system

Starting operation

Additional heat is required to bring the system up to operating temperature during the starting operation, especially if the feed water vessel, the pipework or heat exchanger are still cold. The maximum steam output is only available to the consumers once the system is at operating temperature.

Overload

Overloading of individual consumers or the entire system beyond the maximum load of the boiler leads to a very high steam consumption from the boiler. As well as reducing the pressure in the boiler, this also leads to more moisture-laden steam and foaming of the boiler water. Overloading of the boiler should therefore be avoided, e.g. by using pressure reducing stations at the consumers or by protecting the boiler with motorised steam feed valves (SUCcess).

The problem of overloading the steam boiler can also occur when the heat exchangers are correctly configured. The output at the heat exchangers is specified with reference to the design condition and normally includes a reserve of 10 – 30% for the heating surfaces within the heat exchanger. If the heat exchangers are new, they also achieve a higher output when the steam demand is higher.

Development of steam consumption during changes in operation

Special attention should be paid to possible future changes in an operation. If extensions are already planned or envisaged, this must be taken into account in the anticipated maximum steam output. In this case, it is normally possible to devise an overall system concept which allows a degree of flexibility in terms of steam output in order to accommodate subsequent expansion and avoid adversely affecting the current operation due to excessive oversizing.

3.2.2 Minimum output and light load phases

The minimum output normally occurs when production stops at night or at the weekend. In addition to the internal consumers, so-called downtime losses in particular must be taken into account. They do not depend on the current steam demand of the system and occur at any time.

These are essentially:

- Heat losses due to heat emission at the steam boiler
- Heat losses in pipework
- Heat losses at the components
- Exhaust vapour losses at the deaerating unit

Light load phases during which the required steam output is below the control range of the burner should especially be avoided.

As soon as the burner is cycling frequently (> 4 burner starts/h), efficiency is severely affected due to the occurring pre-ventilation losses.

→ Efficiency – Chapter 2.2.4: Pre-ventilation, page 273

In addition, the overall service life of the system is impaired by the thermal stresses that occur when the burner starts.

These partial load conditions can often be avoided or reduced by higher level controls and in-house energy management systems, considering they have already been taken into account during the planning of the system.

→ Technical report FB027: avoidable stresses on steam shell boilers

3.3 Definition of boiler output

The following specifications have been defined as result of the consumption analysis:

- Maximum steam output
- Minimum steam output
- Documentation of safety margins
- Concept for future operational changes to the steam output demand
- Possibility of a chronological course of steam output

The individual boiler outputs can be defined with this data.

3.3.1 Single-boiler systems

When selecting the output size of the boiler, it should be certain that the boiler system subsequently operates in the range of 40 – 90% of the maximum output of the steam boiler as the efficiency is particularly high in this range.

Defining the minimum and maximum steam output also establishes the necessary control range of the system.

$$\text{Required control range} = \frac{\text{Minimum steam output}}{\text{Maximum steam output}}$$

Use of a single boiler is a convenient solution if the control range during normal operation on weekdays is between the following values:

- Single flame-tube boiler: 1 to 0.125 (control range 1:8)
- Double flame-tube boiler: 1 to 0.061 (control range 1:16)

The following output sizes are available:

- Single flame-tube boiler: 175 – 28,000kg/h
- Double flame-tube boiler: 18,000 – 55,000kg/h

3.3.2 Multi-boiler systems

It may make sense to use a multi-boiler system for several reasons. The following description aims to cover the various reasons for distribution of the nominal steam output. However, as many distribution variations are possible, it is not possible to provide a full and comprehensive assessment encompassing all aspects. The decision to opt for a single system or to distribute among several boilers must always be made for each project individually and should be done by the operator and planner with the support of the plant engineer and boiler manufacturer.

Security of supply and redundancy

Distribution of the boiler output among several generation units is necessary, if the security of supply also needs to be maintained when a unit drops out. For example, this is necessary in hospitals or in the pharmaceutical industry.

In this case the reserve unit must provide the minimum output required to ensure continued operation.

Furthermore, in food companies, such as dairies or in sugar manufacturing, and industrial firms, such as the paper and printing industry, breakdown of the steam generator unit would often be disastrous from an economic standpoint.

Partial load operation and steam boiler system control ratio

Reasons for distributing the total output between several units are:

- Difference between smallest and biggest heat consumer
- Cyclically fluctuating steam demand, e.g. between day and night
- Different steam demand on workdays as opposed to weekends

The smallest power requirement is normally far less than the smallest load of an individual boiler unit, and it therefore makes sense to adapt the output distribution to the light load. This avoids a costly and environmentally-polluting on/off switching operation of the combustion system and premature wear.

In large-scale systems the output limit of the heat source determines the number of units. The total output should ideally be distributed among units with identical construction. Reduction in the number of spare parts kept in stock and part replaceability alone are sufficient reasons for doing so. If efficient operation cannot be achieved with the smallest load using the smallest unit determined in this manner, only then should an adapted low-load unit be used.

→ Technical report FB027: avoidable loads on steam shell boilers

Starting duration cold start/heat maintenance system

Fast availability of the maximum steam output is from time to time also a good reason to use a multi-boiler system. While a cold boiler needs roughly an hour until it reaches the operating state and is ready to deliver its full output, a boiler which has been kept warm and is in the standby state can respond to such a request in only 5 minutes. In this process, heat maintenance is more efficient and gentle using a steam-heated heating coil as opposed to a combustion system.

→ Technology – Chapter 3.2: Heat maintenance system, page 145

Optimised operating costs

The question as to how many boilers should be installed in a system and what their respective outputs must be investigated with a view to reducing the operating costs (to a minimum). Particularly in cases where the steam demand fluctuates cyclically, e. g. week/weekend load or if the heating load fluctuates depending on the season, it makes sense not to select the same boiler output for the individual units.

Use of sequential control

The boiler stresses and the operating costs can be optimised by defining each boiler as either a base-load boiler or peak-load boiler and by using a state-of-the-art sequential control.

→ Technology – Chapter 4.6: System control SCO, page 206

Space requirements – installation requirements

Most boiler systems are set up in a separate boiler house, or at least in a separate area of the building, because special conditions relating to installation and operation must be observed due to the potential dangers associated with their operation.

In some countries, such as Germany, for smaller boilers with a lower safety relevance, there might be reduced requirements regarding the location of the boiler (please check your local country requirements). It is possible to build these in an existing boiler room or energy centre.

Requirement	Maximum value
Maximum boiler steam output	2,000 kg/h
Maximum permissible operating pressure	32 bar
Maximum water content up to low water	10,000 l
Maximum product of water content and permissible operating pressure	20,000 l · bar

Tab. 4 *Steam boiler with facilitated installation conditions (example Germany)*

In some systems, it may be necessary due to the installation conditions for the total steam output to be shared by several boilers that satisfy the above conditions. Eased installation conditions are frequently used in hospitals, small laundrettes or food production plants if a separate boiler house is not available and the boilers can be set up in the cellar for example.

Sensible distribution of the boiler output

A number of requirements in relation to failure safety and the required control range, and also sensible distribution of the boiler output between several boilers, are stated as examples in the following table in order to satisfy the requirements:

Requirement	Distribution of the boiler output
Failure safety of 100% of steam output	100:100, between 2 boilers
Failure safety of 80% of steam output	80:80, between 2 boilers
Failure safety of 50% of steam output	50:50:50, between 3 boilers
Control range > 1:8	50:50, between 2 boilers or 1 double flame-tube boiler
Control range > 1:20	30:70, between 2 boilers
Control range ≤ 1:20 + failure rate 80%	40:40:40, between 3 boilers

Tab. 5 *Distribution of boiler output to satisfy requirement examples*

Additional combinations for distributing the boiler output between several boilers are possible. The investment, operating and maintenance costs must be taken into consideration when deciding on the steam output distribution.

When the total output is distributed between several boilers, a sequential control must be used. It applies the switch-on/shutdown and heat maintenance logic of the individual steam boilers.

→ Technology – Chapter 4.6: System control SCO, page 206

4 Fuel

The following fuels are used in the majority of steam boiler systems:

- Natural gas
- Fuel oil

These fuels are more or less available everywhere, and to a large extent, standardised and thus have a high quality.

However, other fuels can be used to generate steam:

- Medium oil or heavy oil
- Other gases (e. g. hydrogen, LPG, LNG)
- Biofuels (e. g. lean gases, sewage gases and biogases)
- Contaminated by-products from the chemical industry (e. g. styrene, toluene)
- By-products from other industries (e. g. animal fat, fish oil)

The choice of fuel initially depends on the availability at the planned installation location. Oil is delivered via road tanker, whereas for a gas station, gas transfer from the gas distribution system must be available.

If the requirements for security of supply are high, two fuels can also be used in the same boiler. Gas is then normally used as the main fuel and fuel oil as the substitute fuel.

Economy is another important factor in fuel selection. Exact comparability must be ensured when comparing costs. When using gas as fuel, the comparison price can be obtained directly from the gas bill or requested from the gas provider. The fuel oil supply prices are published on the Internet.

→ Planning – Chapter 4.3: Criteria for selection between fuel oil and natural gas, page 56

Apart from the fuel costs, the secondary costs for operation, maintenance and inspection of boiler systems and possibly the occupancy costs for adjacent buildings, must be considered.

Overall, gas-fired boilers tend to be more economical, which is why many existing systems have been converted from oil to gas or dual-fuel burners in the past decade.

In addition to the cost, the impact on the environment during combustion varies, depending on which fuel is used and must be considered. In particular, the permitted emissions at the installation location of the boiler system play a significant role. When used as a fuel, natural gas has a lower pollutant emission in terms of CO_2, NO_x and SO_2 emissions.

4.1 Fuel oil

When using mineral oils as a fuel, various additional requirements arising from water pollution and fire prevention regulations, especially in relation to delivery, storage and distribution, must be considered.

Fuel oil EL

The fuel oil type EL, extra light (liquid), is a reliable and readily available source and is normally delivered on a road tanker.

Using Germany as an example, these are the following types of fuel oil EL available:

- Fuel oil EL, standard
- Fuel oil EL, low-sulphur
- Bio fuel oil EL

The most popular type of fuel oil is fuel oil EL low-sulphur, which has a maximum sulphur content of 50mg/kg. Due to the favourable taxation rate, it has in the meantime established a market share of nearly 100%. It is also ideal for condensing technology as it has an even lower soiling tendency than fuel oil EL.

→ Technology – Chapter 3.4: Condensing heat exchanger, page 152

Bio fuel oil EL is low-sulphur fuel oil to which up to 5, 10 or 15% liquid fuel from renewable raw materials is added. Biodiesel is currently used for this as a rule.

The minimum requirements and tests on fuel oil EL are defined in DIN 51603-1.

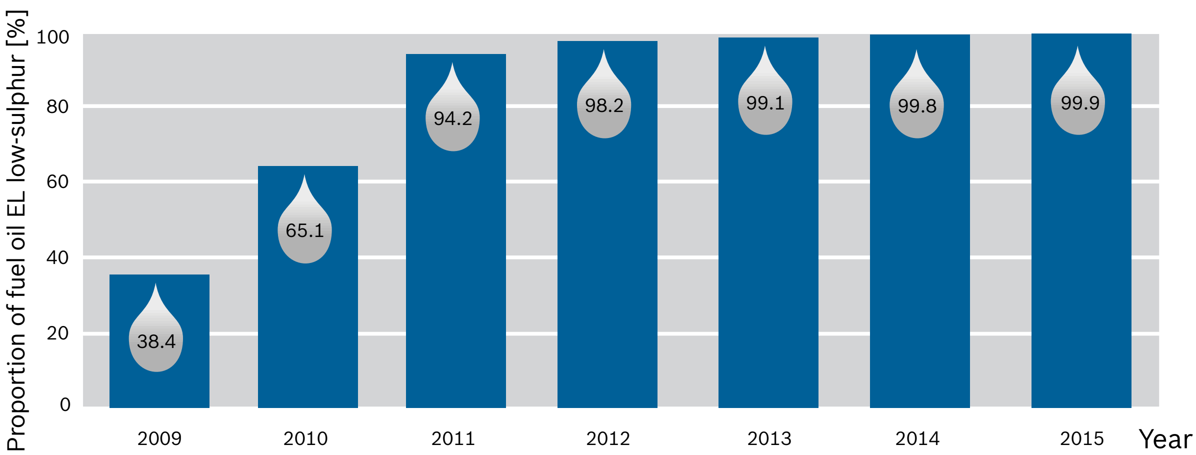

Fig. 9 *Market share of low-sulphur fuel oil in Germany* [I]

Heavy fuel oil (HFO)

Heavy fuel oil is used for steam generators more or less exclusively in large industrial systems. It is produced during refinement of crude oil in the bottom part, the so-called sump of the distillation towers, where the components of the crude oil with a high boiling point are removed. It primarily contains large relatively heavy molecules such as long-chain alkanes and alkenes, cycloalkanes and various aromatic hydrocarbons. It also contains various nitrogen and sulphur compounds.

I) IWO – Institute for Heating and Oil Technology

Heavy fuel oil is viscous and must be heated to a temperature of over 60°C in order for it to be able to flow through pipework. The atomisation temperature required for combustion is even between 100 – 160°C. The atomisation viscosity requirements are significantly higher for pressure-jet oil burners than rotary cup oil burners, which is why the fuel oil must be preheated to higher temperatures.

Heavy fuel oil contains up to 3.5 mass percent sulphur, has a tendency to leave heavy deposits in the flue gas path and the flue gas should not be cooled to below the acid dew point of roughly 120 – 150°C. Additionally, special measures are sometimes required (e.g. urea injection) in order to comply with flue gas emissions.

It has many disadvantages compared to using fuel oil EL and natural gas which in general cannot be outweighed by its low price.

4.2 Natural gas

Use of natural gas is frequently recommended if a supply of natural gas is available at the planned installation location of the boiler. By connecting to the supply network, there is no need to stock up on fuel and in the deregulated gas market it is easy to switch provider. Far less space is required for the gas transfer station compared to the oil storage tank including ancillary systems. In addition, natural gas from the public network is suitable for unrestricted use with condensing technology.

→ Technology – Chapter 3.4: Condensing heat exchanger, page 152

Another thing the fuel gas has in its favour is that the control range for partial load operation is significantly bigger than for oil. While oil burners normally only reach a partial load range of 1:5, state-of-the-art gas burners can cover twice the partial load range, i.e. a control range of up to 1:10.

The net calorific value of the gas, the gas flow pressure available at the installation location of the boiler and information on the maximum quantities of heat available via the gas connection are required for the design of the fuel supply with gas. This information can be obtained from the local gas system operator.

4.3 Criteria for selection between fuel oil and natural gas

The most important factors influencing the selection of fuel are summarised in the following table:

Criterion	Fuel oil EL	Natural gas	Advantage/ disadvantage for natural gas
Fuel store	Yes	No	+
Connection	No	Yes	–
Available everywhere	Yes	No	–
Price stability	No	Limited yes (→ Fig. 10)	+
Preliminary financing	Yes (supply)	No	+
Burner costs	Neutral	Increased	–
Control range	up to 1:5	up to 1:8	+
Heating surface soiling	Low	None	+
Condensing use	Good (efficiency ≤ 99%)	Very good (efficiency ≤ 104%)	+
Fuel transportation	Necessary	Not required	+
Pollutant emission	Low	Very low	+
CO_2 generation	~ 266 g_{CO2}/kWh	~ 200 g_{CO2}/kWh	+

Tab. 6 *Criteria for selection between fuel oil and natural gas as fuel [II)]*

Development of fuel prices for industrial customers (Germany)

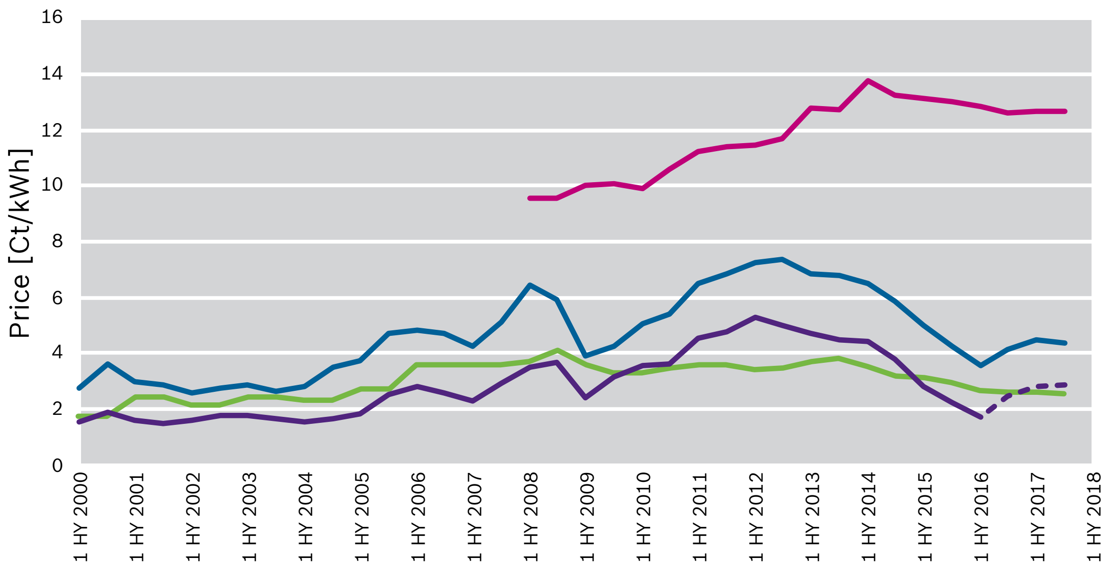

Fig. 10 *Development of energy prices for industrial customers in Germany [II)]*

Electricity
Heavy fuel oil
Light fuel oil
Natural gas

II) Federal Statistical Office

Notes [III]:

- Gas, electricity: details for industrial customers, prices include purchase tax and exclude VAT
- Fuel oil: details for wholesale trade, prices include petroleum tax and petroleum stockpiling fee and exclude VAT
- Conversion of prices for fuel oil EL with density 0.84kg/l and net calorific value 11.89kWh/kg
- Conversion of prices for heavy fuel oil with 11kWh/kg
- Heavy fuel oil: specific data only available until December 2016, after this date the data is extrapolated via the price indices

4.4 Further fuels

If any other fuels apart from natural gas or fuel oil are used, special attention should be paid in these cases.

The following fuels can also be used:

- Other gases (e.g. hydrogen, LPG, LNG)
- Biofuels (e.g. lean gases, biodiesel, vegetable oils, sewage gases and biogases)
- Contaminated by-products from the chemical industry (e.g. styrene, toluene)
- Secondary products from other industries (e.g. animal fat, fish oil)

The combustion characteristics of these fuels must be taken into account when designing the combustion system, ancillary components, boiler and when devising suitable flue gas heat recovery measures.

The following characteristics in particular must be considered in this context:

- Fuels with high sulphur content (e.g. biogas)
- Fuels containing chlorine (e.g. by-products from the chemical industry)
- Fuels that leave heavy deposits on the heating surfaces (e.g. so-called re-raffinates)
- Fuels with a particularly high net calorific value which therefore subject the flame tube to higher thermal stresses (e.g. hydrogen)

III) Federal Statistical Office

5 Installation

When positioning the boiler house on the operating premises, the following requirements, among other things, must be taken into account:

- Fuel supply and storage
- Space requirement for the boiler house and flue
- Possibility of system expansion
- Noise emissions (especially for neighbours)
- Position of production facilities on the operating premises (shortest possible routes to consumers)
- Fire zones
- Architectural and design aspects

Some of these requirements cannot be fully satisfied all at once, especially in companies that have evolved over a long period of time. The location will therefore not necessarily be ideal for all requirements and instead represents a compromise between the operational and technical requirements and cost effectiveness.

5.1 Installation room

A number of basic requirements for the boiler installation room are dealt with below. This information is provided purely to assist with planning. Furthermore, all relevant local and national regulations and applicable standards must be observed.

→ Technical information TI024: requirements for boiler installation rooms – notes on the installation of boilers and boiler house components

Fundamental requirements

The installation room must meet the following requirements:

- The boiler installation room has to be kept clean and free of dust and dripping water.
- The room temperature must be between 5°C and 40°C.
- Entry to the boiler installation room by unauthorised personnel is forbidden.
- One must ensure that sound insulation measures comply with local regulations.
- The control cabinets must be installed in such a way that they are not exposed in any manner whatsoever to vibrations or shaking of system components.
- The control cabinets must be installed in areas where they will be protected from impermissible heat radiation and can be safely accessed even in potentially dangerous conditions.
- Compressed air supply for bottom blowdown and any further pneumatic actuators, if necessary, should be available.
- Escape possibilities with emergency stop buttons, located opposite one another whenever possible, must exist.
- It must be ensured that lighting is sufficient, especially in the area of the valves and safety devices.
- Fixing options for pipework should be available on walls and ceilings.

- Every boiler installation room should have a continuous or nearly continuous, free external wall or ceiling area of at least 1/10 the floor area (or as per local regulations), that will yield much more easily than the other surrounding walls if excess pressure occurs in the boiler installation room. The relevant national and local regulations and applicable standards must be observed when defining the pressure relief surface.

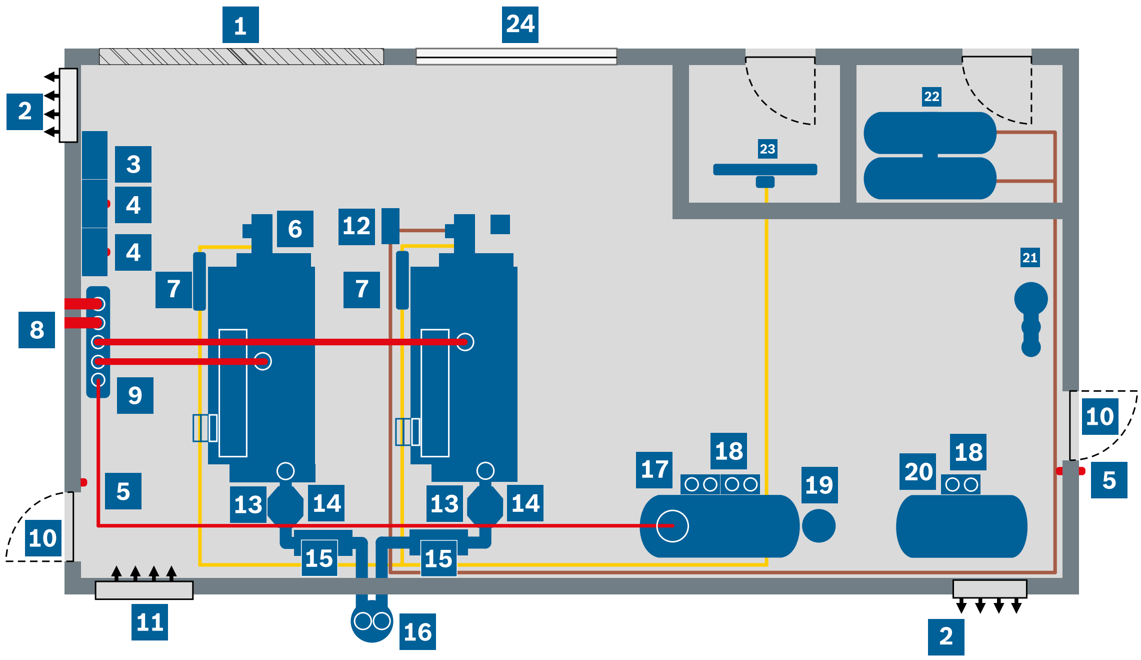

Fig. 11 *Example of a boiler house (simplified representation)*

1 Fitting clearance	**13** Integrated economiser ECO
2 Extract air (top)	**14** Condensing heat exchanger
3 System control SCO	**15** Silencer
4 Boiler control BCO	**16** Chimney
5 Emergency stop button	**17** Water service module WSM
6 Boiler	**18** Pump module PM
7 Gas regulation module GRM	**19** Expansion vessel BEM
8 Steam pipe, consumer	**20** Condensate service module CSM
9 Steam distributor SD	**21** Water treatment module WTM
10 Escape route	**22** Oil tanks
11 Supply air (bottom)	**23** Gas transfer station
12 Oil supply module OSM	**24** Pressure relief area

Steam

Gas

Oil

Pipework identification according to DIN 2403
→ Tools – Tab. 76, page 414

Accessibility

The boiler and system components should be arranged so that the mounted valves, sensors and all inspection apertures are still accessible. It only makes sense in some respects to position the boiler and also several system components on a wall. A clear route at least 1m wide, especially on the operating side of the boiler and the components, should be allowed for. It must also be ensured that surfaces that can be walked on are high enough.

Foundation and installation

It must be ensured that the following requirements for the foundation and installation are met:

- It has to be ensured that the floor at the installation location is perfectly level (evenness tolerance with reference to DIN 18202) and has sufficient load-bearing capacity.
- When calculating the load bearing capacity of the foundation, the maximum operating weight of the components concerned must be taken into account. When determining the operating weight, additional components (e.g. control cabinet, burner, silencer, exhaust pipes) and their cumulative weight must be taken into account. The operating weight is the weight of the components when filled.
- Existing floor channels must be covered and equipped with drainage facilities.
- The entrance to the boiler installation room must be designed according to the dimensions of the individual components. Suitable lifting gear must be provided at the boiler installation room to move heavy equipment.
- If the installation location needs to be separated from the system to reduce structure-borne noise, sound insulating strips must be placed underneath before installing the system.

Supply and extract air apertures

The supply air must be free of foreign substances and must not contain dusts or corrosive or explosive components, such as solvents or refrigerants. With heat recovery boilers in combination with the unit generating the waste heat (combined heat and power unit or gas turbine) additional notes of the manufacturer of the unit producing the waste heat gas must be observed.

If the ventilation through the boiler house is insufficient or the combustion system air required is drawn in independently of the room air (e.g. via air conduits from other rooms or from the atmosphere), one or several CO monitoring device(s) must be provided in the boiler room.

The supply air aperture should ideally be located in the area at the rear of the boiler. If this is not possible for structural reasons, install baffles or sheet metal channels inside the boiler installation room to deflect the inlet air. When planning the supply air apertures, the arrangement of frost-sensitive (e.g. water treatment) system components which cannot be installed directly in the flow of supply air must also be taken into account.

Extract air apertures must also be provided. Their purpose is to remove the heat underneath the ceiling that accumulates even when heat loss in the boiler house is low.

Supply air apertures should be fitted 500mm above the boiler room floor; extract air apertures should be fitted at the highest point of the installation room. Cross-ventilation should also be ensured in this case.

Supply and extract air apertures have to be sized appropriately to obtain a pressure of ±0mbar in the boiler installation room. The calculation formulae below should be regarded as a non-binding recommendation. It is essential that the system installer seeks the agreement of the responsible approval or building control authority. Additional consumers of supply air (e.g. compressors) have to be taken into account when sizing.

Group	Limits	Supply air cross-sections (formula)
Sz 1	$\dot{Q} \leq 2{,}000kW$	$F_{GR}\ 1 = 300 + (\dot{Q} - 50) \cdot 2.5$
Sz 2	$2{,}000kW < \dot{Q} \leq 20{,}000kW$	$F_{GR}\ 2 = 5{,}175 + (\dot{Q} - 2{,}000) \cdot 1.75$
Sz 3	$20{,}000kW < \dot{Q}$	$F_{GR}\ 3 = 36{,}675 + (\dot{Q} - 20{,}000) \cdot 0.88$

F_{GR} Clear flow cross-section [cm²]
$\dot{Q}$ Thermal output

The side ratio should not be more than 1:2. Each of the required extract air cross-sections correspond to 60% of the supply air cross-sections.

The specified cross-sections must be planned as clear openings (net cross-sections). Shading by grilles or louvres must also be taken into consideration.

If the combustion air is routed via air inlet channels to the burner, an optimised flow path and adequate sizing with regard to the pressure loss have to be ensured. The pressure loss must be taken into consideration in the combustion design. Any condensate that accumulates in the air intake ducts must be removed before the combustion air fan.

Pipework

Pipework must be designed in accordance with national and local regulations and the applicable standards, taking the resulting pressure losses and flow speeds into account.

For guide values on sizing, selection of materials and many more aspects, refer to the chapter Technology.

→ Technology – Chapter 5.1: Pipework, page 211

5.2 Installation conditions

Installation conditions such as installation altitude, coastal location, general construction conditions and/or electrical supply have a significant effect on the design of the steam boiler system.

The installation altitude, for example, affects the ambient pressure and the airtightness affects the design of the combustion air fan. Additional aspects such as reduced motor cooling with pumps must be taken into account at very high installation attitudes of >1,000m.

The salty air in coastal regions promotes corrosion, which affects the burner and chimney materials, for example.

The electrical supply (voltage and frequency) must be taken into account at the control cabinet and motors (e.g. of fans, pumps and valves).

6 Legislation

Steam boiler systems are usually subject to compulsory monitoring and various legal framework conditions must be observed and complied with when manufacturing the components, during planning and construction and when operating the system. The following requirements are stipulated at all levels of the legislation (and monitoring):

- **European directives and ordinances**, such as the Pressure Equipment Directive, Machine Directive, Low Voltage Directive, Gas Appliances Directive, EMC Directive, Hazardous Substances Directive and Explosion Protection Directive
- **National laws and ordinances**, such as the German Health and Safety at Work regulation, Emission and Immission Control Act, Occupational Health and Safety Law, Hazardous Substances Ordinance, Water Resources Law
- **Regional and local regulations**, such as building regulations, water conservation, fire safety, additional emission requirements

The most important laws, directives, ordinances and standards governing the installation and operation of a steam boiler system are described below. These are arranged in the following groups:

- Manufacturing of boiler systems
- Emission and immission protection laws
- Approval regulations/operating permit
- Operation of boiler systems

In this case it must be observed that further EU directives or national laws and regulations apply.

Using Germany as an example, the following diagram shows the basic procedure and is separated into two parts; manufacturing, for which European law applies and operation, for which national law predominantly applies.

Pressure Equipment Directive 2014/68/EC
Putting into circulation and operation of steam boilers

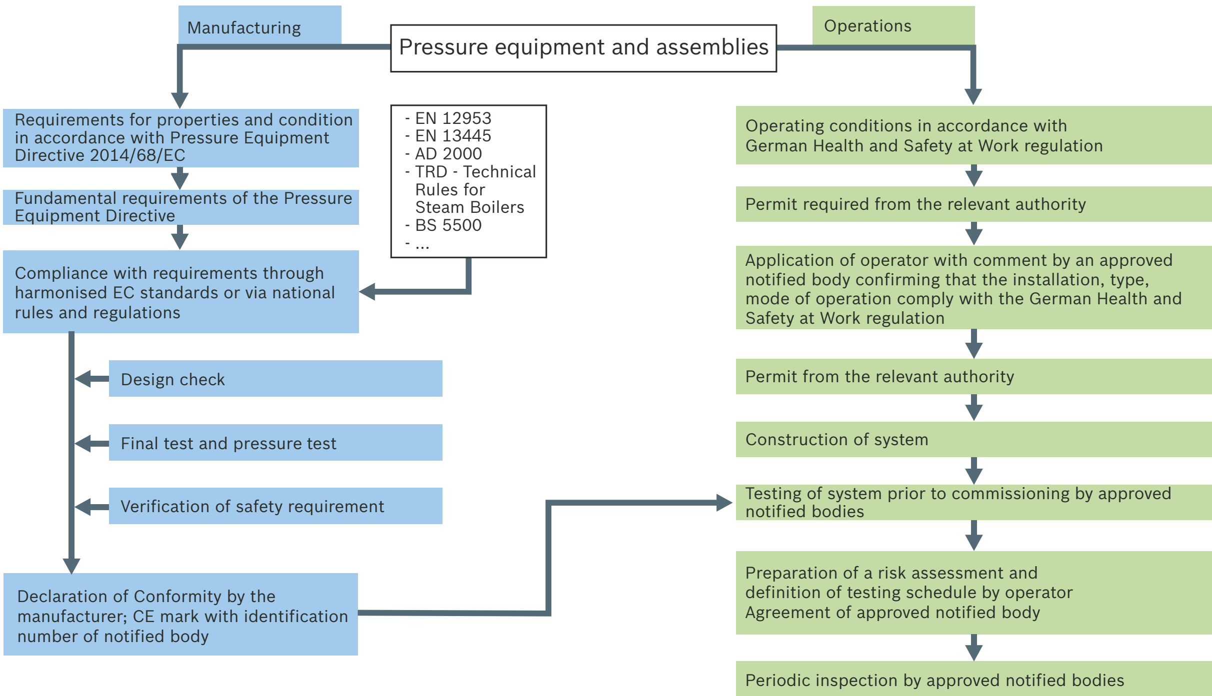

Fig. 12 *Procedure for manufacturing and operation based on the Pressure Equipment Directive 2014/68/EU* [IV]

EU law

German law

DGRL: Pressure Equipment Directive 2014/68/EU
BetrSichV: German ordinance on industrial safety and health in relation to the use of equipment and materials
ZÜS: Approved notified body

IV) Rhineland Technical Inspection Authority (TÜV Rheinland)

6.1 Manufacturing

The manufacturing and distribution of boiler systems is regulated in national law through the implementation of the Pressure Equipment Directive (EU Directive 2014/68/EU). For example, in Germany, this is done in the 14th Ordinance on Equipment and Product Safety Act (Pressure Equipment Regulation). This describes the design, manufacturing, material, testing and preparation of the Declaration of Conformity for pressure equipment. This defines valid, uniform quality requirements within the EU that allows free circulation and consequently free trade in goods and initial commissioning. Manufacturers of boiler systems must have the conformity of their products evaluated and as a result, issue a certification of conformity and attach a CE marking.

An important limit that defines whether a boiler or pressure vessel is regulated at all by the Pressure Equipment Directive, is the maximum permissible operating pressure of 0.5 bar. If the maximum permissible operating pressure is not higher, as is the case for example with low-pressure boilers, so-called "good engineering practise" applies in relation to their manufacture. All other steam boilers are assigned to categories in the Pressure Equipment Directive according to Appendix II as the potential hazard increases. The product of water content and permissible operating pressure is decisive for the classification. Most steam boilers belong to Category IV.

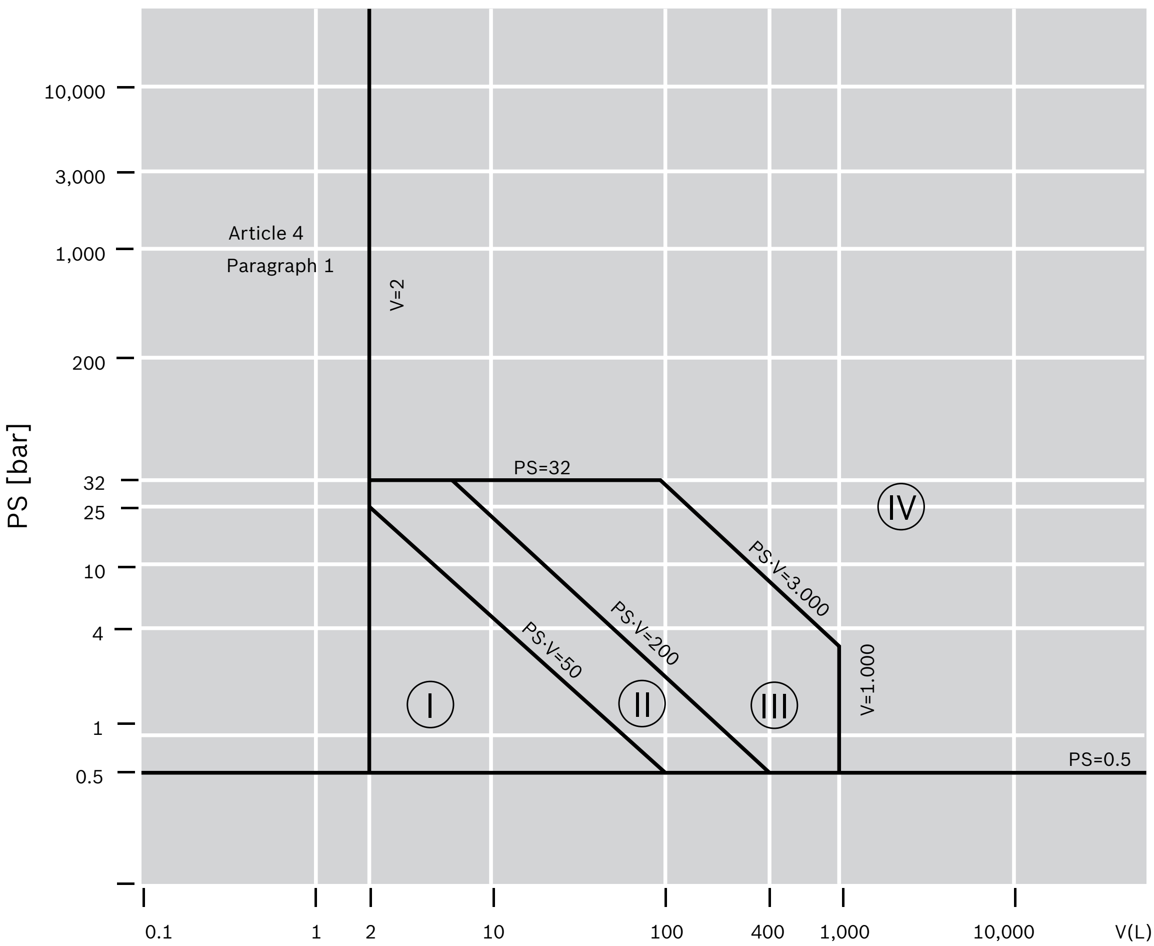

Fig. 13 *Classification of steam boilers into module categories in accordance with Pressure Equipment Directive*

The many certificates and approvals for our products in more than 140 countries worldwide testify to the high quality and production standards of Bosch Industriekessel GmbH. All Bosch boilers, boiler and boiler house components satisfy the applicable European Directives in relation to CE marking, especially the Pressure Equipment or Gas Appliances Directive, based on technical standards (including TRD, AD 2000 and EN standards such as EN 12953). Most of our products and components are EC type-tested. Customised solutions receive an individual permit ex works from an official testing institution.

We manage our products according to current national standards, e.g. EAC (Eurasian Customs Union), TSG G0001 (China), SVGW/VKF (Switzerland) and many more. Our equipment according to EN 12953 for the boiler systems is approved for operation without continuous attendance (BOSB 72 h).

Bosch Industriekessel manufacturing plants are equipped with the necessary certified quality management systems, e.g. EN ISO 9001, EN ISO 14001, Module D according to Pressure Equipment Directive, MLSE (China). In addition, Bosch Industriekessel is a certified manufacturer in the highest quality requirement level for welding to EN ISO 3834 (part 2). A process qualification according to TRD and the Pressure Equipment Directive is available for corrugated flame tubes. As we hold a licence for being a maintenance company for boiler systems and boasting an international service network means we can provide service in more than 140 countries worldwide, some with 24/7 availability.

6.2 Emissions and immissions

Emission and/or immission regulations exist in most countries of the world to protect the environment and people that are relevant to operation of a steam boiler system and must be taken into account in the planning.

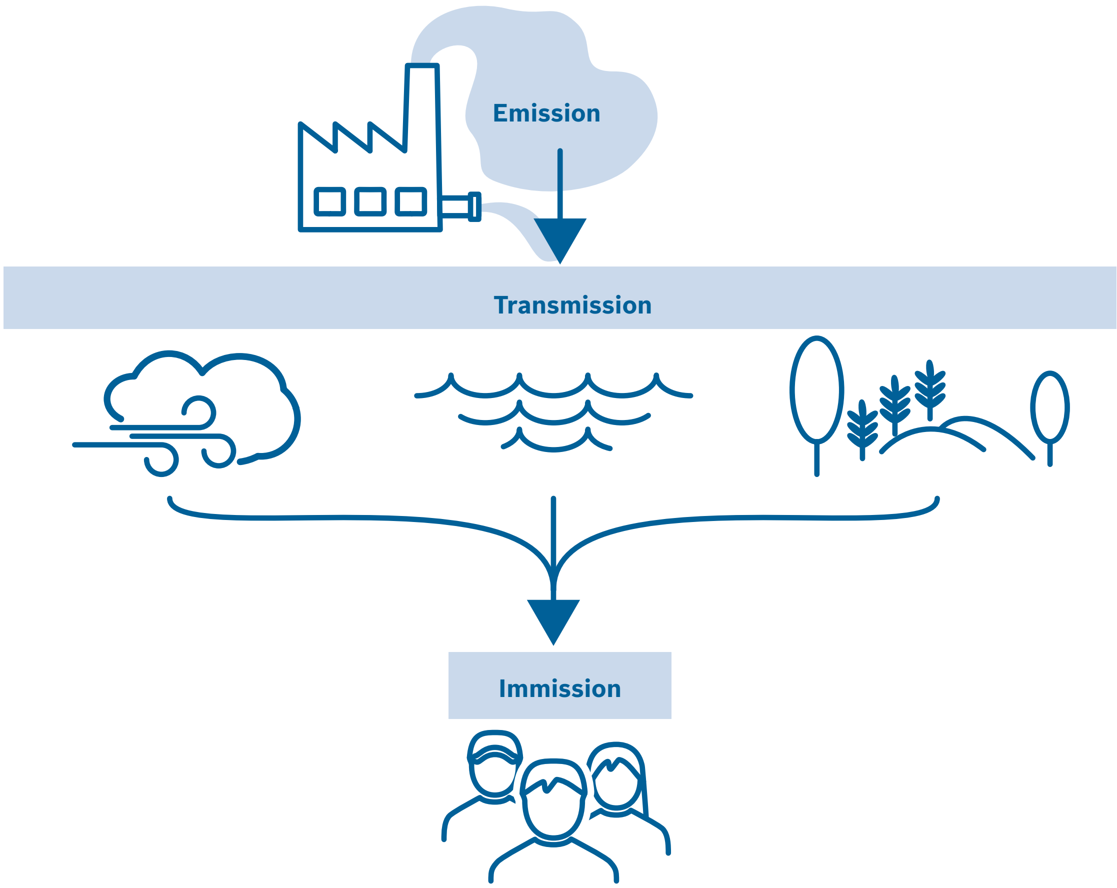

Fig. 14 *Difference between emission, transmission and immission*

- **Emission** is the release of pollutants into the environment. These result, for example, from power plants, industrial facilities and motor vehicles when in operation.The source of emissions (person or object) is referred to as the emitter.
- **Transmission** refers to the distribution of emissions via air, water or soil.
- **Immission** refers to the contamination of air, water or soil which affects people or other organisms.

The following emissions are normally controlled and relevant for a boiler system:

- Airborne emissions (flue gases from combustion systems)
  - Nitrogen oxide (NO_x)
  - Sulphur compounds (SO_2)
  - Carbon monoxide (CO)
- Sound
- Waste water and water protection
  - Delivery, storage and distribution of water polluting substances (e.g. fuel oil)
  - Introduction of waste water the content of which is subject to requirements (e.g. pH value, temperature)

6.3 Combustion systems

6.3.1 European regulations and guidelines

In Europe, the following guidelines provide the legal framework and define minimum requirements that must be more precisely formulated at national or regional level.

Validity/ combustion output	Guideline
≤400kW	**EuP** Directive 2005/32/EC **Energy-using Products Directive**
1 – 50MW	**MCPD** EU 2015/2193 **Medium Combustion Plant Directive**
>50MW	**IED** 2010/75/EU **Industrial Emissions Directive**

Tab. 7 *Validity of European directives for combustion equipment*

A gap between 400kW and 1MW therefore exists and must be covered by national law in the absence of EU requirements. In addition, the important topic of emission analysis is not defined in the EU guidelines and can therefore be dealt with differently from one country to the next.

The combustion outputs of systems with several heat sources, if applicable, are to be added up, according to the MCPD and IED. This basically depends on whether the flue gases are removed via a shared chimney or whether in the view of the relevant authority they can be removed. This also allows freedom for interpretation in national legislation and regional regulations which means that systems in different parts of Europe can be evaluated differently.

6.4 Approval

In general, the installation of steam boiler systems requires an approval from the authorities or a permit. The nature and scope of the approval procedure depends on the national and regional legislation at the place of installation. The procedure normally comprises an expert inspection of the system planning by an inspection agency.

6.5 Operation

Country-specific legal framework conditions apply for the operation of a steam boiler system. These conditions are imposed by various areas of legislation, which are typically:

- Boiler law
- Occupational health and safety laws
- Immission and water laws
- Hazardous substances and chemicals regulations
- Fire safety

The following points among others must be observed in this regard:

- Preparation and regular review of a risk assessment
- Determining the inspection intervals for the system parts and the overall system, instruction of approved notified bodies to confirm these inspection intervals
- Training of operating personnel
- Availability of operating instructions
- Implementation of hazard warnings in the operating instructions as working instructions
- Preparation of checklists for the boiler attendant
- Keeping a boiler operating log
- Regular maintenance of the boiler system by the operating and maintenance personnel and also experts
- Performance of routine boiler checks

Failure prevention

Learning from errors

> “A clever man does not make all mistakes himself. He also gives others a chance.”
>
> Winston Churchill [IV)]

The purpose of this chapter is to help draw your attention to errors that can occur during planning, installation and operation of steam boiler systems using a number of examples.

In this regard you should always bear the following in mind:
- While the number of possible errors is endless, only one solution exists for the optimum system.
- Every conceivable error is also made.

This chapter is structured according to common errors that occur
- during planning,
- during installation (or detailed planning) and
- during operation

of steam boiler systems. Sooner or later these errors lead to damage to the boiler system, potentially hazardous situations, reduced efficiency of the system or other operating problems. This list does not cover all possible errors, and also does not attempt to do so.

The biggest error that can be made, however, is not to report it. You are also welcome to contribute towards avoiding further errors by providing examples.

IV) Quotations for managers: more than 2,600 adages that clearly communicate your message, 2018

1 Planning

Planning errors frequently occur due to insufficient knowledge of subsequent operation or because essential requirements for the boiler system have not been properly taken into consideration. With this in mind, it is helpful to verify the plausibility of all existing data together with all those involved in planning. Significant deviations from the basic evaluation can arise, especially for projects running over longer periods.

1.1 Steam output

1.1.1 Oversizing

Oversizing in itself does not represent a problem in terms of continued operation of a boiler system. However, this does increase the likelihood of an uneconomical mode of operation of a system and, due to cycling of the combustion system, high thermal stresses can arise at the flame tube which can reduce the service life.

Oversizing frequently occurs if safety margins are planned at several points. The operator plans from the outset with subsequent expansion in mind, the planner stays on the safe side, and manufacturers design many components with a built-in safety margin.

Problems:
- Uneconomical operation
- High stresses due to cycling of the combustion system

Cause:
- Installed steam output higher than actual demand

Remedy:
- Correct planning of steam output
- Design systems for smallest possible partial load capability
- Define partial load operation concept
- Install smaller combustion output

→ Planning – Chapter 3.2.1: Maximum steam output, page 47

1.1.2 Undersizing

Undersizing poses a significant operating problem. Boilers not equipped with suitable safety functions fall below the standard operating pressure. When this happens, more and more water is carried along in the steam pipe and faults occur due to the enormous fluctuations in water level.

Problems:
- Steam pressure drops
- Steam moisture increases
- Heat outputs cannot be reached

Cause:
- Installed steam output less than actual demand

Remedy:
- Correct planning of steam output
- Observe large load steps
- Planning the boiler sequence control

1.2 Fuel supply

When supplying fuel for gas combustion, the gas flow pressure at full load in particular must be taken into account. If the gas flow pressure is too low, faults will occur in the combustion system. Sometimes the necessary flow pressure at the gas regulation module is forwarded directly to the gas supplier without considering the resistances in the gas line between the gas transfer station and gas regulation module. It must also be ensured that there is enough of a difference between the gas flow pressure, which is necessary for operation and the setting values for the pressure limiting and safety equipment, so that they are not triggered when the double solenoid valves of the combustion system close.

Problems:
- Full load steam output is not reached
- Frequent burner faults

Cause:
- Gas flow pressure at gas regulation module too low
- Strong fluctuations in gas pressure
- Gas filter dirty

Remedy:
- Correct planning of gas line
- Cleaning of gas filter
- All resistances between the gas transfer module and gas regulation module of the boiler at maximum output must be taken into consideration

1.3 Installation room

To ensure reliable combustion, it is essential for the supply air apertures in the boiler house to be sufficiently large and also fully open when the burner is in operation. If the supply air is insufficient, this can lead to problems ranging from soot formation through to hard ignition resulting in severe damage to the boiler.

If pipes in danger of freezing, e.g. freshwater lines, are located near the supply air apertures, the risk of frost in the winter must be taken into account.

Extract air apertures must also be provided to avoid large thermal stresses due to an accumulation of heat under the boiler house ceiling. The insulation of boilers, pipework and valves is in fact becoming more and more effective which reduces the thermal output in the boiler house. The residual heat must however still be removed from the boiler house. Electronic switching equipment in particular can fail due to high ambient temperatures.

Problems:
- Insufficient air during combustion (CO formation)
- Negative pressure in the boiler house
- Accumulation of heat in the boiler house
- Risk of frost at the supply air apertures

Cause:
- Supply air apertures too small
- Extract air apertures

Remedy:
- Correct planning of supply and extract air apertures
- Avoid risk of frost


R. Nuber
BOSCH

2 During installation

Installation and assembly errors occur now and again because in larger projects, several companies are often working together for the first time. Many interfaces and many installation instructions of specific manufacturers must be observed. Time pressure which is often an aspect of such projects can also have a decisive effect. The various trades install their pipework without coordinating with one another and whoever arrives on-site first installs first without taking the following installations into account.

In these situations problematic faults occur, e.g. a volumeter installed in the incorrect flow direction or incorrect connections at a heat exchanger or at safety valves which come to attention during commissioning and must then be rectified.

Unfortunately, often systems and pipework are either poorly or not perfectly installed. The following problems are either not or only partially identified during commissioning and acceptance of the system, which then leads to a permanent deterioration in operating conditions.

Signs of this are:

- Overly high investment costs (too many elbows, nor direct pipe routing)
- Corresponding operating costs (high-pressure losses, high heat losses)
- Poor operability and maintenance options

Fig. 15 *Introduction of waste water at temperatures over 100°C at the bottom blowdown vessel below the water line (at the connector for <100°C)*

2.1 Pipe routing

For various reasons, the pipework must be routed through changes in height at many points. In these situations, two simple basic rules should be followed.

- Drain pipework at the lowest point
- Vent the pipework at the highest point

2.1.1 Steam pipes

When starting up, it is especially important to bear in mind that large amounts of condensate accumulate in steam pipes, not only during the heat-up operation but also during continuous operation due to the heat losses in the pipework. This condensate must be removed from the steam pipe as otherwise water droplets could form and be carried along at high speed in the steam flow which leads to water hammer resulting in damage to the pipework, valves or holders. The following points must be observed when routing the steam pipe.

Provide dewatering points

- Immediate upstream of all control valves and pressure reducers to prevent condensate accumulating when these fittings are closed
- Upstream of manual or motorised valves that remain closed for longer periods
- At the lowest points in all vertical sections of pipework and before changes in height
- At the end of the pipe

Observe pipe gradients

It must be possible for condensate that accumulates in a section of pipework to flow to the nearest condensate drain. In the flow direction, this is supported by the prevailing flow speed in the pipe. A gradient in the flow direction is therefore desirable. There should be a dewatering point every 25 – 50m.

The gradient should not be less than 1 – 3%, and should ideally increase slightly the greater the distance from the last drainage point as a larger quantity of condensate must then also be carried along.

Short pipe sections can also be dewatered in the counterflow direction by increasing the gradient accordingly to >5%.

The important thing is to ensure that the condensate can flow away unimpeded and that water pockets cannot form at any point in the pipework.

Condensate collector pipes

Due to the high-pressure gradient, only a small connection diameter (DN 15 – 25) is required at the end of the condensate drains for dewatering of the pipework. However, if the diameter of the connection end that connects directly to the steam pipe is too small, some of the condensate flowing at high speed through the pipework is flushed beyond the dewatering point which renders the condensate drain more or less ineffective. The condensate collector pipe should therefore always be sufficiently sized to ensure effective dewatering. It must also be ensured that sufficient volume is available in the condensate collector pipe for dirt deposits to minimise failures of the condensate drains.

The collector pipe also acts as a storage volume, particularly when starting up the system when large condensate accumulation rates occur due to heating of the pipework. The connection of the condensate drain should branch off roughly 50 – 100mm above the base of the collecting pipe to prevent dirt and deposits directly entering the drain.

→ Technology – Chapter 5.2: Steam pipes, page 219

Problems: • Water hammer causing damage to pipework, valves and holders

Cause: • Due to inefficient dewatering, water droplets travelling at high speeds form in the pipework

Remedy: • Select correct condensate drain and install in suitable location

2.1.2 Merging of pipework

Merging of pipework with the same function is a standard procedure in plant engineering. It goes without saying that steam pipes from several boiler systems are combined into one supply pipe with suitable nominal diameter, for example. However, this is only possible if the function is not impaired. This can lead to severe problems, particularly in the case of safety valve blow-off pipes.

Safety valve blow-off pipes must always be routed separately to the open air and, whenever possible, via the most direct route. When pipework is merged, this affects the function of the safety valve and the necessary blow-off quantities are undercut. As the reaction forces that occur when the valve responds are high, the pipe could even break off.

Problems:
- Impermissible increase in pressure in the boiler possible
- Safety function no longer exists
- Infringement of the regulations
- Possible break in pipework

Cause:
- Excessively high flow resistance in the pipework
- Retroactive effect on the safety valve (flutter)

Remedy:
- Always route the blow-off pipes of the various safety valves separately

Fig. 16 *Impermissible merging of safety valve and expansion steam pipe*

2.1.3 Reduction of internal diameter and excessively long pipework

Air vent lines

If air vent lines, such as those used on the bottom blowdown expansion vessel are not routed onwards with the same nominal diameter as specified, there is a risk of an impermissible build-up of pressure. This occurs as a consequence of restricted air flow and can lead to destruction of the vessel which is designed for unpressurised operation (≤ 0.5 bar).

Fig. 17 *If the internal diameter of expansion steam pipes is reduced, this can lead to an increase in pressure and rupturing of the vessel*

Exhaust vapour pipe

If the internal diameter of the exhaust vapour pipe from the deaerator is reduced, this can impair the removal of oxygen and carbon dioxide to such an extrem, meaning that full deaeration can no longer take place. This would lead to corrosion in the boiler and the pipework. If in addition the water quality is not regularly tested as prescribed, large components of the boiler system may need to be replaced.

Problems:
- Impermissible increase in pressure
- Restricted function

Cause:
- Reduction of the nominal pipe diameter and therefore greater flow resistance in the pipework

Remedy:
- Route pipework with the prescribed nominal diameter and prescribed material as directly as possible to the outside

Fig. 18 *Tapering (1) of expansion steam pipe on the bottom blowdown vessel. Merging (2) of expansion steam pipe, safety valve blow-off pipe and exhaust vapour pipe. Exhaust vapour pipe not made of stainless steel (3).*

2.1.4 Hazard free outlet

All pipework, especially safety valve blow-off pipes that divert steam to the open air, must be routed in such a manner that they do not pose any further danger to persons, systems or the building. The steam normally flows at a very high speed and high temperature to the open air. The outlet must therefore not cross any routes nor should it be directed at temperature-sensitive parts of the system.

Damage:
- Destruction of rooflight domes in the building due to the hot steam from the safety valve blow-off pipe (image on left)
- Hazard for operating personnel and damage to electronic components (image on right)

Cause:
- Potential hazard not identified
- Outlet of discharge pipe pointing directly at the rooflight dome or inside the boiler house

Remedy:
- Terminate pipework harmlessly in the open air

Fig. 19 *Safety valve blow-off pipe*

2.1.5 Incorrectly installed valves

Valves are often fitted incorrectly in the flow direction. As the function is impaired this is normally discovered immediately. This cannot always be detected immediately, especially in the case of non-return valves. In this case the non-return valve was incorrectly installed at the feed water control module bypass which meant that the minimum quantity required for the pump could no longer flow back to the feed water vessel. This initially led to cavitation in the first feed water pump. The cause was not investigated further as the feed water pump was replaced under guarantee. As the fault was not rectified, cavitation occurred in the second and third pump. Only then was the actual cause investigated and subsequently rectified.

Damage:
- Three defective feed pumps due to cavitation

Cause:
- No minimum quantity transportation as the non-return valve was installed in the bypass pipe in the wrong flow direction

Remedy:
- Use pre-installed modules
- Check all operating conditions during commissioning
- Check causes of damage

2.2 Support

Now and again, serious defects are found on pipework holders, such as:

- Insufficient sizing of holders
- Distances between holders too large
- Thermal expansion during operation not taken into consideration
- Wall or ceiling too weak to absorb the forces

The forces released when the safety valve responds cannot be absorbed either by the safety valve or the metal roof. Here, the discharge pipes are propping each other up, which does not help the situation. Fortunately the fault was discovered before the initial test as otherwise there would have been a risk of the pipework rupturing.

Problem: • Possible severe damage to the building and danger to operating personnel
Cause: • No holder for pipework
Remedy: • Provide suitable holders for all forces that arise

Fig. 20 *Holders of safety valve blow-off pipes missing*

Fig. 21 *Thermal expansion of safety valve blow-off pipes not possible*

MEC-Schrank
übergeordnetes
Leitsystem
T. Pischborn
BOSCH

3 During operation

Provided care and maintenance is properly carried out, the boiler will have a service life of more than 50 years. In practice however, the boiler system is affected by many different factors that can significantly reduce the service life of the boiler. In this chapter, we aim first and foremost to make the operator aware of this topic based on individual examples. In doing so, possible causes of defects cannot of course be described in every aspect. However, the following applies as a general rule: there will always be specific causes for defects that occur. In addition to correctly repairing the defect and restoring the operational availability of the system, the causes should be found and eliminated so that they do not recur during subsequent operation.

→ Technical information TI038: boiler defects – failure analysis and cause analysis

The service life of electronic and electrical components is generally significantly less than the boiler shell. They must be replaced before the end of their service life, especially if they are safety-related components. One of the functions of the digital efficiency assistant MEC Optimize is to help the operator carry out this task and also preventive maintenance in general.

→ Products – Chapter 6.4: MEC Optimize, page 371

Defects could often be identified in advance and their causes eliminated. The prerequisite for this however is an open exchange of knowledge between operators, plant engineers and customer service.

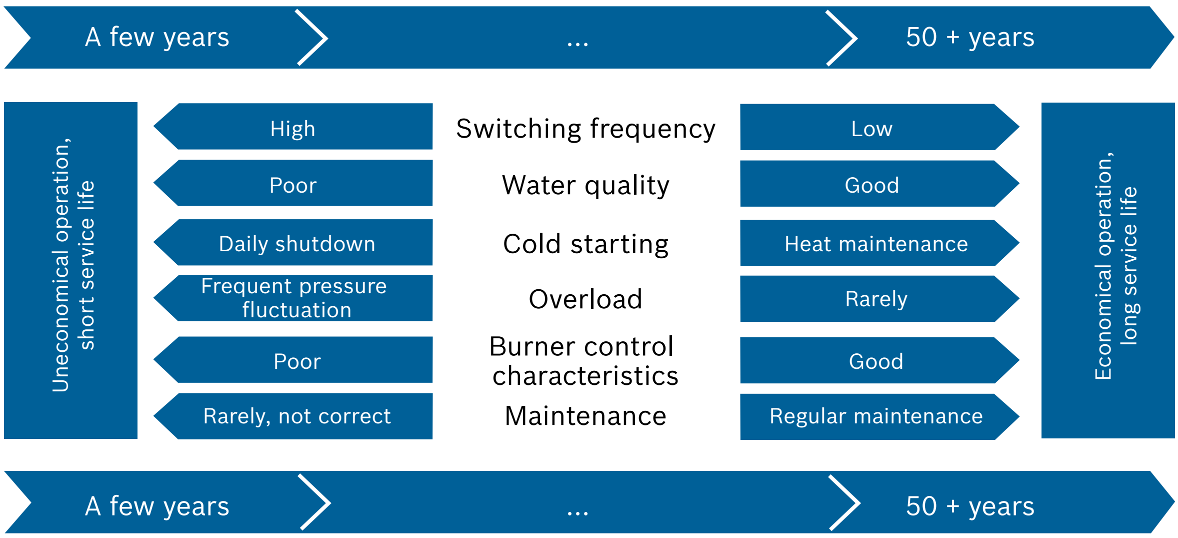

Fig. 22 *Influence of the mode of operation of the boiler on its service life*

3.1 Monitoring of the water quality

3.1.1 Water hardness/limescale

In addition to other harmful ingredients, freshwater also contains alkaline earths, often referred to as "hardness". We are also familiar with this from the deposits in the kettle or the coffee machine. A limescale layer of only 1mm can significantly reduce heat transfer on the water side. This can lead to significant damage, particularly to components that are subject to high thermal stresses such as the flame tube or the tube plate of the internal reversing chamber.

In this case, the existing softening system has been consistently overloaded by additional in-plant consumers. There was no hardness monitoring and the overloading was therefore not detected.

As a result, residual hardness also ended up in the boiler in which layers had formed on the water side. These layers reduced the heat transfer which in turn caused local overheating and cracks in the tube plate between the holes.

Did you know?

With a water hardness of 10° dH (medium hardness), up to 70g of limescale is transported per m^3 of water.

If this value is extrapolated for a boiler with a steam output of 10 t/h operating continuously for 10 days, the results is nearly 500kg of limescale in the boiler.

Damage: • Cracks in the ribs of the tube plate of the smoke tube due to overheating in this area

Cause: • Hardness invasion and deposits in water space

Remedy:
- Keeping of a boiler log book with regular entries on the water quality and check of adherence to water quality guideline
- Use of residual hardness monitoring

→ Technology – Chapter 4.5: Water quality monitoring, page 203

→ Technical information TI012: requirements for operation of high-pressure boiler systems without constant supervision

Fig. 23 *Water-side deposits on the tube panel and tube plate of the boiler*

Fig. 24 *Flue gas side with cracks in the ribs in the tube plate of the reversing chamber*

3.1.2 Ingress of foreign matter into condensate

From an energy and efficiency standpoint it makes sense to return condensate that accumulates during operation to the water/steam circuit. It can however become contaminated during the production process. In this example, the condensate has been contaminated with grease due to a leaking production heat exchanger. The grease was deposited in the boiler on the heating surfaces and also on the low-water indicator which caused the heating surfaces to overheat.

Damage:
- Irreparable damage to the boiler shell due to overheating
- Dents in flame tube and smoke tubes

Cause:
- Condensate not monitored to prevent the ingress of foreign substances

Remedy:
- Check whether it is possible for the condensate to become contaminated
- Provide condensate monitoring

→ Technology – Chapter 4.5: Water quality monitoring, page 203

→ Technical information TI012: requirements for operation of high-pressure boiler systems without constant supervision

Fig. 25 *Layer of grease and contamination in the boiler resulting in deformation of the flame tube and internal reversing chamber due to overheating*

3.1.3 Dosing of chemicals for water treatment

The dosing must generally fulfil two tasks. On the one hand, any components of residual oxygen or residual hardness must be bonded, and on the other the pH value in the feed water and in the boiler must be maintained within the allowable limits. The dosing pumps are frequently switched in parallel with the boiler feed pumps or make-up water control system which means that dosing is effectively quantity based. The dosing output is adapted to the values measured in the boiler water to ensure the concentration of dosing agent remains within the range of guide values. A setting within the range of 30 – 100% of the dosing pump output is advisable. If this is not sufficient, the concentration of dosing agent must be changed.

Both underdosing and overdosing can disrupt smooth boiler operation or can lead to serious damage.

Frequently recurring problems in the water quality are however not normally attributable to the dosing itself and instead can often be traced back to the upstream water treatment and monitoring. In these cases, normal fluctuations can no longer be compensated for by dosing.

Problem:
- Adherence to water limit values

Cause:
- Dosing settings
- Problems with the water treatment

Remedy:
- Regular water testing
- Checking of dosing settings
- Checking of water treatment
- Checking of condensate monitoring
- Automatic water testing

3.2 Cavitation at pumps

Cavitation refers to the formation and breakdown of steam bubbles in fluids. In this case, the evaporation is caused by a reduction in the static pressure, e.g. due to acceleration of the medium at the impeller inlet in the pump. The steam bubbles break down in the flow path as the increase in external pressure causes the bubbles to implode (microscopic steam hammer). This can cause significant damage and even complete destruction of the inner workings of the pump.

There are many possible causes of cavitation in pumps. Installation height too low, fluctuating pressures in the intake side or fluctuating medium temperatures. The feed pump has often not been correctly throttled, as is also the case with this specific issue. At the start of operation there is no or only very little prevailing back-pressure in the boiler. The pump therefore delivers a significantly higher quantity of water. This causes the acceleration at the inlet to the pump impeller to increase considerably and a significant drop in the static pressure occurs. If the feed water is already hot, cavitation can occur at this point. The pump was damaged beyond repair after only a few minutes.

Everybody can hear cavitation:

At the start of cavitation the sound is like rain on a metal roof and full cavitation sounds like hail on a metal roof.

Problem:
- Cavitation at pumps

Cause:
- Pumps not throttled

Remedy:
- Throttle pumps as specified in operating instructions
- Observe installation conditions

Fig. 26 *Pump damage due to cavitation*

1 Denting at pump impeller

2 Blown off pump impeller blades

3 Damage/destruction of further pump components due to pump impeller blades being blown off

3.3 Combustion setting

In addition to the water treatment, the settings of the combustion system are decisive for ensuring economic operation and a long service life of the boiler. These settings should therefore be regularly checked as part of routine maintenance. This should not only involve checking that the boiler is working correctly but also that actual operation corresponds to the planned operation.

3.3.1 Burner cycles

The problem of frequent burner cycling is encountered time and again. This can have many different causes, such as oversized design, reduction in demand, changes to operating conditions and also insufficient control settings.

The rule that generally applies for all systems is that burner cycling should be avoided whenever possible. During pre-ventilation, cold air is routed through the boiler. This leads to higher thermal stresses and therefore a reduced service life and greater heat losses. Cycling can often be significantly reduced simply by optimising the settings of the load control.

If the burner is far too big for the required steam output, it will need to be replaced.

→ Efficiency – Chapter 2.2.3: Output adjustment, page 272

→ Efficiency – Chapter 4.4.1: Maintenance, page 299

→ Technical report FB027: avoidable stresses at steam shell boilers

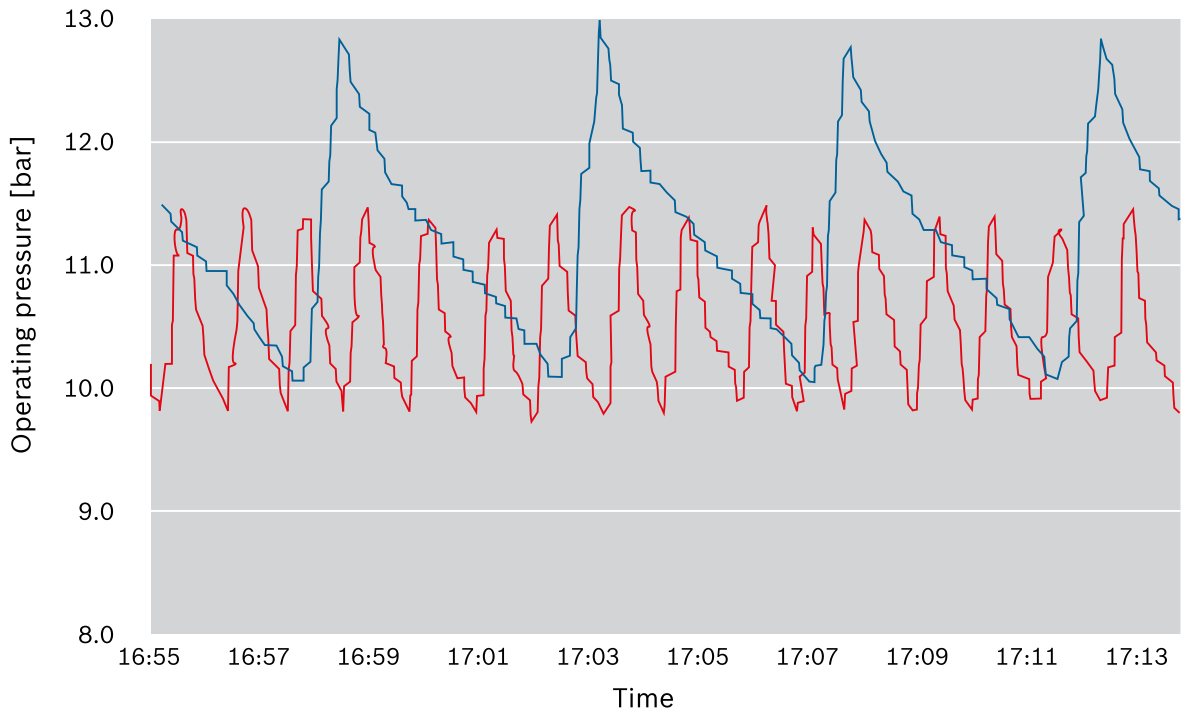

Fig. 27 *Reduction of burner cycling via optimised setting*

Burner cycling in minute range

Burner cycling following readjustment of the control range

Problem:
- Extremely frequent burner cycling leading to thermal stresses and therefore increased wear and heat losses during pre-ventilation

Cause:
- Load control settings
- Control range of burner too small

Remedy:
- Set a larger pressure control range
- Installation of light load controls
- Use of burners with high control range or matching of burner output to the actual requirements

3.3.2 Boiler overload

The design of shell boilers makes them relatively insensitive to load fluctuations of the consumers. A short-term increase in steam feed of up to 20% over the design capacity which can arise due to a pressure drop in the boiler usually does not pose a problem. If the load demand is higher, this can lead to significant problems in the system and boiler and to strong fluctuations of the water level in the boiler. Water carried from the boiler into the system can lead to extremely high steam moisture content that causes steam hammer.

Problem:
- Water carried along in the steam pipe and therefore very high steam moisture content and steam hammer in the pipework

Cause:
- Boiler overload

Remedy:
- Installation of output restriction with motorised valve on the steam feed

3.4 Contamination and residues in pipework

Often, contamination and residue in pipework, containers and valves leads to impaired operation and damage. This can happen at the commissioning stage for example, due to insufficient flushing of pipework, or may emerge later during operation due to ongoing contamination. Although, in this case, gradual contamination is still detected, the negative impact on costs that can occur is often overlooked.

3.4.1 Defective condensate drain

Condensate drains are installed in every steam boiler system. Depending on the overall size of the steam network, more than 100 drains may be installed. If only one of these is leaking, steam can overflow into the condensate system directly without using its enthalpy. This leads to economic loss. Additionally, in this scenario, downstream components can also be adversely affected as a result.

A defective condensate drain in the steam pipe drainage system led to continuous heating of the feed water vessel due to steam overflowing into the condensate system. This led to an increase in pressure in the feed water vessel until the safety valve started responding cyclically and then itself became defective.

Damage: • Defective safety valve and uneconomical operation
Cause: • Defective condensate drain
Remedy: • Regular inspection of condensate drain

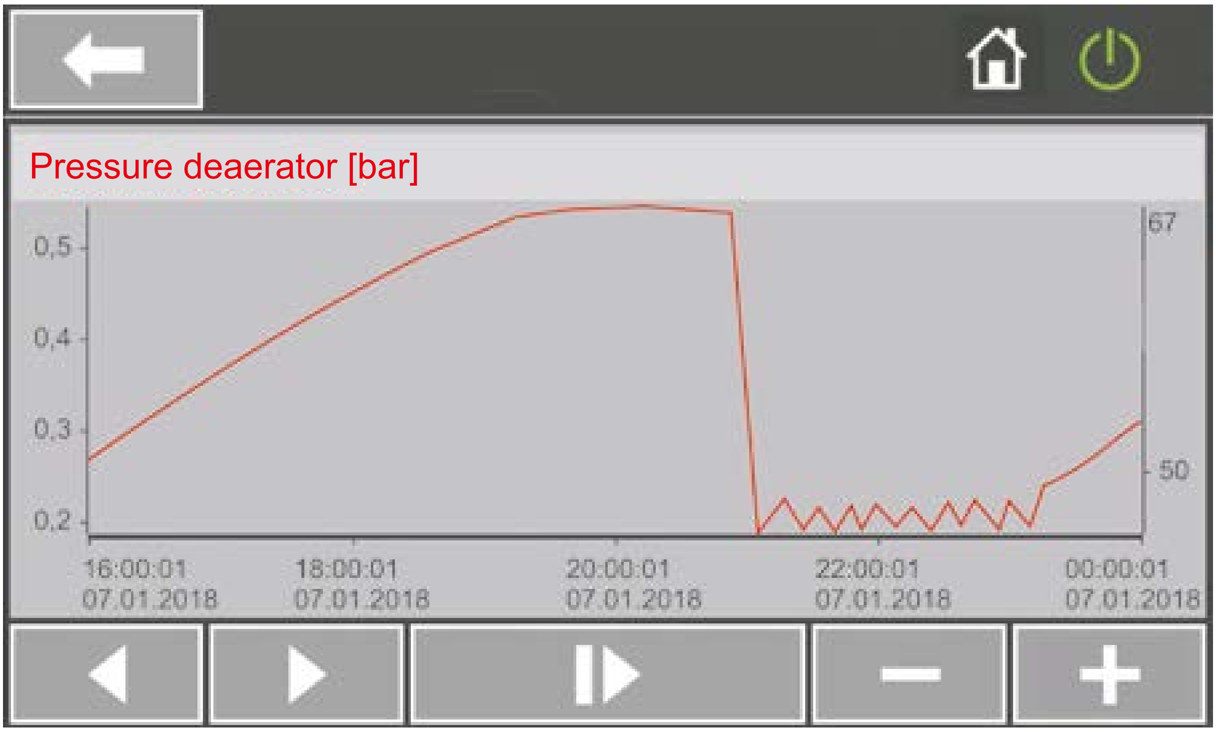

Fig. 28 *Continuous increase in feed water vessel pressure due to defective condensate drain*

Example calculation:

$$\text{Steam losses [D]} = A \cdot K$$

A	Number of defective condensate drains	10
B	Annual operating hours	8,000h/a
D	Steam losses	
E	Cost of generating one ton of steam	30 Euro/t
K	Loss per condensate drain	2kg/h

$$\text{Resulting costs [€/a]} = \frac{B \cdot D \cdot E}{1{,}000}$$

F16. *Calculation of costs resulting from defective condensate drains*

Number of defective condensate drains	10		
Loss per condensate drain [kg/h]	2	Steam losses [kg/h]	20
Operating hours (h/a)	8,000		
Steam generation costs (€/1,000kg)	30	Resulting costs (€/a)	4,800

B7. *Example calculation for determining the costs resulting from defective condensate drains*

3.4.2 Contamination in the economiser

Deposits can occur in the flue gas path due to soot produced during combustion and also inferior fuel quality. In this case, it is the cold end, i.e. the economiser, that is most heavily affected. The ribs of the economiser become clogged with deposits. On the one hand, the flue gases can no longer be cooled as effectively and the degree of utilisation falls, and on the other, the flue gas back pressure also increases which leads to a shortage of air during combustion and eventually the risk of hard ignition.

Problem:
- Contamination in the economiser

Cause:
- Poor combustion setting

Remedy:
- Regular maintenance and checking of combustion settings
- Cleaning of flue gas path
- Correct design

Fig. 29 *Deposits on the ribs of the economiser*

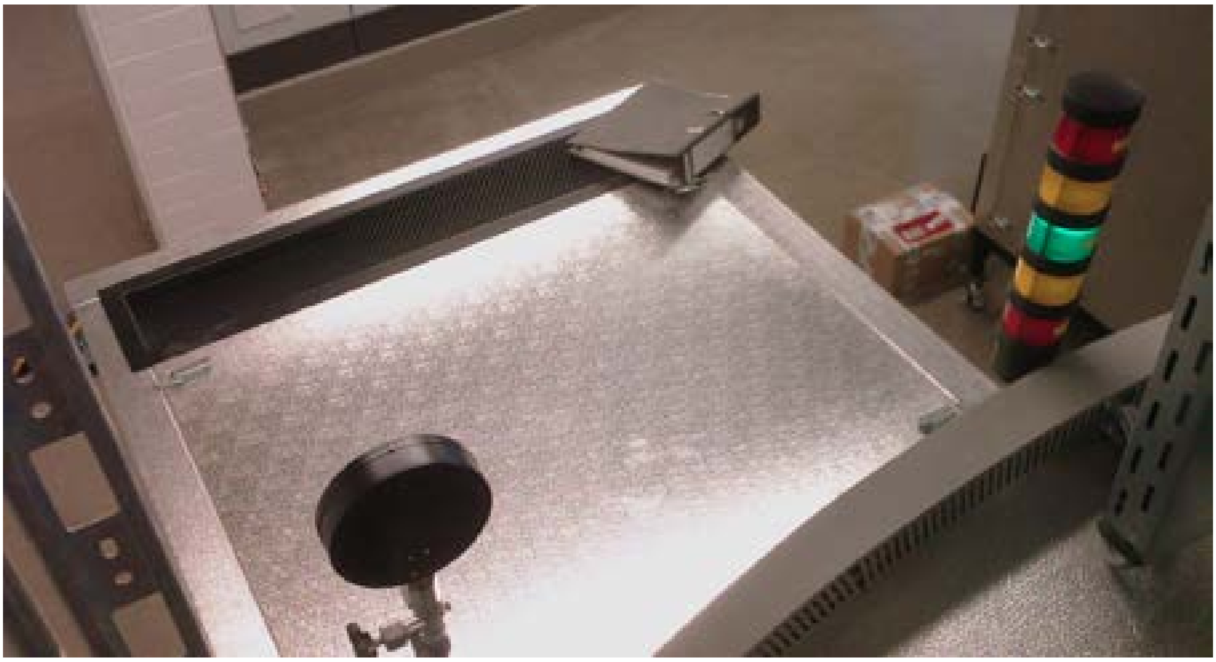

Fig. 30 *Danger of air shortage due to blocked supply air apertures*

3.4.3 Contamination of gas filter

During assembly, soiling in the pipework always occurs. This can however be reduced to a minimum by ensuring appropriate quality during manufacturing. Remnants are then removed by flushing the pipework. In this case, the soiling in the gas line was so excessive that even at the commissioning stage it caused a significant pressure drop in the gas filter and problems with commissioning the combustion system.

Problem:
- Soiling in the gas filter during commissioning

Cause:
- Poor welding quality of the gas line
- No flushing of gas line prior to commissioning

Remedy:
- Flushing of pipework prior to commissioning

Fig. 31 *Welding seam beads and film rust in the gas filter*

3.4.4 Calcification in the blowdown, expansion, and cooling module (BEM)

All waste water is collected and cooled down to the permissible temperature level in the BEM before being introduced into the public sewage system. If the temperature level for cooling is set too low, cooling is carried out continuously using fresh water, which leads to financial losses. In this case, the hardness of the fresh water used for cooling was also extremely high in the range of 20° dH. This led to heavy limescale in the BEM which eventually completely clogged up the overflow.

Damage:
- Fully calcified blowdown, expansion, and cooling module
- Replacement required

Cause:
- Temperature control set incorrectly and excessively hard cooling water

Remedy:
- Comply with maximum hardness of 10° dH for cooling (some softened water can be used if required)

Fig. 32 *Overflow at BEM removed; complete calcification at BEM*

3.5 Bypassing of safety equipment

Safety equipment is prescribed for good reason. Their purpose is to prevent catastrophic failure with potential disastrous consequences for persons, machine and environment in the event of faults during routine operation. This safety equipment has, whenever possible, already been tested at the factory. The final wiring, assembly and function check is however only carried out during commissioning. Commissioning is often carried out under a great deal of time pressure. However, it is imperative this does not lead to the omission of basic safety equipment or, as shown in this example, bypassing of this equipment.

Damage:
- Irreparable damage to the boiler shell due to overheating
- Dents in flame tube and smoke tubes

Cause:
- Low water indicator bypassed

Remedy:
- Commissioning of boiler exclusively by qualified specialists
- Never disable safety equipment or render it ineffective

Fig. 33 *Deformation due to overheating as a result of water shortage*

3.6 Hazardous work

The installation of all necessary systems, valves and measuring devices required for system management should be as straightforward as possible. However a compromise between ensuring optimum operation and maintenance and the constraints of space limitations is often inevitable. Normally all that is required to identify potential hazards is some common sense. However, the risk assessment which is a requirement for operation also provides notes on safe operation. The operator can request the plant engineer to do this, especially prior to acceptance of the system, to ensure smooth operation of the system.

Problem:
- Water sampling in dangerous location without cooling device and above electrical switchgear

Cause:
- Insufficient understanding of operation of a steam boiler system

Remedy:
- Route sampling line downwards
- Installation of a water sample cooler

Fig. 34 *Water sampling without suitable cooler and with unsuitable container*

Technology

1 Steam

Heating of products is indispensable for many industrial processes and applications. A temperature level of between 100°C and 250°C is frequently required for this. Saturated steam or slightly superheated steam is an optimum heat transfer medium which offers many benefits:

- High energy density
- Outstanding heat transfer during condensation
- Suitable for direct and indirect heating
- Good controllability
- Water/steam is not poisonous and available everywhere
- Pumps are not required for the transportation of steam

1.1 Steam types

A differentiation is made between the following steam types:

Steam type	Special feature	Application	Residual moisture content
Wet steam	Can cause erosion in steam pipes	–	>3%
Saturated/ high-pressure steam	The most commonly used type of steam	Process heat <~230°C	theoretical 0% technical standard up to 3%
Superheated steam	Reduced heat losses in the steam pipes	Steam turbines	0% (steam temperature > saturation temperature)
Low-pressure steam	Is not subject to the Pressure Equipment Directive: More favourable installation and operating conditions are the result	Process heat up to 0.5 bar, laundrettes	0 – 3%
Culinary steam	Use of non-steam volatile dosing agents	Food industry	0 – 5%
Pure steam	Generation via stainless steel pure steam generator supported by saturated steam	Pharmaceutical industry, hospitals	0 – 3%
Expansion steam	Produced by reducing pressure of pressurised boiling water	Steam accumulator (desired) Following bottom/ surface blowdown (obligatory)	0 – 5% (in the steam accumulator)

Tab. 8 *Differences between the individual steam types*

1.1.1 Saturated steam or dry saturated steam

Steam which is at the border between the two steam types wet and superheated steam, is called either "dry saturated steam" or "dry steam". It is called dry steam to distinguish its difference to wet steam. The values stated in steam tables refer to this specific state.

→Tools – Chapter 4.2: Water vapour table, page 398

The physical characteristics of saturated steam are almost always used when designing heat exchangers in practise, or when calculating the steam demand of thermal processes.

However, in reality saturated steam only occurs precisely at the phase boundary. Even if it is only very slightly cooled at the same pressure it turns into wet steam or, if very slightly heated, it turns into superheated steam. If, however, the steam states are close to the phase boundary, the physical characteristics of saturated steam can be used for calculation purposes when designing a steam system.

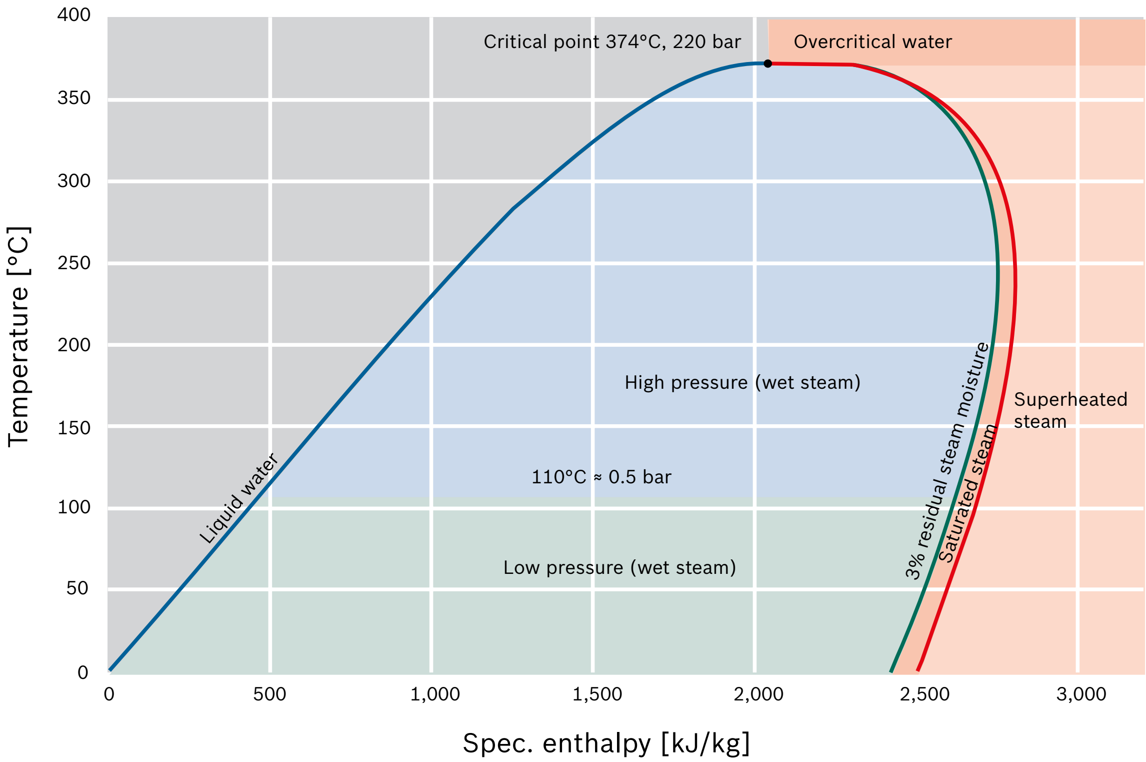

Fig. 35 *Diagram showing states of water or steam in temperature-enthalpy graph (T-h diagram) with the technical designations of the surfaces*

1.1.2 Wet steam

Wet steam is a mixture of the liquid and gaseous phase of water. Steam with a very low mass fraction of water up to approx. 3% is also referred to in technical circles as saturated steam. This is the most common steam state which is used in industrial systems to heat products.

When steam flows out of the steam boiler, it carries along tiny droplets of water which means the steam has a residual moisture content, i.e. a liquid fraction (1 – 3% of the total mass). This residual moisture content can be reduced to roughly 0.5% of the steam quantity when exiting the boiler, by installing steam dryers for example.

When the residual moisture content is ≤3%, this is still referred to in technical circles as saturated steam rather than wet steam.

The residual moisture content is the mass fraction of water with reference to the total mass of the water/steam mixture. In addition to residual moisture content, the expression steam fraction x is also used to refer to the proportion of steam in the water/steam mixture.

This is expressed in the following formula:
steam fraction = 100% – residual moisture content

Example at the limit of the technical saturated steam:
100% – 3% residual moisture content = 97% steam fraction

→ Fig. 35, page 104

Due to the heat losses to the environment that occur in all steam pipes, some of the steam condenses once again which means that in this case too damp steam with a small water fraction always exists in the pipework. This water fraction must be removed from the steam at suitable intervals by control valves and vertical sections of pipework (e.g. with condensate drains).

Wet steam with a very low steam mass fraction occurs for example during re-evaporation downstream of float-type condensate drains. In this case it is particularly important to note that the volume increases significantly during re-evaporation. This must be taken into account when sizing the condensate pipes.

→ Technology – Chapter 5.4: Condensate pipes, page 222

1.1.3 Superheated steam

If saturated steam is heated further, the temperature of the steam increases with the same pressure. This is then referred to as hot steam or superheated steam. Superheated steam can be generated in shell boilers using the additional superheater module. Temperatures ≤100K above the saturated steam temperature can be achieved in this case.

Superheated steam is used to drive gas turbines or distribute steam over very large distances as condensation still does not occur despite the heat loss.

However it should be noted that the heat transfer from superheated steam until the onset of condensation is lower. This is why superheated steam is a little less suitable for heating in heat exchangers than saturated steam.

1.1.4 High-pressure or low-pressure steam

Steam with a pressure of p ≤0.5 bar (1.5 bara, 110°C) is referred to as low-pressure steam. Steam with a pressure of p >0.5 bar is referred to as high-pressure steam. This differentiation exists exclusively due to the regulations for installation and operation of steam boiler systems as specific operating, installation and monitoring conditions apply for high-pressure steam. As the density of low-pressure steam is very low and pipework, valves and apparatuses must be very generously sized to allow for this, it is normally only used for small steam outputs (up to roughly 3 t/h) and short distances.

→ Technology – Chapter 5.5: Safety valve blow-off pipe, page 224

1.1.5 Culinary steam

Culinary steam is technical saturated steam with the additional requirement that no steam-volatile dosing agents are used for alkalisation and binding of residual oxygen.

It is used, as the name implies, for the processing of food for people and animals. This steam can come into direct contact with the food (e.g. when peeling potatoes).

1.1.6 Pure steam

Pure steam, also referred to as ultra-pure steam, is generated in special stainless steel evaporators which are heated using normal saturated steam.

This is used in situations in particular where stringent requirements exist in relation to the sterility of the steam (e.g. in hospitals for sterilisation of surgical instruments or in the pharmaceutical industry).

1.1.7 Expansion steam

Expansion steam occurs at many points in a steam boiler system and therefore, must be taken into consideration.

This occurs at the blowdown expansion vessel or condensate tanks, among other places, where the expansion steam causes heat losses. Expansion steam losses can be reduced by taking appropriate heat recovery measures.

The re-evaporation of boiling water is consciously utilised in steam accumulators to provide very large quantities of steam.

→ Efficiency – Chapter 3.1: Surface blowdown and bottom blowdown, page 277

→ Technology – Chapter 4.3.4: Steam storage, page 194

Expansion steam/re-evaporation:

If the pressure of hot water in the liquid state is reduced to below the boiling pressure, some of the water evaporates and separates in the liquid and vaporous phase. During this process, the temperature of water and steam reduces to the boiling temperature of the applied pressure.

This physical effect is often referred to as re-evaporation.

Example:

Water at a temperature of T = 195°C is expanded to a pressure of p = 4 bar. The enthalpy (energy) of the system remains the same during expansion. At the same time the mass of the system also remains constant, which means that an energy balance in the form of an enthalpy balance can be established.

Energy in the system **prior** to expansion = energy in the system **after** expansion

$$h = (1 - x) \cdot h' + x \cdot h''$$

F17. *Equation for the energy balance during expansion*

$$x = \frac{h - h'}{h'' - h'} = \frac{h - h'}{r}$$

F18. *Equation for calculating the mass fraction of expansion steam*

x	Mass fraction of expansion steam [%]
h	Enthalpy [kJ/kg]
h'	Enthalpy of the boiling water [kJ/kg]
h''	Enthalpy of the saturated steam [kJ/kg]
r	Evaporation enthalpy [kJ/kg]

$$x = \frac{919\ [\text{kJ/kg}] - 782\ [\text{kJ/kg}]}{2{,}780\ [\text{kJ/kg}] - 782\ [\text{kJ/kg}]} = 6.9\%$$

B8. *Example calculation for determining the mass fraction of expansion steam*

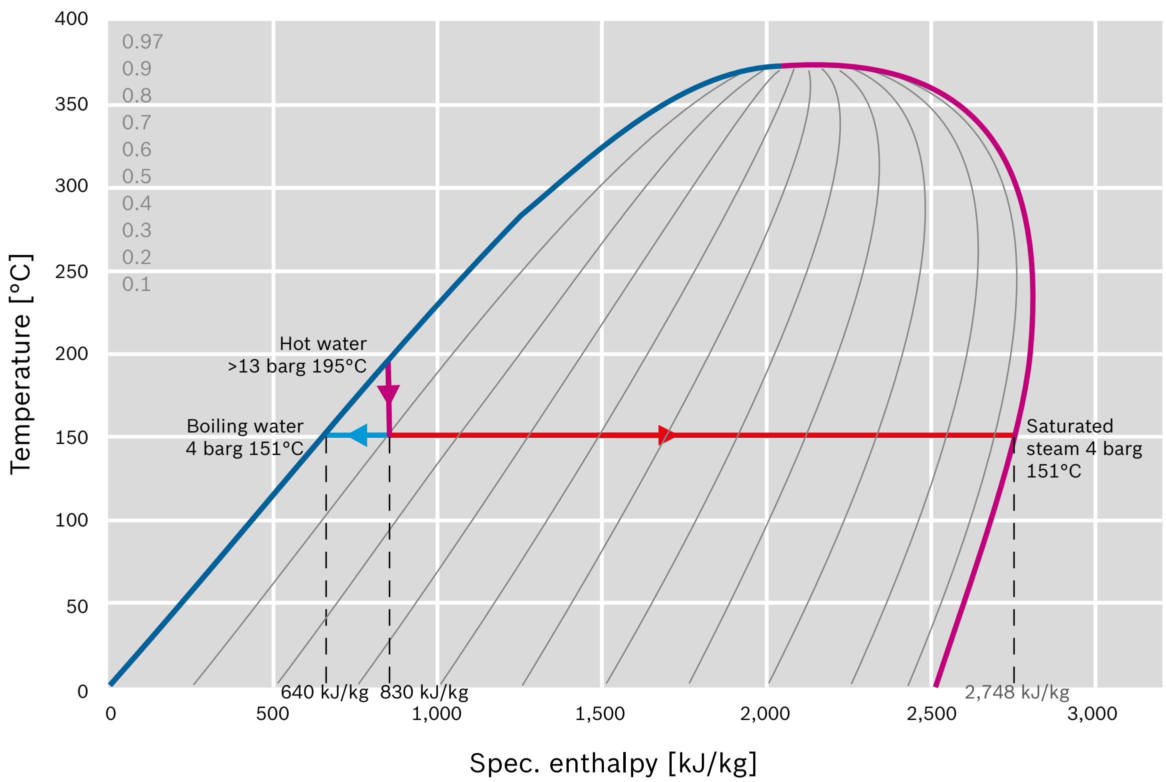

Fig. 36 *Re-evaporation shown in temperature-enthalpy graph (T-h diagram)*

1.2 Pressure and temperature

With saturated steam boilers, a physical correlation exists between temperature and pressure. This is represented graphically using what is referred to as a boiling curve.

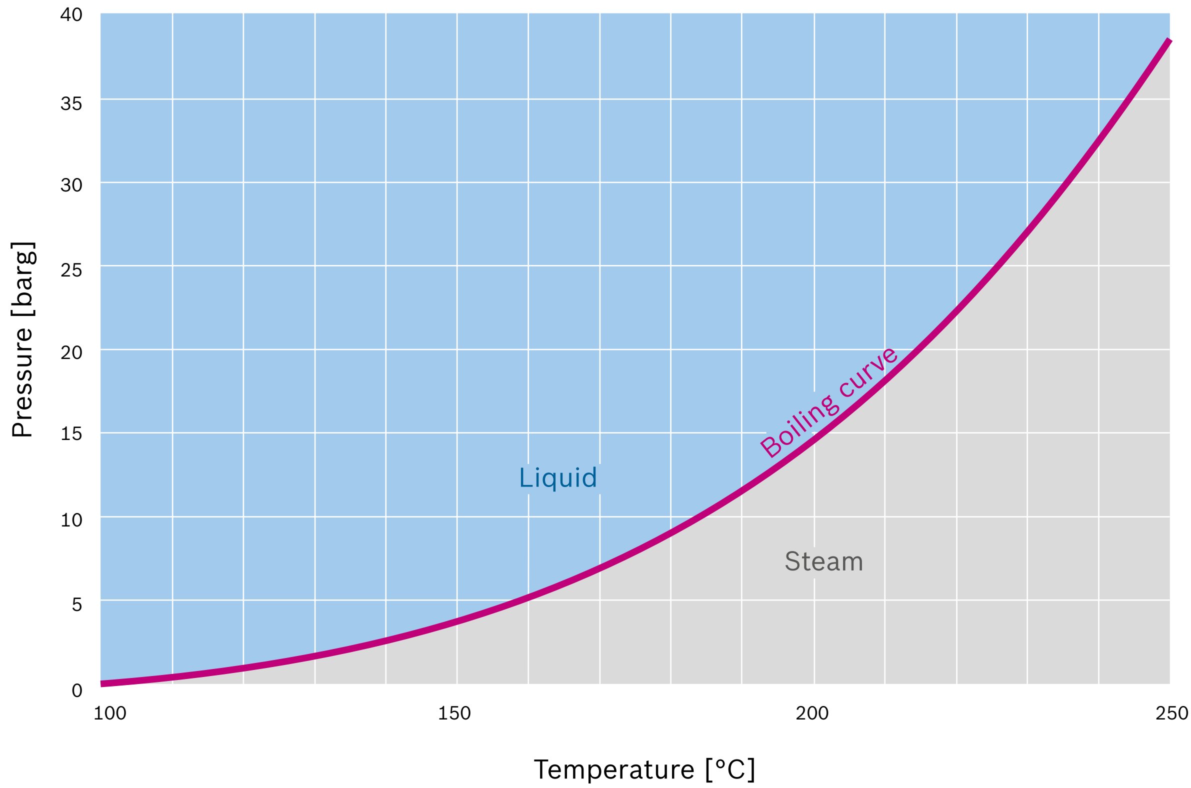

Fig. 37 *Boiling curve of pure water in pressure-temperature graph (range < 40 bar)*

This means that the temperature in a saturated steam system can always be established by measuring the pressure. This correlation is very important for the heating as the temperature remains constant until the steam has fully condensed (e.g. in a heat exchanger). Only when no steam at all is present, the water, which is then exclusively present, is cooled down. This correlation is also used to control steam systems. As the pressure can be measured very quickly and accurately, this means the temperature can also be precisely determined.

1.3 Enthalpy

The specific enthalpy h [kJ/kg] is the total quantity of heat contained in the steam.

The enthalpy is split into the sensible part which produces a change in temperature and the latent ("hidden") part in which the proportion of steam varies between 0 – 100% at a constant temperature.

During heating, the water heats up until the boiling curve is reached. Once the boiling curve is reached, the vaporous proportion increases as further energy is supplied until the water has fully evaporated.

The specific evaporation enthalpy r of water in [kJ/kg] is the quantity of heat that must be absorbed by 1kg of water in order for it to change from the liquid to the vaporous state. As heat is supplied in the boiler at a constant pressure and the temperature therefore does not increase, this quantity of heat is also referred to as latent or "hidden" heat.

Conversely, the same process occurs when heat is transferred. The steam condenses when the latent heat is transferred to the product until only liquid (water) is left. Only at this point is the condensate cooled. This cooling process which occurs in the condensate is often described as supercooling to below the temperature that corresponds to the steam pressure on the boiling curve.

Sensible heat
Adding or removing heat leads to a change in temperature, e.g. heating of water or superheating of steam.

Latent heat
Adding or removing heat has no effect on the temperature. The heat is hidden in the phase transition, e.g. from water to steam.

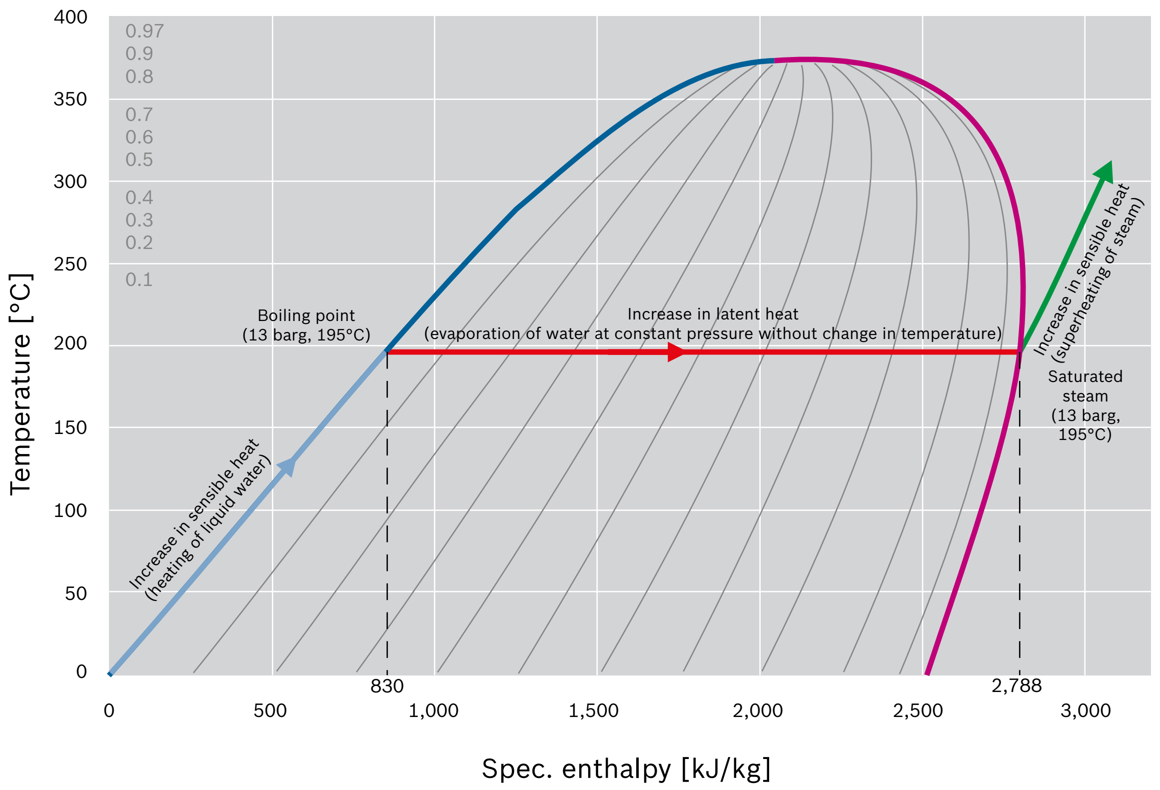

Fig. 38 *Concept of sensible and latent heat in temperature-enthalpy graph (T-h diagram)*

1.4 Advantages and disadvantages of steam systems

1.4.1 Advantages and disadvantages of steam systems compared to hot water systems

Benefits

- Smaller mass flow rate for same quantity of heat transferred (by factor 10 – 50)
- No circulating pumps required
- Smaller pipe cross-sections
- Possibility of very fast uniform heating-up at heat consumers
- Fast and precise temperature control possible by adjusting steam pressure
- Large amounts of energy can be released at a constant temperature
- Very high heat transfer coefficient during condensation. This leads to smaller heat exchanger surfaces and reduced system costs for generation of process heat
- Suitable for heating up products directly (e.g. food, autoclaves)
- System can easily be extended in a modular fashion
- Uncritical response in the event of leaks at gaskets or valves

Disadvantages

- Qualified personnel required for operation[1)]
- Continuous water treatment required

1) Requirements for heating systems ≤110°C are less exacting

1.4.2 Advantages and disadvantages of steam systems compared to thermal oil systems

Benefits

- Smaller mass flow rate for same quantity of heat transferred (by factor 20 – 80)
- No circulating pumps required
- Significantly better thermal transfer characteristics of steam
- The heat transfer oils of thermal oil systems are harmful to the environment and therefore:
  - Use of safety heat exchangers is required
  - Spill troughs equipped with leak detection systems are required at all joints
  - Special shaft seals are required at pumps and valves
- Heat transfer oils are a fire hazard
- Lower operating costs for the process heat, especially because a high efficiency and degree of utilisation can be achieved

Disadvantages

- Not suitable for cooling
- Heating temperatures ≤230°C (saturated steam systems) or ≤300°C (superheated steam systems)


BOSCH

2 Boiler

Two types with different designs are available for steam generation:

Water tube boilers

In water tube boilers, the water flows through the pipes which are heated externally. This boiler type is predominantly used with very large steam outputs > 100 t/h and high steam pressures > 32 bar. Solids can also be burnt in water tube boilers as the combustion chamber can have any form by arranging the tube walls in the desired manner.

Shell boilers

With shell boilers, the flue gas or waste heat gases used for heating flow through the pipes and release their energy to the surrounding water space. The combustion takes place in a flame tube located in the water chamber. The flue gases are subsequently cooled in tube passes. This is why these are also referred to as flame-smoke tube boilers.

→ Technical report FB013: comparison of shell and water tube boilers

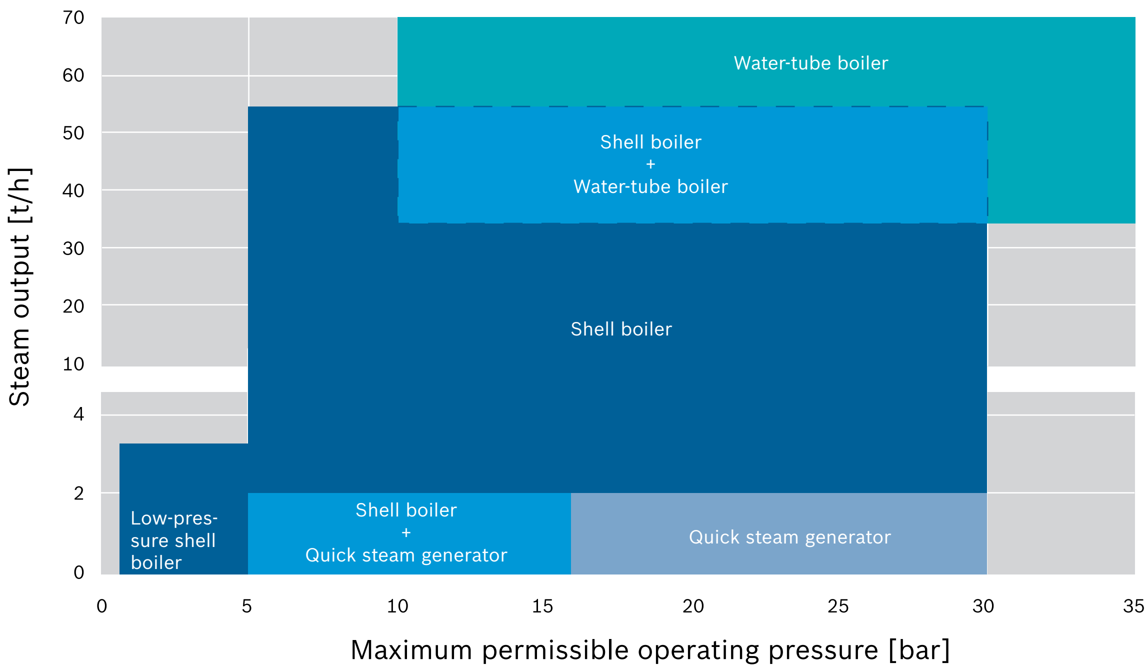

Fig. 39 *Standard areas of application of shell boiler, quick steam generator and water tube boiler types*

2.1 Types

Due to the following requirements for steam boilers, various types have emerged:

- Installation
- Operation
- Steam pressure and steam output
- Low-emission combustion systems
- High efficiencies

2.1.1 3-pass boiler

The 3-pass boiler consists of three horizontal flues built into a large cylindrical pressure vessel closed at each end by two level bases. All flues are located in the water space, which takes up roughly 75% of the area. The steam space is located above this. These boilers are also referred to as shell boilers and contain a large volume of water.

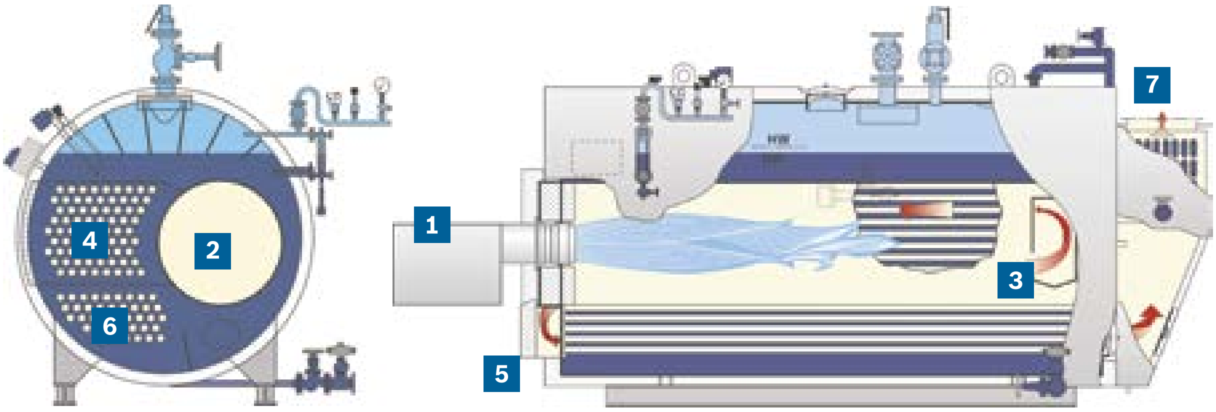

Fig. 40 *3-pass shell boiler*

1 Burner
2 Flame tube (pass 1)
3 Internal reversing chamber
4 Smoke tube pass (pass 2)
5 Front reversing chamber
6 Smoke tube pass (pass 3)
7 Flue gas connection for economiser

Combustion takes place in pass 1, the flame tube. Roughly half the heat is transferred here, primarily by means of thermal radiation to the flame tube walls. The combustion is complete at the end of the flame tube and the flue gases are diverted in the internal water-cooled reversing chamber into pass 2.

Roughly 35% of the thermal output is then transferred in the pipe panel of pass 2. The flue gases then enter the reversing chamber at the front on the outside at a temperature of ~400°C where they are redirected to pass 3.

After pass 3, the temperature of the gases is still normally 200 – 280°C, depending on the temperature of the medium in the water chamber of the boiler.

This heat potential can then be further utilised in an integrated economiser so that a temperature of 90 – 140°C is reached at the flue outlet.

This allows single flame-tube boilers to reach a steam output of up to 28,000kg/h.

Double flame-tube boilers can be used to achieve higher outputs. These boilers feature two flame tubes with separate second and third smoke-tube pass arranged in parallel in the water space. This allows boilers with steam outputs of up to 55,000kg/h to be built. The unrestricted single flame-tube operation also increases the reliability and control range of the boiler.

Fig. 41 *3-pass shell boiler with double flame-tube design*

2.1.2 Reverse flame boiler

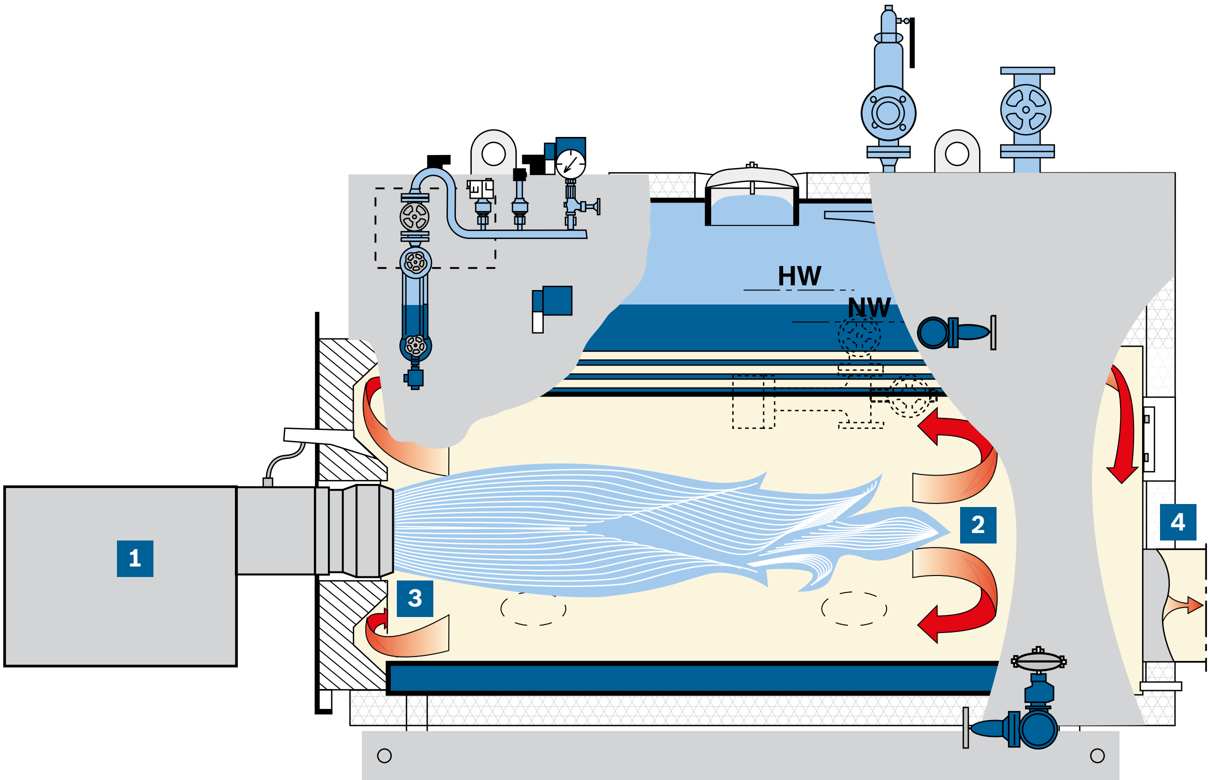

Fig. 42 *Reverse flame boiler*

1 Burner
2 Internal reversing chamber
3 Front reversing chamber
4 Flue gas connection for economiser

The reverse flame boiler was developed as steam boiler for small outputs of 175 – 3,200kg/h. In this boiler, the flame tube is arranged centrically and the flow direction is reversed at the end of the flame tube so that the flue gases inside the flame tube flow back towards the front. This is why it is called the reverse flame boiler. In the front reversing chamber, the flue gases are then diverted into the tube array around the flame tube. This type is characterised by a very compact design. Oil or gas can be used as the fuel.

Fig. 43 *Reverse flame boiler*

2.1.3 Boiler with waste heat utilisation

A 4-pass boiler or pure heat recovery boiler is a special type of boiler which utilises waste heat to generate steam. With the 4-pass boiler, part of the third smoke-tube pass is used as a separate pass for through-routing of hot flue gases and delivers up to 15% of the energy supplied. A pure heat recovery boiler has no burner. It obtains all of its energy from hot flue gases (e.g. from CHP modules or gas turbines).

→ Efficiency – Chapter 5.1: Combined heat and power, page 303

→ Products – Chapter 3: Heat recovery boilers and waste heat recovery, page 333

2.1.4 Quick steam generator

Due to its design, the quick steam generator belongs to the family of water tube boilers whose pressure system consists of one or several coils. Water flows through the coil(s) and is heated from the outside by the flue gases. Quick steam generators operate according to the once-through forced-flow principle which means the water evaporates completely in one cycle. Only a small amount of energy is stored in the water chamber. These boilers can therefore reach their full output within a few minutes after starting from cold, which is also why they are referred to as quick steam generators. They are heated by oil or gas-fired pressure-jet burners and the output regulation must always be adjusted to the quantity of water running through.

	Shell boilers	Quick steam generator
Water content	Large water content	Small water content
Heat-up duration	Longer	Cold start within several minutes
Response to load fluctuations	Damping of load fluctuations of consumers High short-term overload possible when using steam accumulators	High-pressure fluctuations even with slight load variations at consumers
Steam moisture	Dry steam	Steam dryer required
Approval of installation and monitoring[1)]	Normally subject to mandatory approval and monitoring	The installation and monitoring conditions have been partially eased in the very small output range
Procurement costs	Slightly higher	Lower
Operating personnel[1)]	Qualified boiler attendant required[1)]	Trained operating personnel required[1)]
Maximum steam output	≤ 55,000kg/h per boiler	≤2,000kg/h per boiler
Efficiency	94 – 105% therefore ideal for continuous operation	<90% therefore only suitable for short-term provision of steam at short notice
Annual degree of utilisation	≤95%	Frequent <75%
Service costs	Lower	Higher
Service life	Robust, low wear, therefore durable	Low

Tab. 9 *Comparison of quick steam generators with shell boilers*

1) Refers to Germany

2.2 Equipment and control

The minimum requirements for operation and the safety equipment of steam boilers are set out in EN 12953-6. This includes the primary shut-off valves in the pipework, the safety equipment to safeguard against pressure exceedance and water shortage, heating equipment and all valves and measuring devices required for operation and control. All of this equipment requires an approval in accordance with the Pressure Equipment Directive.

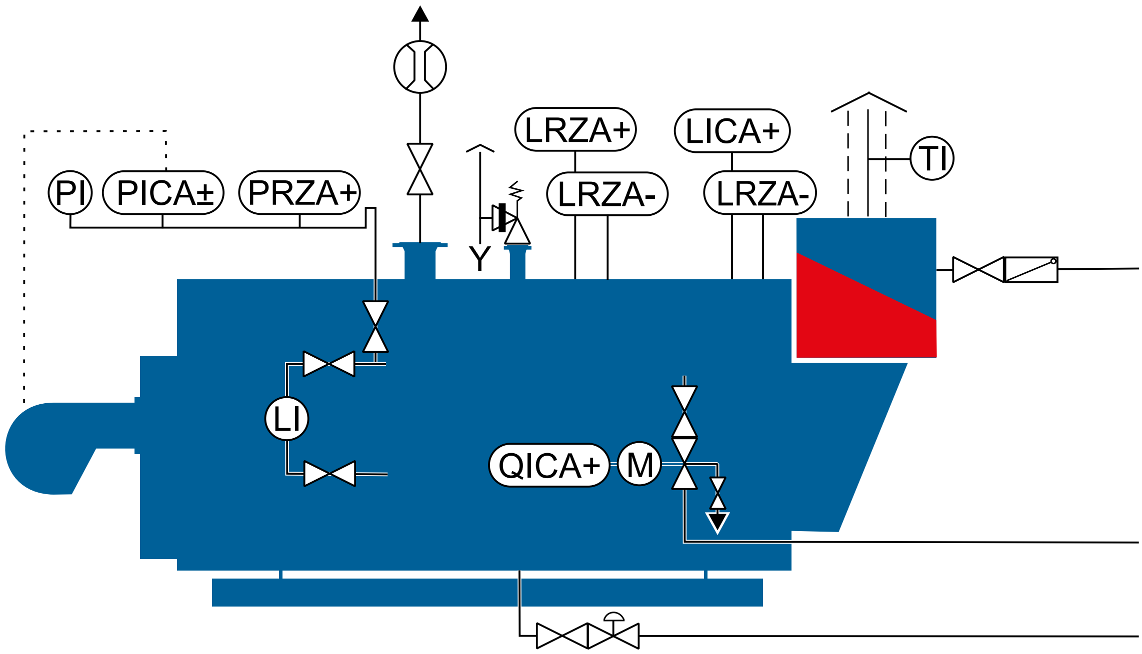

Fig. 44 *Equipment of a steam boiler*

The equipment of a steam boiler generally comprises the following components:

- Steam extraction shut-off valve with steam volume measurement
- Safety valve (overpressure protection)
- Feed water shut-off valve with non-return valve
- Pressure gauge manostat bar with shut-off valve, pressure limiter **(PRZA+)**, pressure transmitter **(PICA±)** and pressure gauge **(PI)**
- Direct level indicating device with shut-off valves
- Level measuring device with protective tube 1 with low water level limiter 1 **(LRZA-)** and level transmitter **(LICA+)**
- Level measuring device with protective tube 2 with low water level limiter 2 **(LRZA-)** and high water level limiter **(LRZA+)**
- Conductivity measurement device **(QICA+)**
- Surface blowdown control valve with shut-off valve
- Water sampling fitting
- Bottom blowdown quick-release valve with shut-off valve
- Flue gas temperature indicator **(TI)**

Additional components, such as devices for measuring the quantity of fuel, steam, feed water and the flue gas temperature, may be required to optimise operation and for possible energy management.

2.2.1 Output control

The steam output of boilers is generally controlled via the existing pressure in the boiler. The boiler pressure in this case is used as substitute variable for the steam quantity. If the consumers require more steam, the pressure in the boiler falls and the output control increases the heat supply or combustion output of the burner. As a basic rule, it should be observed that the burner/boiler system is a slow-response system. All control units and mixing valves that are connected to this system are adjusted to these characteristics. Under no circumstances whatsoever should attempts be made to control the pressure at the consumers or initiate measures at the boiler as this could lead to control oscillations and unnecessary loads and faults at the boiler. With consistent power consumption, correctly adjusted control and stepless burner, the combustion output required at the burner for the current rate of steam extraction is established and the boiler pressure is kept constant within reasonable limits with a deviation of ± 10% from the specified set value.

→ Technical report FB001: output control of steam boilers

→ Planning – Chapter 2.1: Average operating pressure, page 27

The prevailing pressure in the boiler can be read off directly at the pressure gauge **(PI)**. The pressure transmitter **(PICA+)** measures the boiler pressure and converts it to a standard electrical signal (4 – 20mA). This signal is processed in the boiler control and evaluated according to the control mode. The burner is activated via adjustable switching points and set values. In this case the correct fuel-air ratio is set by the burner control.

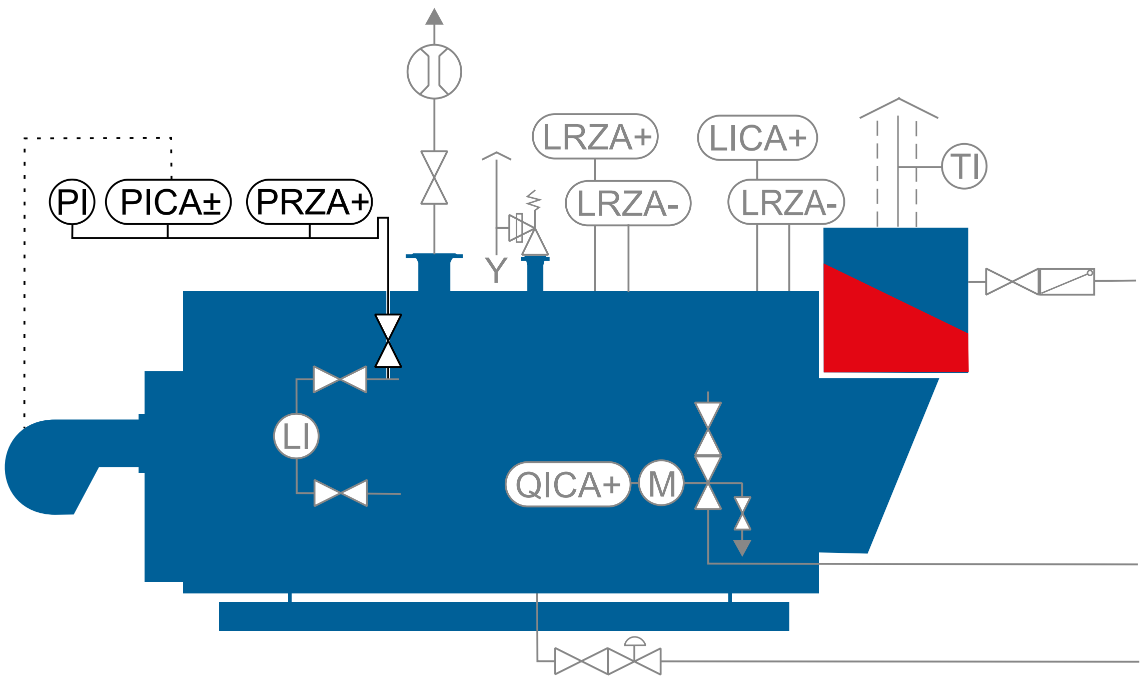

Fig. 45 *Pressure-controlled output control of a steam boiler*

PI Pressure gauge

PICA± Pressure transmitter

PRZA+ Pressure limiter

2.2.2 Level control

The level control in the boiler has the task of maintaining a constant water level as far as possible. Depending on the design, the water normally fluctuates between the maximum limits of 80 – 120mm. The water level in the lower range is limited visually by the low-water mark **(LW)** as the heating surfaces must always be underwater in order to be sufficiently cooled. The upper limit of the water level is defined by the high water mark **(HW)**. The steam space must not be too small, as otherwise water may be carried into the steam pipe which would adversely affect the steam quality. To avoid faults and damage to the boiler or downstream consumers, the setting options in the level regulator for the average water level have been restricted at the factory. The value can only be set within the permitted range.

The prevailing water level in the boiler is continuously measured with the level transmitter **(LICA+)** and converted to a standard electrical signal (4 – 20mA). This signal is processed by the boiler control BCO and controls the feed water control valve or feed pump, depending on which equipment is selected.

A shut-off valve and non-return valve are located at the inlet to the boiler or economiser to prevent water being pushed back into the feed line. A level indicator **(LI)** has been installed at the boiler at the height of the water level in order to display the water level directly.

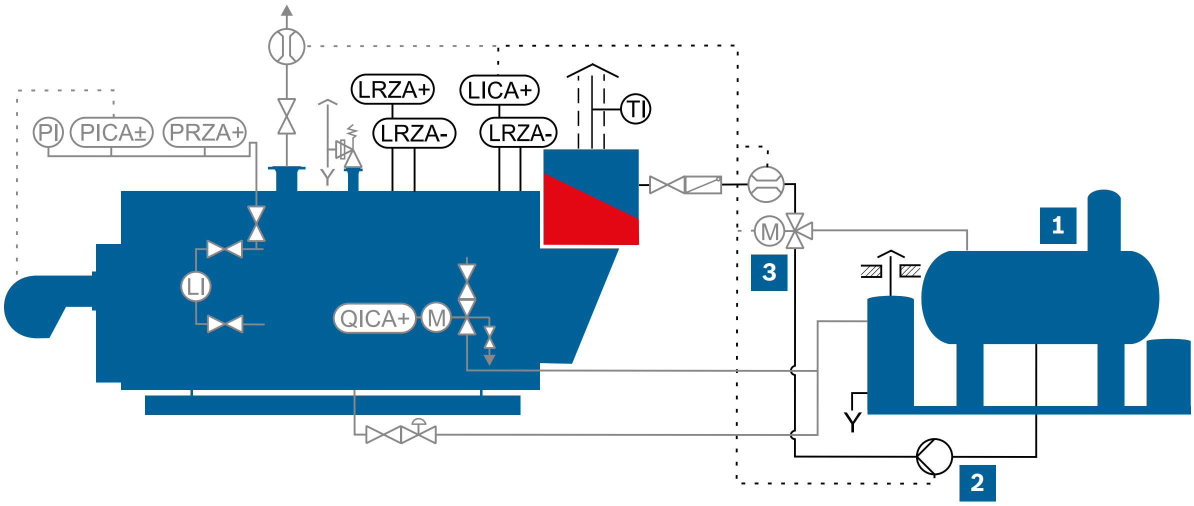

Fig. 46 *Level control of a steam boiler*

LICA+ Level transmitter
LRZA+ High water level limiter
LRZA- Low water level limiter
TI Flue gas temperature indicator

1 Feed water vessel
2 Feed water pump
3 Feed water control valve

In addition to level control, the water level is also limited via the safety chain.

→ Technology – Chapter 2.2.4: Safety, page 127

	Heat recovery with ECO	Requirement for control characteristics	Process characterised by rapid load changes	Investment costs
Continuous with control valve	+++++	+++++	++	Moderate
Busbar with control valve[1)]	+++++	+++++	++	Low
Continuous with IM[2)]	++++	+++	++	Low
3-component control with control valve	+++++	+++++	+++++	Very high
3-component control with IM at pump[2)]	++++	+++	+++++	High
ON/OFF	Not applicable		+	Very low

Tab. 10 *Advantages and possible uses of various types of level control*

1) Can only be used with multi-boiler systems

2) IM = inverter module

Modulating control with control valve

The continuous level control with control valve is still the most popular variant as it provides the benefits of fast, reliable and straightforward control.

→ Products – Chapter 4.10: Feed water regulation module RM, page 351

Busbar switching with control valve

When busbar switching is used, several steam boilers are fed by one feed pump. In this case the water level of each boiler is controlled independently via an inlet control valve.

Modulating control with inverter module

Controlling the level via the speed control at the feed pump is the most economical variant for boiler outputs ≤ 10 t/h in terms of investment costs and operating costs.

Furthermore, it makes particular sense to use this type of level control if the boiler is run at different operating pressures (e.g. a pressure drop at the weekend) as then the benefits of the speed control with matching to the pump curve can be fully exploited.

When equipping the boiler with an economiser for heat recovery, it must be ensured that the partial load range of the burner can also be covered by the smallest frequency control range of the feed pump as otherwise there is no flow through the economiser in low-load operation which means that heat recovery cannot take place.

3-component control

When the load increases rapidly, a problem occurs as the water level initially appears to increase due to foaming of the boiler water and, although an increase in the quantity of feed water is required, this does not occur.

By continuously comparing the current measurements for steam and feed water quantities, the 3-component control can respond much more effectively to status changes.

On/Off control

On/Off pump activation is only used in a few exceptional cases and with low steam outputs up to ~ 1 t/h.

As, compared to the other control variants, the benefit in terms of investment costs is relatively low and as significantly less heat is recovered in the economiser because the pumps are frequently switched off, a continuous control often pays for itself after less than two months.

2.2.3 Water quality

Depending on the various physical and chemical water treatment methods, the chemical dosing for binding residual hardness and residual oxygen and the necessary alkalisation (increasing pH value in the feed water vessel), the feed water contains dissolved salts and other ingredients.

→ Technology – Chapter 4.1: Water treatment, page 177

Due to the continuous evaporation process when the boiler is in operation, the residual ingredients of the feed water in the boiler water increase. The accumulation of impurities in the boiler water is particularly measurable due to the increase in conductivity of the boiler water.

To avoid the negative consequences of an excessively high boiler water salt content described below, specified limits must not be exceeded.

- Foaming of boiler water
- Water entrainment in the steam pipe
- Water level fluctuations
- Deposits in the boiler
- Corrosion in the boiler and pipework

→ Technical report FB026: modern water treatment and water analysis

A certain amount of water is therefore removed from the boiler as a result of continuous surface blowdown and bottom blowdown.

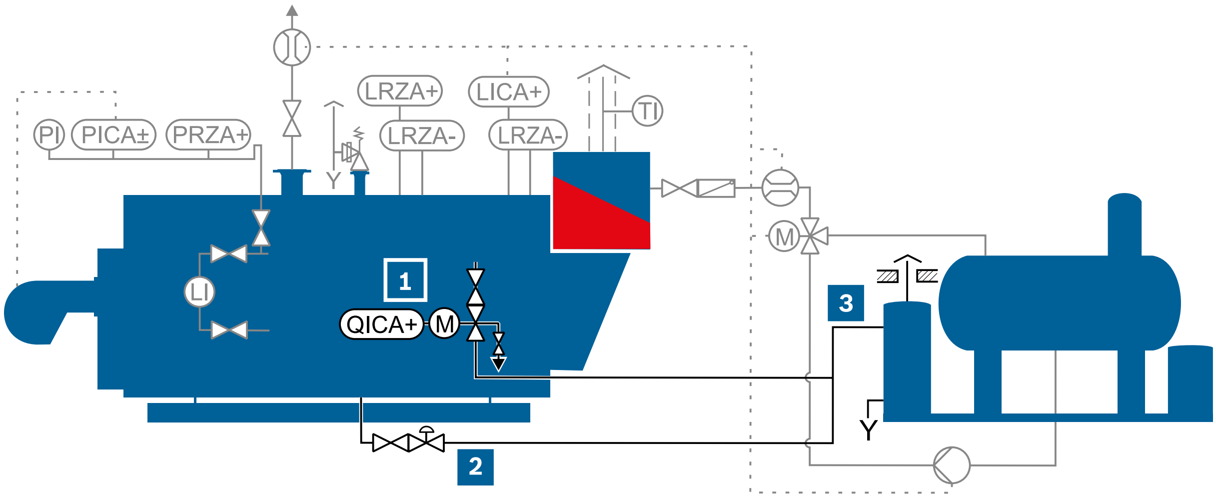

Fig. 47 *Control of the boiler water quality by means of discharge to the blowdown expansion vessel*

QICA+ Conductivity transmitter

1 Surface blowdown valve
2 Bottom blowdown valve
3 Blowdown expansion vessel

Conductivity control

The conductivity of the boiler water is measured with the conductivity transmitter **(QICA+)** and converted to a standard electrical signal (4 – 20mA). This signal is processed in the boiler control BCO, the measured conductivity displayed in the control cabinet and the actuating signal to open the motorised surface blowdown valve is generated. To allow a visual inspection to be carried out, a sight glass with non-return valve is often installed in the pipework downstream of the surface blowdown valve.

As the boiler water quality is an important factor influencing correct and smooth operation, this must be regularly checked and documented in the boiler log.

Heat recovery measures can be taken to utilise the energy content of the boiling surface blowdown water.

→ Efficiency – Chapter 3.1: Surface blowdown and bottom blowdown, page 277

The conductivity measured in the boiler at operating temperature is slightly higher due to the electrolytic dissociation. The conductivity sensor performs a conversion internally using the reference temperature of 25°C. This pre-adjusted conductivity is displayed at the boiler control.

In addition to electrical conductivity, the silicic acid content (SiO_2) and acid capacity 8.2 value (p-value) are important factors influencing the boiler water quality. If the allowable limit of one of these variables is reached due to densification in the boiler water, this variable is definitive for the surface blowdown. However, as only the conductivity in the boiler water is measured, the conductivity reference value in the boiler water must be reduced until all limit variables can be adhered to.

→ Tools – Chapter 5.2: Surface blowdown and bottom blowdown, page 405

Bottom blowdown control

The bottom blowdown control removes the suspended matter in the boiler water that settles on the base of the boiler. To do this, the bottom blowdown quick-release valve is opened for a few seconds at regular intervals. The valve opens abruptly which produces a local negative pressure with a suction effect that removes deposits that have accumulated on the base of the boiler from the boiler (e.g. accumulations of salts, broken down dosing agent).

The opening times of the valve during this process should be very short and be within the range of a few seconds. If the bottom blowdown valve opening times are longer, this only increases the water and energy loss from the boiler without making the bottom blowdown more effective. The bottom blowdown can be carried out manually or automatically if the boiler is not attended continuously during operation.

A manual shut-off valve is installed upstream of the bottom blowdown quick-release valve. To support the suction effect and allow boiler water that has re-evaporated to be removed, the pipework leading to the blowdown expansion vessel directly downstream of the valve should be 2 nominal diameters bigger. To avoid steam hammer, the pipework leading to the blowdown expansion vessel should whenever possible be installed without changes in height or water pockets.

Most boilers are also drained via the bottom blowdown valve.

2.2.4 Safety

The safety of the system is primarily ensured by proper operation, perfect functionality and maintenance of the equipment and control units of steam boilers.

To ensure safety at all times, also when the normal control units fail, limiting devices are prescribed for all steam boilers. Together with the emergency stop buttons at the control cabinet and the escape doors, these are connected in series in the safety chain in the boiler control cabinet so that when one of these elements is tripped, boiler operation is deactivated.

If one of the limiting devices is triggered, the combustion system and therefore the boiler heating is switched off and locked. In waste heat boilers, this is done by changing the flue gas dampers over to bypass or by switching off the heat-generating unit. This interlock can only be enabled once again manually on-site at the boiler. This ensures that following exceptional operating conditions the boiler attendant has identified and eliminated the cause of the fault before the boiler is brought back into operation.

Safety pressure limiter

The safety pressure limiter **(PRZA+)** cuts in at 95% of the maximum permissible operating pressure and switches the heating of the boiler off.

Safety valve

The safety valve must reliably prevent the maximum permissible pressure in the boiler being exceeded if the safety pressure limiter fails.

In shell boilers, this is done using direct-acting spring-loaded full-stroke safety valves with open spring bonnet.

Once the safety valve has cut in, the pressure in the boiler must fall to roughly 10% below the maximum permissible pressure before the safety valve automatically closes due to the spring tension. The subsequent pipework must whenever possible be routed directly to the atmosphere.

→ Technology – Chapter 5.5: Safety valve blow-off pipe, page 224

Level indicator – low water

The heating surfaces of the boiler must be surrounded by water at all times to ensure sufficient cooling. If the water level in the boiler falls to the extent that the heating surfaces are no longer in contact with water, there is an acute danger of overheating and possible destruction of the boiler.

One must be sure to avoid emergence of the heating surfaces, two type-tested low water indicators operating independently of one another are installed in the boiler. In steam generators, the level indicator electrode is installed in a protective tube to avoid dangerous maloperation due to foaming of the boiler water.

→ Technical report FB005: history of development of water level indicators in steam and hot water boilers

Level indicator – high water

In boiler systems operated over a 72-hour period without attendance, an additional high water indicator is required so that when the highest allowable water level is exceeded in the boiler no water can be fed into the downstream steam pipes.

Conductivity limitation

The maximum permissible conductivity is also limited in boiler systems for a 72-hour period of operation without attendance to prevent uncontrolled foaming or accumulation of deposits in the boiler. When the limit is exceeded, the combustion system is also switched off in this case.

Further safety equipment

The combustion system can be shut down by other faults in addition to the limiting devices directly mounted on the steam boiler. The precise changes for the relevant fuel and the various equipment are described in the standard EN 12953 part 9.

→ Standard EN 12953-9 “Shell boilers – Part 9: requirements for limiting devices on boilers and accessories”

Emergency stop

Emergency stop pushbuttons are mounted in all escape routes and at the boiler control cabinet. When an emergency stop pushbutton is pressed, the boiler safety chain is triggered. An additional emergency stop pushbutton outside the boiler house is recommended.

Monitoring of the combustion system – flame monitoring

If a flame is not detected in the combustion chamber when the fuel feed is in operation, this leads to a fault shutdown of the boiler after a few seconds. This prevents unburnt fuel forming an ignitable mixture in the flue gas system which could cause a hard ignition during a subsequent burner start.

Monitoring of the combustion system – fuel feed

The tightness of the gas shut-off valve and the minimum and maximum pressure of the fuel feed are also monitored to ensure that an ignitable mixture cannot form in the boiler or in the flue gas path.

→ Fig. 59, page 142

Monitoring of the combustion system – air deficiency safety device

Operation and function of the combustion air fan are monitored by what is referred to as an air deficiency safety device. To do so, a minimum air pressure indicator **(PZA)** is installed between the fan and flame head.

Steam feed

The steam feed connector with shut-off valve is located at the boiler crown. The saturated steam is fed from here into the downstream steam network. To limit noise emission, the steam feed connector must be sized so the flow speed cannot exceed ≥ 40m/s. It must also be considered that the diameter of the connector is to be sized with reference to the minimum anticipated operating pressure, as the biggest specific steam volume exists at this pressure.

A baffle plate is located underneath the connector on the inside of the boiler to ensure that small droplets carried along in the flow remain in the boiler and that the steam exiting the boiler is as dry as possible. The residual moisture content can still be as much as 3%.

To improve the steam quality, a demister made of wire mesh can also be mounted here. This can reduce the residual moisture content to roughly 0.1%.

→ Technology – Chapter 4.3.1: Steam drying, page 192

2.2.5 Optional measuring equipment

Additional measuring devices, e.g. for flow-rate and temperature measurement, provide more in-depth information about operation of the boiler. These can be integrated into the control of the boiler in order to satisfy more exacting demands in relation to control quality. On the other hand, they are an important means of assessing the efficiency of the boiler operation. By acquiring, recording and evaluating this data, the operation of the boiler can also be optimised following commissioning (e.g. in the event of operational changes). Furthermore, this can therefore also satisfy the requirements arising from any existing in-house Energy Management System. The most common measurement methods are described below.

→ Controls and connectivity brochure

Steam volume measurement

With steam volume measurement, the steam flow delivered to the steam network is measured. In combination with a pressure or temperature measurement with saturated steam or a pressure and temperature measurement with superheated steam, the volume of steam can be converted into a steam flow and into the useful heat output delivered by the boiler.

Feed water flow measurement

During feed water flow measurement, the feed water supplied to the boiler is measured.

Fuel flow measurement

Fuel flow measurement is required for each individual boiler system in order to be able to set the maximum permissible combustion output during commissioning.

With liquid fuels, the measurement is always carried out with direct assignment to one boiler. The fuel flow rate is measured in [l/min] or [l/h].

With gaseous fuels, a measurement assigned directly to the boiler is urgently recommended. For cost reasons this is occasionally omitted and the measurement of the energy supplier in the gas transfer station is used. The measurement of the gas flow rate in [m_B^3/h] must subsequently be converted to [m_n^3/h] together with a pressure and temperature measurement for evaluation purposes.

Together with the information on the net calorific value [kWh/kg] or [kWh/l] for liquid and [kWh/m_n^3n] for gaseous fuels, a conversion to the quantity of energy supplied to the boiler can then be carried out and therefore used as starting basis for an efficiency calculation or to determine the annual degree of utilisation.

Flue gas temperature measurement

The flue gas temperature measurement is an important indicator of the current mode of operation of the boiler. Many optimisation options and uneconomical boiler operation or soiling of the heating surfaces can be immediately identified simply by using this straightforward low-cost measurement and by continuously recording and evaluating the flue gas temperature.


BOSCH

3 Components

3.1 Combustion and heating

The purpose of the combustion system is to turn the carbon, hydrogen and possibly sulphur in the fuel completely into CO_2, H_2O and SO_2. So that combustion is as clean as possible, the correct mixture ratio of fuel and combustion air must be present at the right time and place in the combustion chamber.

Pressurised combustion is almost exclusively used for this in shell boilers. This means that the combustion air fan must provide the positive pressure necessary to overcome the 5 – ≤50 mbar resistance caused by the boiler and, if installed, the downstream heat exchanger. A slight positive pressure therefore always exists in the combustion chamber.

→ Technical information TI030: requirements for an on-site burner system

3.1.1 Fuels

Natural gas and fuel oil are still the most commonly used fuels. Depending on the mode of operation of the steam boiler, the required output or emission level requirements, each of these standard fuels offer different benefits and are suitable for different applications.

→ Planning – Chapter 4.3: Criteria for selection between fuel oil and natural gas, page 56

The correct combination of fuel, combustion equipment and combustion chamber is particularly decisive for the cleanest possible combustion.

In addition to the standard fuels, different gaseous and liquid fuels can also be used in shell boilers. Depending on the fuel, this is easy to implement or may require a great deal of effort. Whatever the case, use of these fuels should be carefully considered in the project phase as, in addition to higher investment, stricter monitoring and maintenance during operation is sometimes required.

→ Planning – Chapter 4.4: Further fuels, page 57

Examples of liquid special fuels:

- Biodiesel
- Animal fat
- Rapeseed oil
- Soya oil
- Palm oil/grease

Examples of gaseous special fuels:

- Biogas
- Bio-natural gas
- Sewage gas
- Gas from biomass gasification
- Hydrogen enriched natural gases

Combustion of these fuels can take the form of individual auxiliary fuel combustion, e.g. when using a dual-fuel burner with natural gas and a liquid special fuel, or as proportioning combustion, e.g. natural gas with biogas.

3.1.2 Fan variants of combustion systems

Monoblock burner

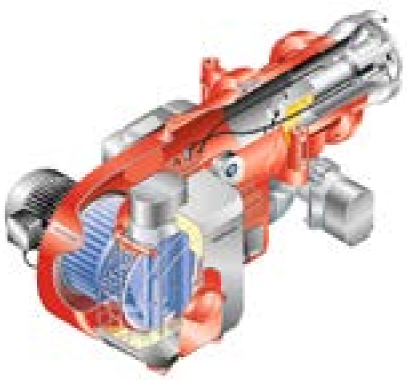

Fig. 48 *Sectional representation of monoblock burner (Weishaupt)*

Combustion systems in which the combustion air fan is directly integrated into the casing of the burner are referred to as monoblock or pressure-jet burners. This burner system is suitable for fuel oil, gaseous fuels and also as a combination system in which a straightforward changeover between gas and oil combustion is possible. The most obvious advantage of monoblock burners is their compactness and therefore favourable design, and also that all systems in the combustion system can be mounted directly at the boiler in a space-saving manner. Monoblock burners can be used up to a combustion output of roughly 10MW. They are however not suitable for use with an air preheating system.

Duoblock burner

Fig. 49 *Duoblock burner with fan on the boiler crown and combustion air ducts (Saacke)*

The term duoblock burner is used to describe burners whose combustion air fan (shown mounted on the boiler) and combustion unit are installed separately. The combustion air fan and burner are connected by a combustion air duct. Duoblock burners are used specially for large combustion outputs and when using air preheating.

3.1.3 Combustion systems for liquid fuels

The most important terms and distinguishing features for combustion systems and the necessary equipment are described below.

Pressure atomiser

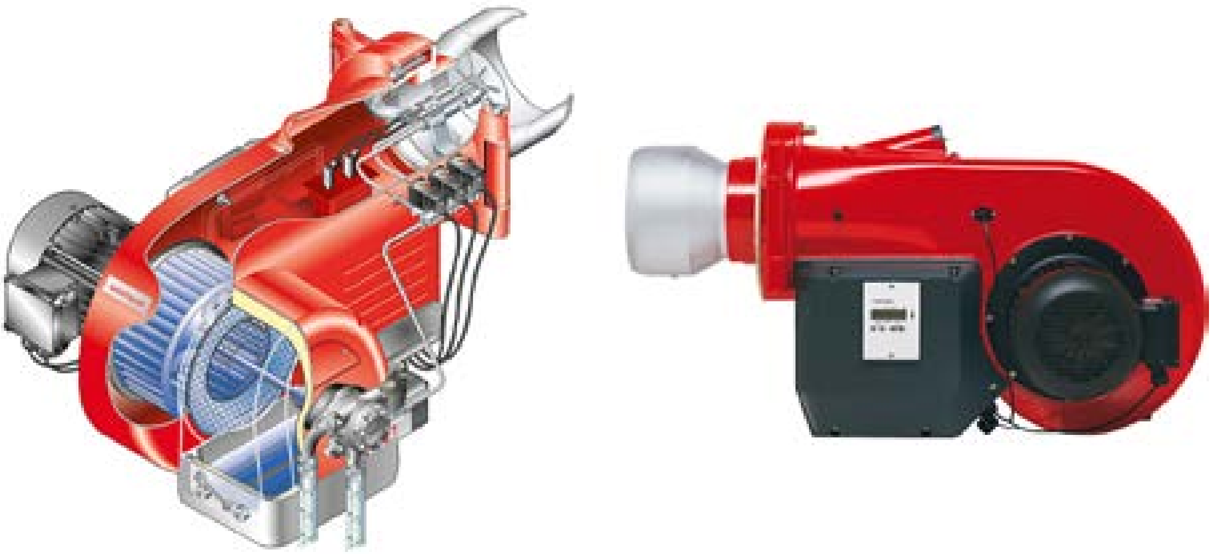

Fig. 50 *Image and sectional representation of oil burner (Weishaupt)*

With pressurised atomisation, the oil is guided through a nozzle and discharged as a fine spray into the combustion chamber. The pre-charge pressures in the oil infeed must be roughly 6 – 30 bar. When the oil jet exits from the nozzle, fine oil droplets with a large reaction cross-section form. The prerequisite for this is that the viscosity of the fuel must be within the range of 5 – 8mm²/s. If this is not the case at ambient temperature, the oil must be preheated.

The burner can be controlled in different ways. With step burners, several nozzles are installed in the burner head. Depending on the required output, nozzles are switched on or off by activating solenoid valves. Burners with up to three nozzles are available.

Return flow atomising burners are used so that the output can be controlled steplessly. To do this, a valve in the fuel oil return flow regulates the quantity of fuel admitted to the combustion chamber. This valve is activated in combination with the position of the combustion air damper.

Rotary atomiser

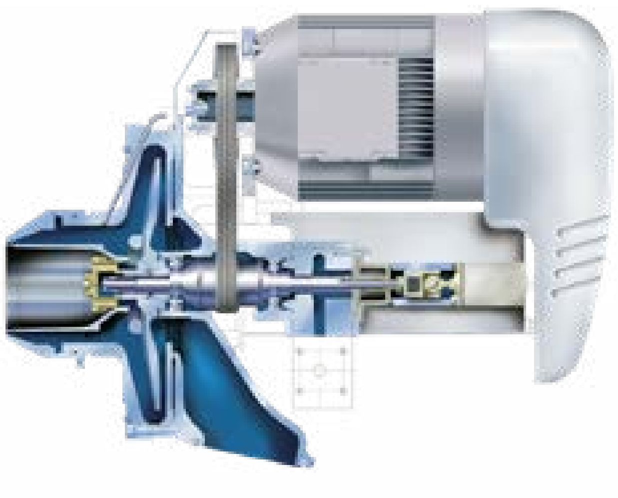

Fig. 51 *Sectional view of a rotary atomising burner (Saacke)*

The liquid fuel is admitted at low pressure to a conical cup atomiser via a hollow shaft which rotates at high speed. The oil film that forms on this migrates to the edge of the cup which opens out towards the combustion chamber. Due to the centrifugal force, the oil film at the edge of the cup breaks off and forms fine oil droplets which are flung into the combustion chamber in a swirling motion.

Some of the combustion air is guided into the cup and the rest flows into an annular gap around the cup which normally has an opposing swirling motion. The admission and distribution of combustion air affects the flame appearance. This results in an intensive mixing of the oil with the combustion air.

A significant advantage of the rotary atomiser compared to the pressure atomiser is that it depends less on the viscosity characteristics of the fuel. This means that fuels with varying quality can also be reliably burnt. The rotation of the cup can also be monitored to ensure clean combustion without CO and soot formation.

Oil supply

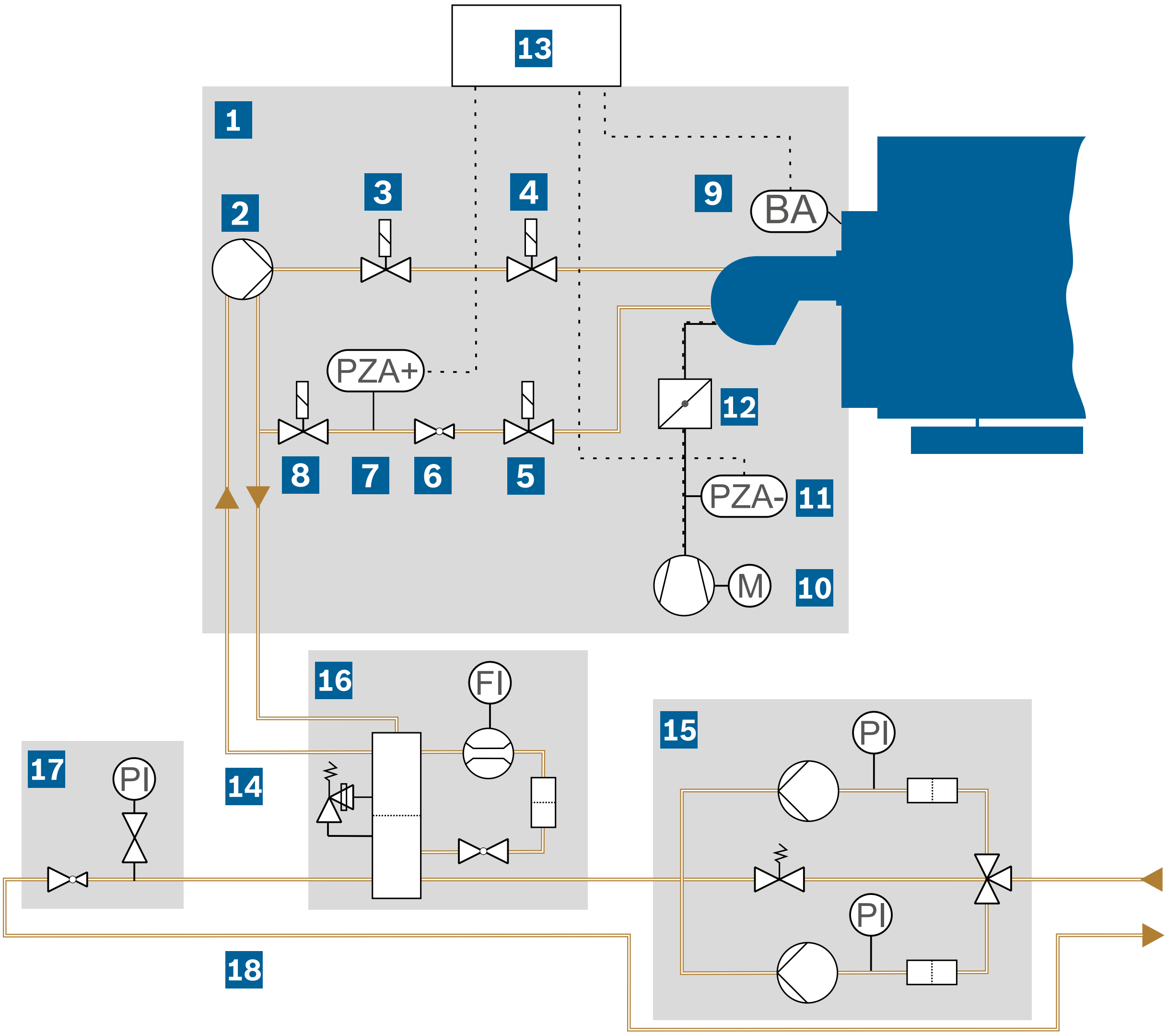

Fig. 52 *Example of a light fuel oil combustion system with pressure-jet oil burner*

BA Flame monitoring
FI Flow rate indicator
PI Pressure indicator (pressure gauge)
PZA- Air deficiency safety device
PZA+ Maximum pressure limiter

Combustion equipment

1 Burner
2 Burner oil pump: generates the pressure of 12 – 30 bar required for atomisation
3 Solenoid valve: first shut-off of fuel supply in the oil flow
4 Solenoid valve: second shut-off of fuel supply in the oil flow
5 Solenoid valve: first shut-off in the oil return
6 Oil pressure controller: adjustment of oil pressure at the return flow atomiser of the burner depending on the required load
7 Maximum pressure limiter: shuts down the combustion system if the oil pressure is too high
8 Solenoid valve: second shut-off in oil return

9 Flame monitoring: switches the combustion system off if combustion in the combustion chamber is not stable after a starting time interval

10 Fan: combustion air supply

11 Air deficiency safety device: shuts down the combustion system if the delivery pressure of the combustion air fan is low

12 Air damper: controls fuel/air ratio

13 Burner control unit/safety chain

14 Oil branch line

Oil supply

15 Oil supply module OSM

16 Oil circulation module OCM

17 Oil pressure regulation module ORM

18 Oil ring line

Oil supply module OSM

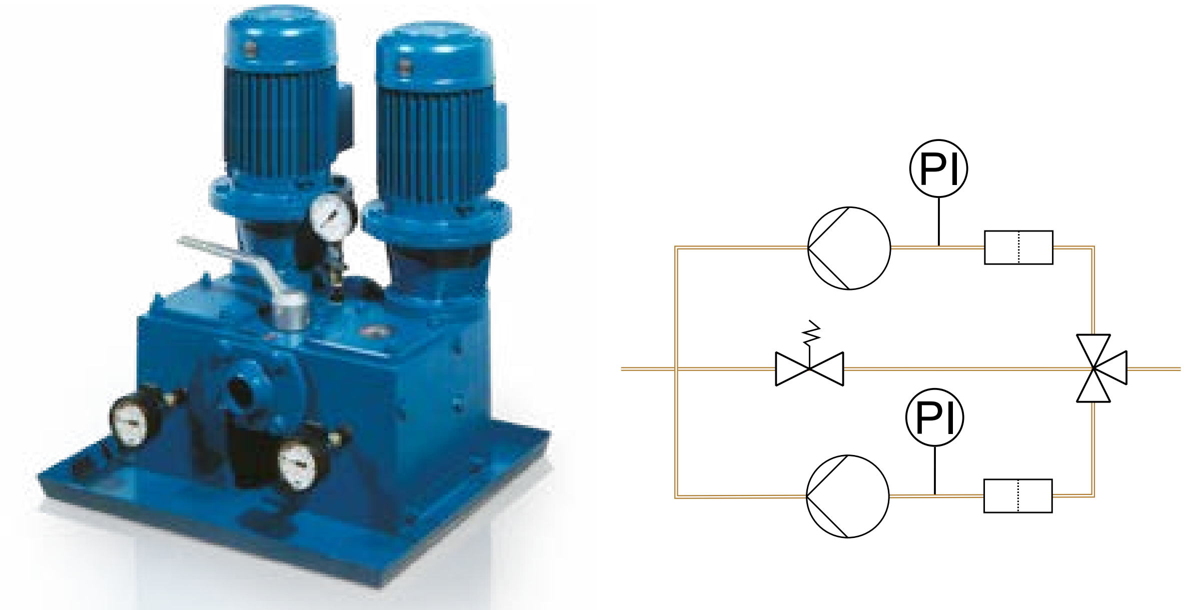

Fig. 53 *Oil supply module*

PI Pressure gauge

The oil supply module pumps the fuel from the oil storage tank which is set up outside the boiler house via the oil ring line to the individual oil circulation modules that supply each oil burner individually.

It is pre-assembled as a single or double station with 100% reserve to ensure security of supply, also in the event of an oil filter change, with all valves in an oil sump for ease of installation in the ring line.

Oil pressure regulation module ORM

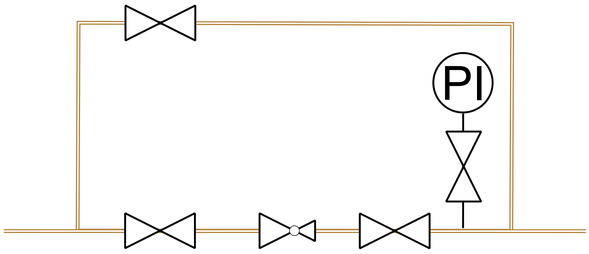

Fig. 54 *Oil pressure regulation module*

PI Pressure gauge

The purpose of the oil pressure regulation module is to set a constant oil pressure in the flow of the oil ring line. It consists of an oil pressure controller, upstream and downstream shut-off valves that allow the oil pressure controller to be removed, a pressure indicator **(PI)** and a bypass valve. It is always integrated downstream of the last branch line that supplies the burner.

Oil circulation module OCM

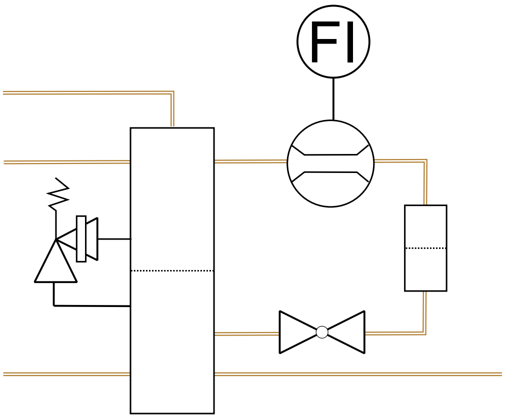

Fig. 55 *Oil circulation module*

FI Filter valve

The oil circulation module prepares liquid fuels by means of filtering and air separation and measures the oil flow rate. It is designed for light and heavy fuel oil pressure-jet burners equipped with return flow atomiser system and is installed as ready-to-use unit including casing for every burner in the ring lines with a pre-charge pressure of ≥ 1.5 bar.

The module contains an oil reservoir with two chambers which supplies oil directly to the burner and receives the return flow quantity from the burner. The pipework can be directly connected to the oil hoses of the burner.

It includes a filter valve **(FI)**, oil volumeter, shut-off valves, overpressure safety valve, ventilation shut-off valve and drain plug. In the case of heavy fuel oil operation, insulation is also fitted under the metal cladding.

Oil preheating module OPM

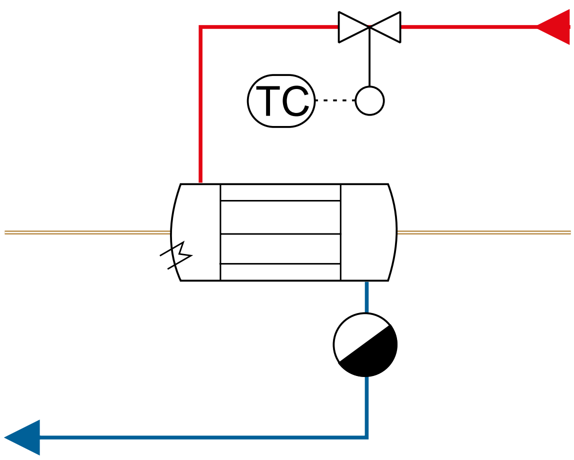

Fig. 56 *Oil preheating module*

TC Temperature control valve

When using medium and heavy oils as fuel, they must be preheated because at ambient temperature they do not have the flow characteristics required for atomisation. The oil must be preheated in order to reduce the viscosity. Depending on the burner make and fuel, heating up to a temperature of 100 – 180°C is required to ensure reliable combustion.

The fuel is heated by a heat exchanger with extendable tube bundle which can be operated with steam or a combination of steam heating and electric heater. It must be ensured that trace heating is also fitted to all pipework and valves. In the start-up condition, the oil is initially heated by electricity then during continuous operation it is heated with steam to a constant temperature via the temperature control valve **(TC)**. The module is pre-assembled ready to use, including the heating control, thermal insulation and all valves.

3.1.4 Combustion systems for gaseous fuels

Nowadays, natural gas is available at most locations and normally costs less than oil. The market share of gas combustion systems has been steadily increasing in recent years.

→ Planning – Chapter 4.3: Criteria for selection between fuel oil and natural gas, page 56

In addition to the economic advantage, using gas as fuel has other benefits:

- No fuel storage
- Less soiling of heating surfaces
- Less prone to faults
- Lower NO_x and CO_2 emissions
- More straightforward use of condensing technology

Fig. 57 *Burner with monoblock design (Dreizler)*

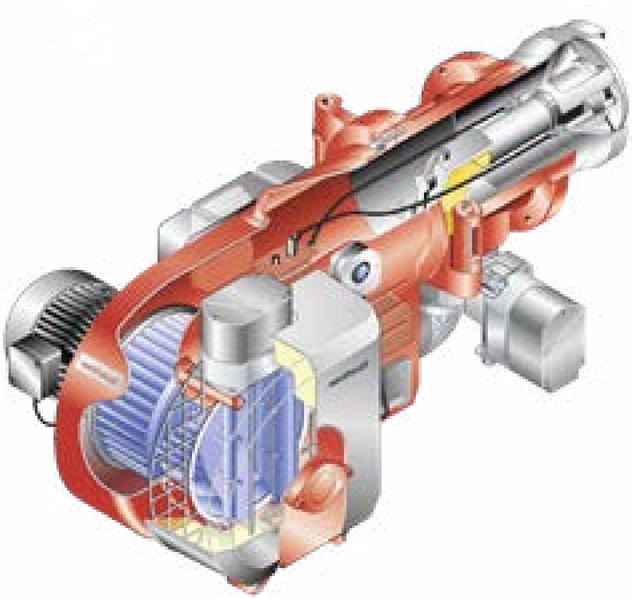

Fig. 58 *Sectional representation of gas burner (Weishaupt)*

Gas supply

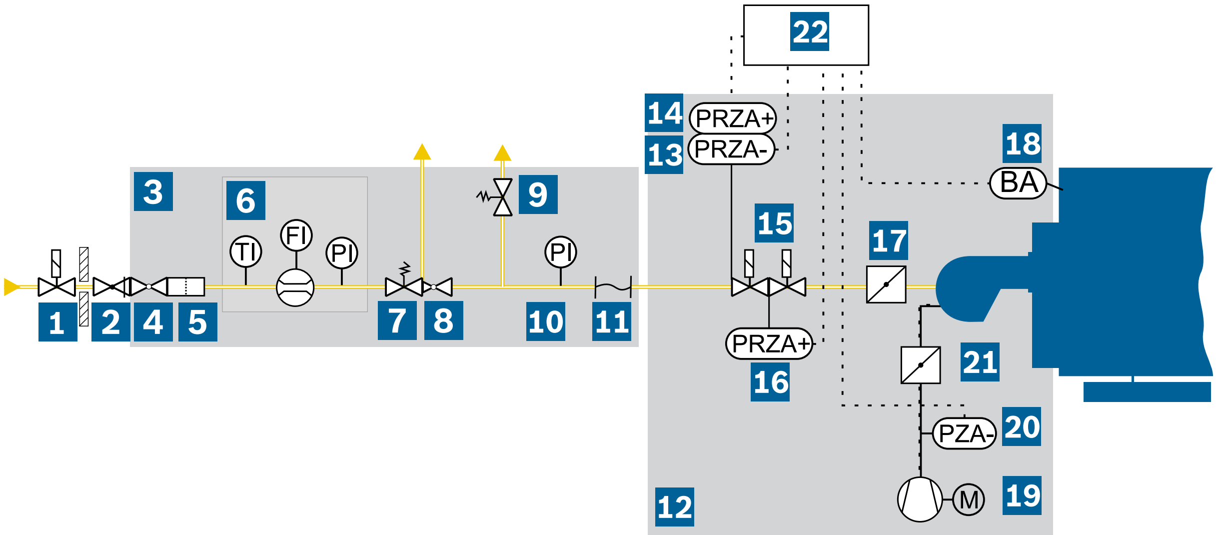

Fig. 59 *Example showing schematic representation of gas combustion (high-pressure supply)*

Gas supply

BA	Flame monitoring	**PRZA-**	Minimum gas pressure limiter
FI	Flow rate indicator	**PRZA+**	Maximum gas pressure limiter
PI	Pressure indicator (pressure gauge)	**TI**	Temperature indicator
PZA-	Air deficiency safety device		

1 Safety shut-off valve: shuts off the gas supply in the event of faults and an emergency stop (located outside the boiler installation room)

2 Thermal shut-off valve: shuts off the gas supply if fire breaks out in the boiler house

3 Gas regulation module

4 Shut-off valve: for shutting off manually

5 Gas filter: protects sensitive parts from contamination

6 Gas meter module: gas meter with temperature and pressure measurement for converting quantities from operation m^3/h to standard m^3/h

7 Safety shut-off valve: locks out gas supply in the event of unacceptable increase in gas pressure

8 Gas pressure governor: ensures uniform gas pressure for combustion

9 Safety relief valve: cuts in if an unacceptable positive pressure occurs downstream of the gas pressure governor

10 Pressure indicator **(PI)**

11 Expansion joint: compensates for pipework expansion

Combustion equipment

12 Burner

13 Minimum gas pressure limiter **(PRZA-)**: switches off the combustion system if the gas pressure is too low

14 Maximum gas pressure limiter **(PRZA+)**: switches off the combustion system if the gas pressure is too high

15 Double solenoid valve: double shut-off of gas supply when the burner is not in operation

16 Tightness test **(PRZA+)**: tests the tightness of the solenoid valves

17 Gas control damper: controls the gas volume

18 Flame monitoring **(BA)**: switches the combustion system off if combustion in the combustion chamber is not stable after a starting time interval

19 Fan: combustion air supply

20 Air deficiency safety device **(PZA-)**: shuts down the combustion system if the delivery pressure of the combustion air fan is low

21 Air damper: controls fuel/air ratio

22 Burner control unit/safety chain

Gas regulation module GRM

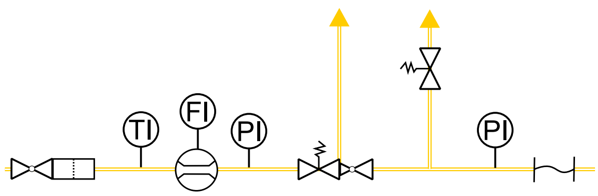

Fig. 60 *Gas regulation module*

FI Flow rate indicator

PI Pressure indicator (pressure gauge)

TI Temperature indicator

The gas regulation module contains all the control and safety equipment required for safe and fault-free combustion. The gas and air supply in particular are set via an electronic or pneumatic integrated control so that the correct fuel/air ratio for complete, safe and efficient combustion in the combustion chamber exists at all load points.

The gas pressure regulator is installed to ensure a uniform gas pressure upstream of the burner irrespective of the changing pre-charge pressures. If the gas pressure was changed, the gas/air ratio at the burner would change and consequently either an unstable flame or combustion leading to a heavy build-up of soot and CO formation would occur. If there is a possibility of the safeguarded upstream gas pressure exceeding the permissible operating pressure of the components of the gas train, then a safety shut-off valve and safety relief valve must be installed upstream of the control unit.

The pressure switches monitor the minimum and maximum permissible gas pressure if the gas pressure governor indicates a defect. During downtimes or pre-ventilation, gas must not enter the combustion chamber as otherwise a hard ignition may occur. The solenoid valves in the gas train must therefore close reliably. For safety reasons, the gas solenoid valves are redundantly configured and the burner sequence program checks before every burner start whether the valves are tight (gas tightness check).

3.1.5 Heating via waste heat gas

The heat of flue gases from upstream processes, e.g. combined heat and power from CHP modules or gas turbines, industrial manufacturing and production processes in the metal industry or the utilisation of thermal energy from waste material is suitable for generating steam in shell boilers.

→ Efficiency – Chapter 5.1: Combined heat and power, page 303

The possible steam output from the flue gases essentially depends on three criteria:

- **Temperature level of the available flue gases**
  The higher the temperature level of the flue gas, the greater the achievable steam output. The temperature level can be up to around 300°C with micro gas turbines, 360 – 550°C with flue gases from engines or 1,000°C with industrial processes such as smelting or forging of tools or from utilisation of thermal energy.
- **Flue gas volume and duration of availability of flue gases**
  It must be considered whether flue gas will be available continuously or only at certain operating times. The quantity of flue gas must also be considered.
  When using combined heat and power with a gas turbine, for example, up to 5 times more flue gas is available than that produced by an internal combustion engine with the same electrical output due to the large amount of excess air during combustion.
- **Pressure level at which the steam is to be made available**
  The higher the pressure level and therefore temperature of the saturated steam in the steam boiler, the lower the temperature gradient from the flue gas to steam which is available for heat transfer. For flue gas temperatures ≤330°C the operating pressure should ideally be < 5 bar. At higher flue gas temperatures, a higher steam pressure can be realised in the boiler.

Additional framework parameters for selection of a suitable boiler are the corresponding sulphur content, solids content or other corrosive substances, e.g. chlorine content in flue gas.

In this case, due to the large number of possible flue gas variations, detailed engineering is always recommended in preparation for a waste heat steam boiler system in order to use the available thermal energy as efficiently as possible.

Fig. 61 *Combined heat and power unit with 4-pass waste heat boiler*

3.2 Heat maintenance system

If a steam boiler is not required for a short period, e.g. at weekends or when not in use at night, the heat maintenance system is useful. This keeps the boiler hot at a reduced boiler pressure. By reducing the pressure in the boiler and therefore also the medium temperature, the heat losses during downtimes are reduced.

→ Technical information TI019: heat maintenance systems for steam boilers

The boiler heat maintenance system essentially has three benefits:

- Fast availability of full steam output within a few minutes
- Avoids ingress of oxygen which prevents idle corrosion
- Avoids the extremely high mechanical stresses involved in cold starting

Fig. 62 *Heat maintenance coil installed in base of boiler*

Heat maintenance via heating coil

In multi-boiler systems or systems that obtain saturated steam from an external steam network for heating of the heat maintenance coil, the heat maintenance system is implemented using a heating coil which is integrated into the base of the boiler. Here, heat maintenance can be controlled via a control valve in the steam inlet with reference to a setpoint pressure, or can also not be controlled.

The main advantage of this variant is the uniform temperature distribution throughout the boiler. It reliably avoids thermal stratification. This reduces the thermal stresses that accompany the changeover from heat maintenance mode to normal mode significantly.

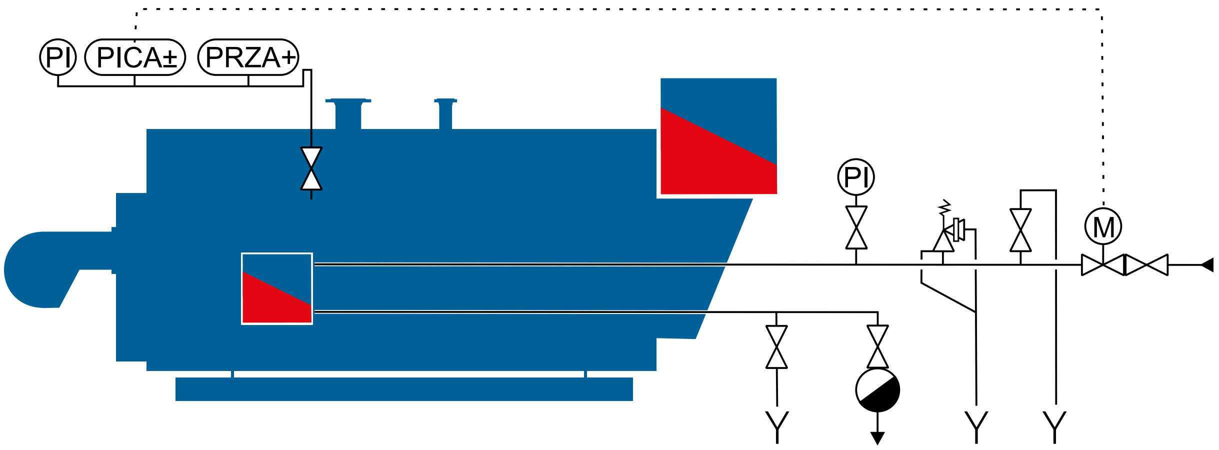

Fig. 63 *Heat maintenance via a heating coil*

PI Pressure indicator (pressure gauge)

PICA± Pressure transmitter

PRZA+ Pressure limiter

Heat maintenance via a combustion system

The heat in single boiler systems or the lead boiler of a multi-boiler system for which no steam is available from the network must be maintained by a dedicated combustion system.

As the rated heat input of the burner in this operating mode only needs to compensate for the heat losses in the system, the combustion output control is set to minimum load. In well insulated systems, the combustion system is only enabled once every few hours. In this case, the heat maintenance operation is frequently enabled at roughly 50% of the average boiler operating pressure so it can be started up very quickly.

However, the burner heat maintenance system inevitably has all the disadvantages of frequent burner cycling, such as pre-ventilation losses and mechanical loads.

→ Efficiency – Chapter 2.2.4: Pre-ventilation, page 273

Furthermore, if the heat maintenance system is active and no steam is drawn for an extended period (several days) temperature stratification occurs inside the boiler which causes additional mechanical and thermal loads when the boiler is fired again.

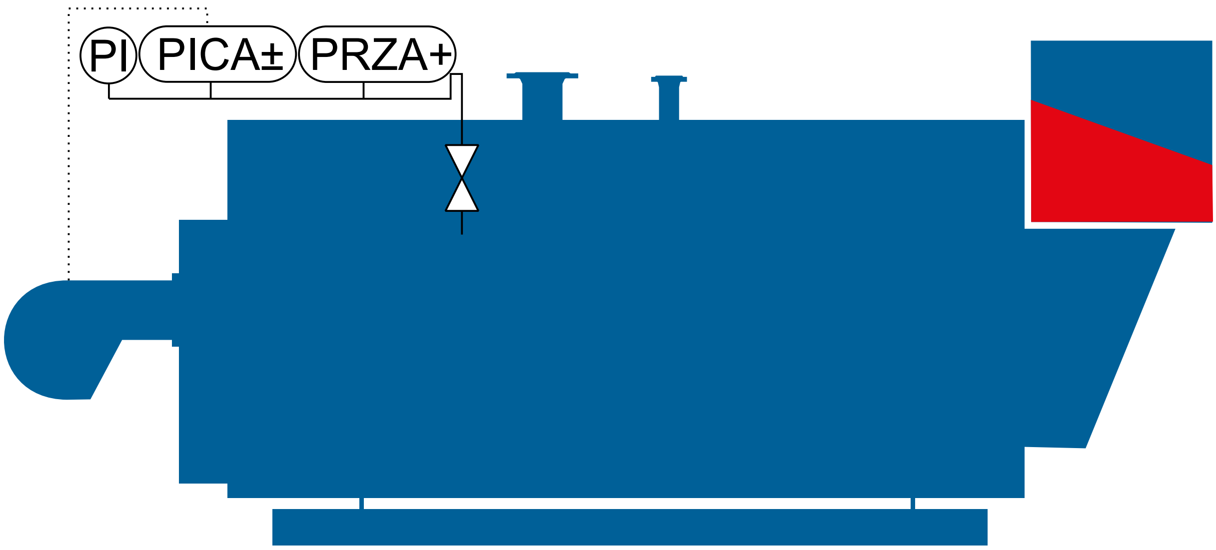

Fig. 64 *Heat maintenance via the combustion system*

PI Pressure indicator (pressure gauge)
PICA± Pressure transmitter
PRZA+ Maximum pressure limiter

3.3 Economiser

Economisers, also referred to as flue gas heat exchangers, belong to the standard equipment of a boiler system as they can be used in more or less any system.

Although the investment costs of an integrated economiser are roughly 7 – 15% of a boiler, it also increases the efficiency of the system by up to 7% and therefore normally pays for itself within several months of operation.

→ Efficiency – Chapter 2.1: Flue gas temperature or flue gas loss, page 261

The flue gas flow emerging from the steam boiler is still at a temperature of 200 – 280°C. The economiser is equipped with highly-efficient heat exchangers for dry flue gas heat recovery which makes use of this thermal potential at a high temperature level. The heat extracted from the flue gas is normally used for feed water heating and therefore improves the boiler efficiency.

Flue gas condensing via flue gas heat exchangers, air preheating or a feed water cooler can be used to further improve efficiency.

→ Efficiency – Chapter 2.1.2: Condensing heat exchanger, page 263

→ Efficiency – Chapter 2.1.3: Air preheater, page 265

→ Efficiency – Chapter 2.1.4: Feed water cooler, page 267

Various types of economiser are available for the system-specific mode of operation of the flue gas heat exchangers which is optimised for each individual plant.

Integrated economiser

The fully integrated economiser which is directly mounted on the boiler offers benefits especially for new boiler systems. The specially developed heat exchanger bundle with variable size and highly efficient finned tubes is installed as an integral component of the boiler in the flue gas collection chamber, fully insulated and connected directly to the boiler on the water side. Integrated economisers are available for the U-MB, CSB, UL-S, ZFR and HRSB boiler series.

An integrated economiser has significant benefits compared to a conventional boiler with separate economiser.

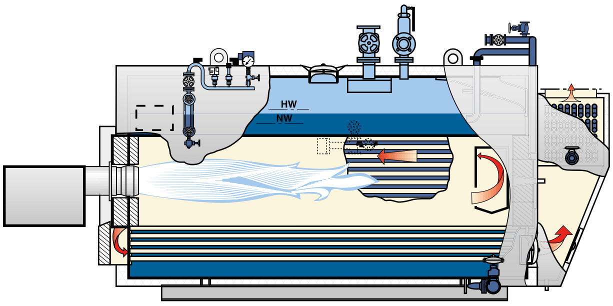

Fig. 65 *Integrated economiser in UL-S*

Benefits:

- Highly efficient spiral finned tube system for gas and fuel oil “EL”
- Integrated in the flue gas chamber on the boiler
- Increase in efficiency of up to 7% points
- Assembled at the plant, piped and ready for connection, tested and thermally insulated
- Low space requirement
- No additional foundation required
- No local installation

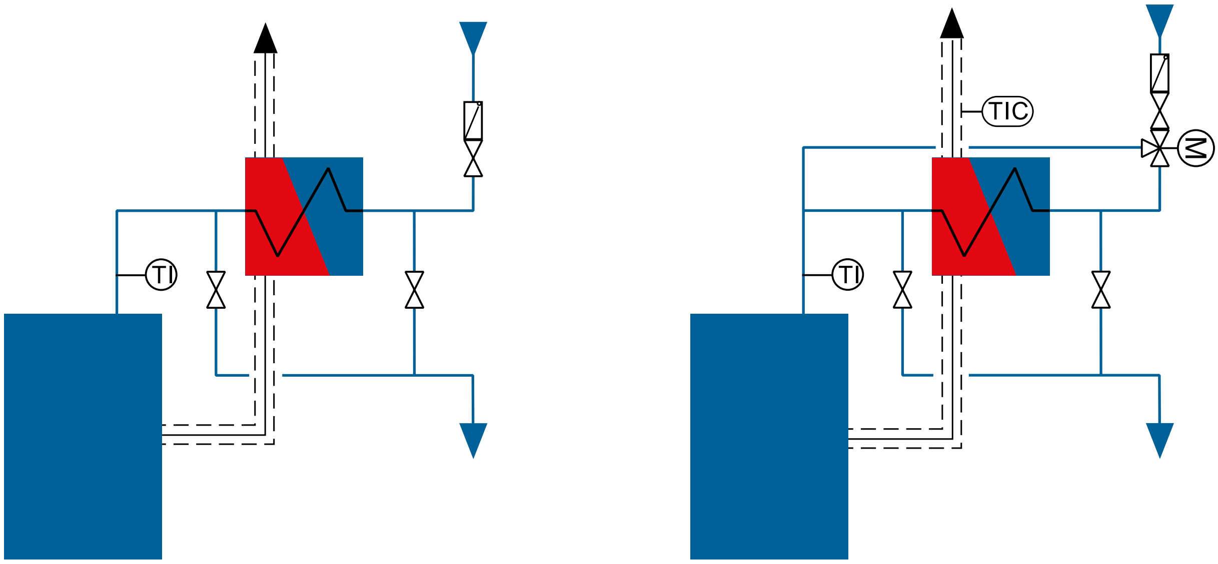

Fig. 66 *Economiser without shut-off facility, uncontrolled (left) and economiser without shut-off facility, controlled on the water side (right)*

TI Temperature indicator

TIC Temperature controller

M Motor

With the uncontrolled variant, all flue gas always flows though the heat exchanger pipes to ensure the maximum amount of energy is recovered from the flue gases in every load position. In addition to achieving the best efficiency, this is also the most cost-efficient and therefore most commonly used variant.

→ Fig. 66, page 150, left

To prevent the flue gas temperature downstream of the economiser from falling too far, if a minimum flue gas temperature requirement exists for masonry chimneys for example, the variant with water-side control is used. With this variant, some or all of the feed water flow is routed via a three-way control valve past the economiser until the preset flue gas temperature downstream of the economiser is established.

→ Fig. 66, page 150, right

Standalone economiser

Standalone economisers can be installed independently of the boiler which means they can be very conveniently retrofitted to existing systems. They are also used if the economiser needs to be bypassed on the flue gas side from time to time, as is the case when using a second fuel containing sulphur (e.g. heavy fuel oil).

The flue gases enter the lower section of the economiser and flow through the heat exchanger in the upper section where the heat recovery process takes place. The flue gas bypass including motorised flue gas damper, the pipework for the connections and valves are ready assembled and belong, together with thermal insulation, to the scope of delivery supplied ex-works. The standalone economiser features a special double finned tube which makes the heating surfaces easier to clean and also makes it suitable for heavy fuel oil or fuels with a high soiling tendency.

The standalone economiser is available for all CSB, U-MB, UL-S, ZFR, HRSB boiler series and also boilers by other manufacturers.

Fig. 67 *Standalone economiser in combination with a dual combustion system (gas/heavy fuel oil)*

3.4 Condensing heat exchanger

With utilisation of calorific value, not only the sensible heat which is directly linked to the temperature but also the condensation heat (latent heat) bound in the water vapour is partially extracted from the flue gas.

→ Technology – Chapter 1.3: Enthalpy, page 110

This produces acidic flue gas condensate which must be neutralised. Corrosion resistant materials are therefore necessary in these heat exchangers, downstream exhaust pipes and the chimney.

→ Technology – Chapter 4.2.2: Water disposal – flue gas condensate, page 192

The standalone stainless steel flue gas heat exchangers are supplied as preassembled modules. They are therefore suitable both for new systems and also for retrofitting to existing systems.

→ Efficiency – Chapter 2.1.2: Condensing heat exchanger, page 263

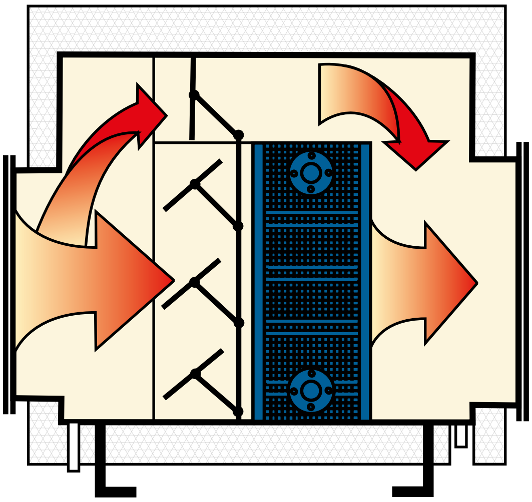

Fig. 68 *Condensing heat exchanger*

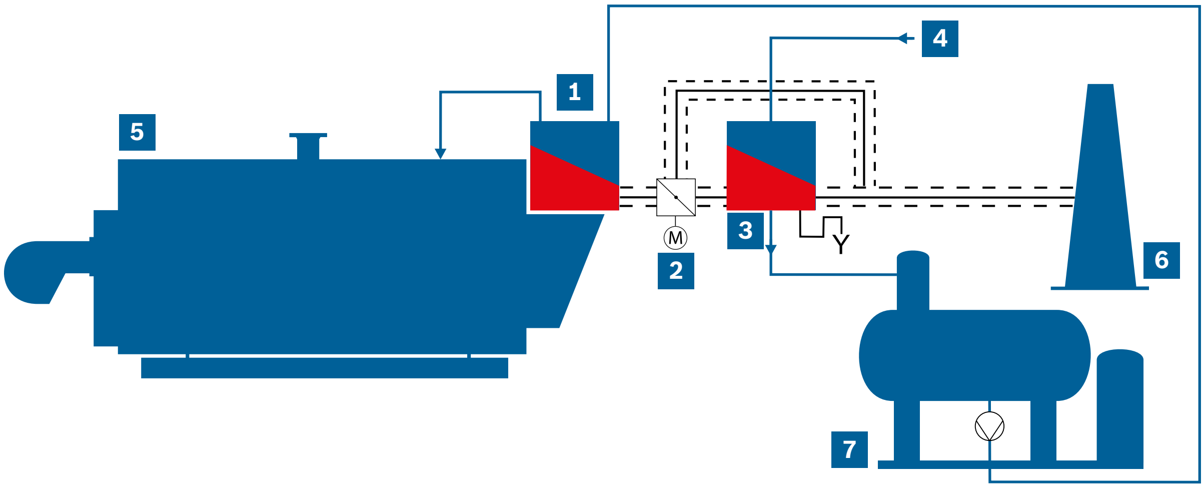

Fig. 69 *Simplified flow diagram of a steam boiler system with integrated economiser and downstream condensing heat exchanger*

1 Integrated economiser (steel)

2 Flue gas bypass flap

3 Condensing heat exchanger (stainless steel)

4 Make-up water

→ Technical report FB023: utilisation of calorific value

3.5 Air preheater

The air preheater uses the hot feed water to preheat the combustion air and obtain a cool water flow in the return. This cold flow can now be used in an additional economiser bundle to further reduce the flue gas temperature. This increases efficiency by 2% points, or flue gas temperatures that are roughly 40K lower.

As the air preheating utilises the combustion air as internal heat sink, the increased efficiency is fully reflected in the reduction in annual fuel costs.

→ Efficiency – Chapter 2.1.3: Air preheater, page 265

Construction

The Bosch air preheating system consists of:

- A second economiser bundle which is delivered mounted on the boiler or supplied loose with the boiler depending on the transport dimensions
- A heat exchanger for air preheating
- The necessary valves and sensors for shutting off and controlling the system

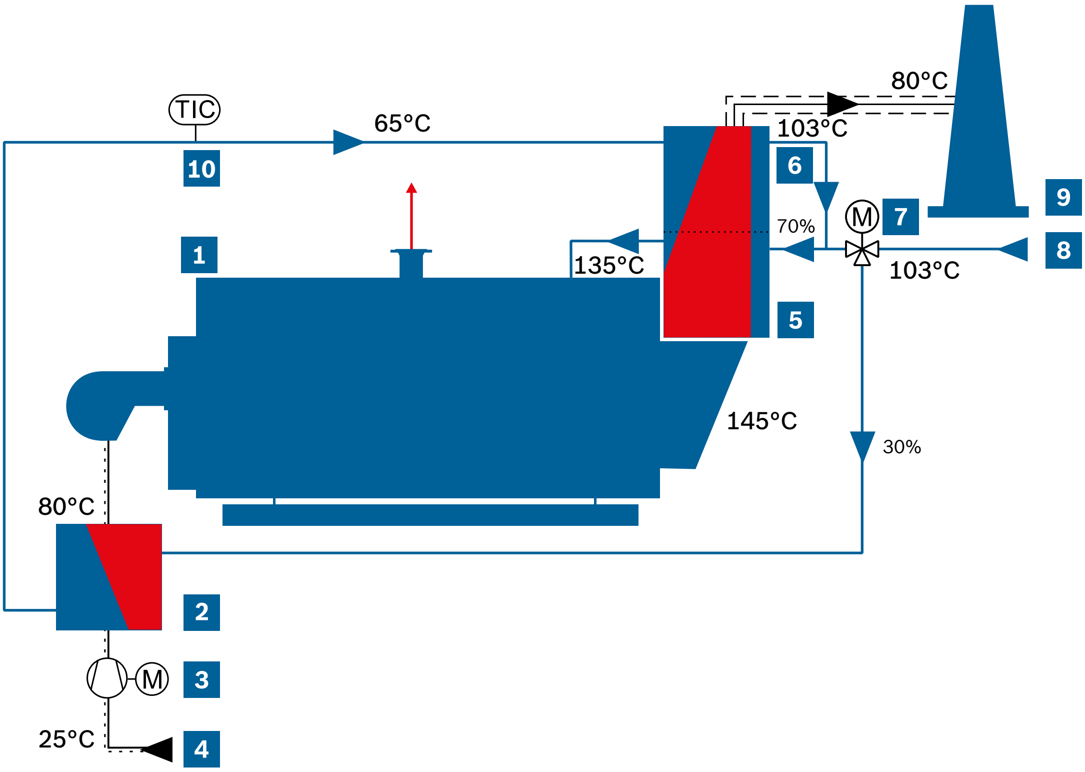

Fig. 70 *Bosch air preheating system*

1 Steam boiler	6 Flue gas heat exchanger stage 2
2 Heat exchanger, combustion air	7 3-way valve
3 Fan	8 Feed water
4 Combustion air	9 Chimney
5 Flue gas heat exchanger stage 1	10 Temperature controller

3.6 Feed water cooler

In the feed water cooling module (FWM), cold make-up water is heated by the hot feed water in a heat exchanger. Cooling of the feed water results in a greater temperature difference between the water and flue gas in the economiser. The improved heat transfer in the economiser reduces the flue gas discharge temperature.

This improves combustion efficiency by up to 1.8%, or by up to 3% if the boiler is equipped with a 4th pass.

The feed water inlet temperature in the economiser is controlled during this process, which reduces flue gas condensation and therefore protects the steel economiser from corrosion.

The feed water control module is an effective reliable measure for reducing energy costs.

→ Efficiency – Chapter 2.1.4: Feed water cooler, page 267

Construction

The feed water cooling module consists of a plate heat exchanger including insulation, valves, pipework adapters and temperature sensors and is supplied on a base frame ready for connection. The module sizing and parameter settings of the control are made specifically to order and are matched to the mode of operation of the system.

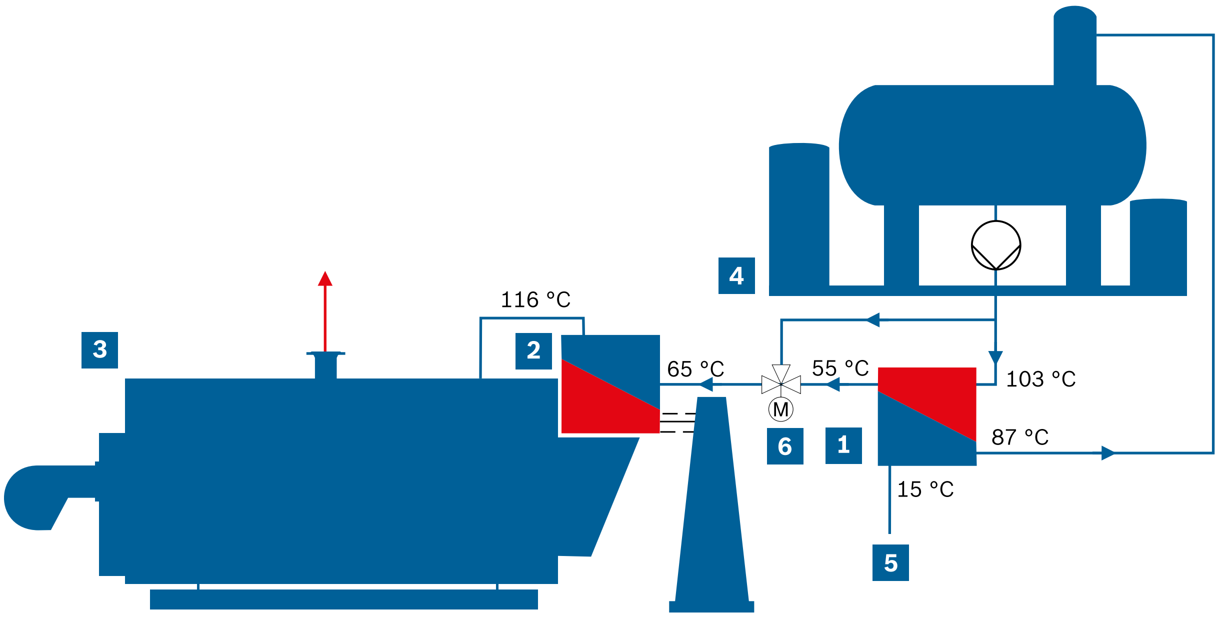

Fig. 71 *Integration of the feed water cooler into a boiler system*

- **1** Feed water cooling module
- **2** Economiser
- **3** Steam boiler
- **4** Water service module
- **5** Make-up water
- **6** 3-way valve

3.7 Feed water preheater

The feed water preheater is used when fuels containing sulphur are used in combination with an economiser. To prevent sulphuric acid from condensing on the economiser tubes, the feed water is heated to temperatures above the acid dew point following deaeration. Temperatures of 120 – 140°C are required, depending on the sulphur content of the fuel.

→Tools – Chapter 3.2: Dew point of flue gases, page 393

The feed water preheater is designed as a steam heated tubular heat exchanger equipped with the necessary control, safety and display elements.

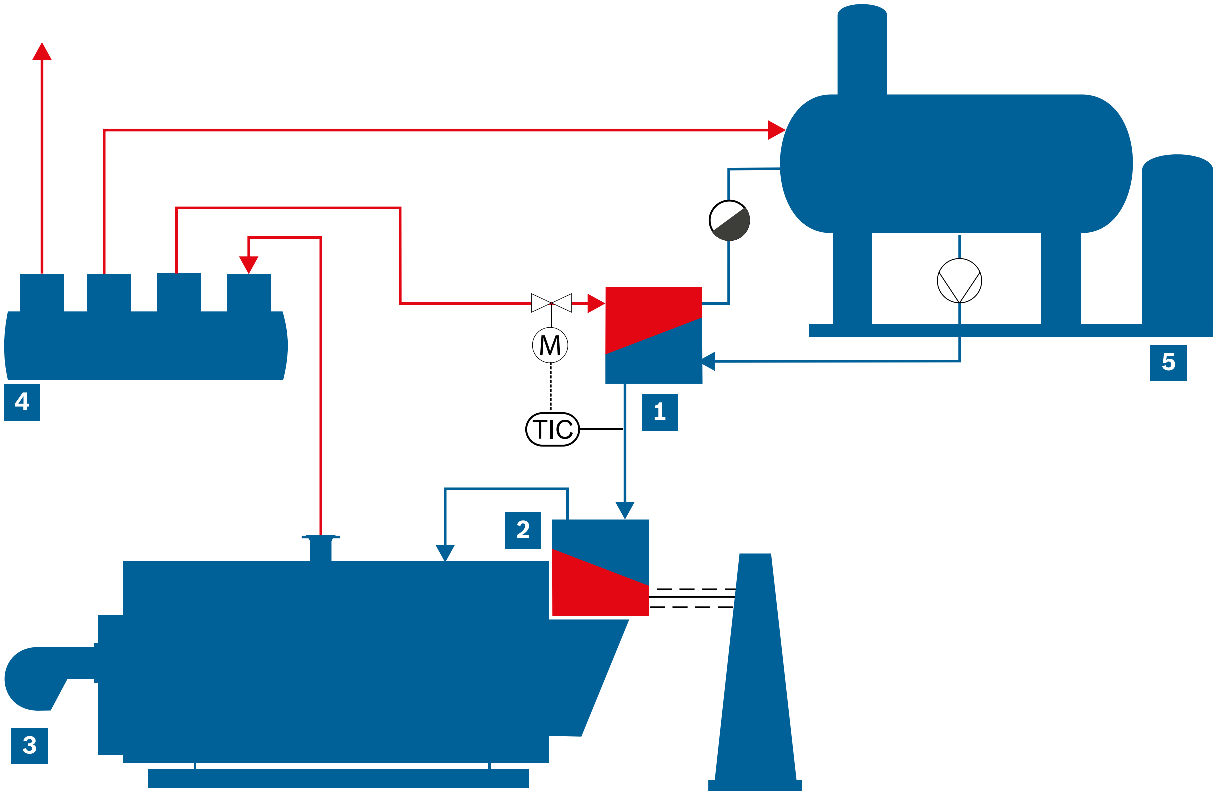

Fig. 72 *Simplified system schematics showing integration of a feed water preheater*

1 Feed water preheater
2 Economiser
3 Boiler
4 Steam distributor
5 Feed water vessel

3.8 Super heater

The super heater is used to heat the water vapour to above its evaporation temperature. This steam is referred to as superheated steam or hot steam. The steam temperature is above the saturation temperature.

Superheated steam is mainly used in complex extensive steam networks used to drive steam engines and steam turbines that generate power or for the heating of power plants. With shell boilers, the super heater is mounted on the front reversing chamber downstream of the first smoke-tube pass. Depending on the pressure stage of the boiler, superheated steam temperatures of 100K above the saturated steam temperature and up to a maximum of 300°C can be reached.

→ Fig. 35, page 104

→ Technology – Chapter 1.1.3: Superheated steam, page 105

Fig. 73 *Double flame-tube boiler with mounted superheater on top*

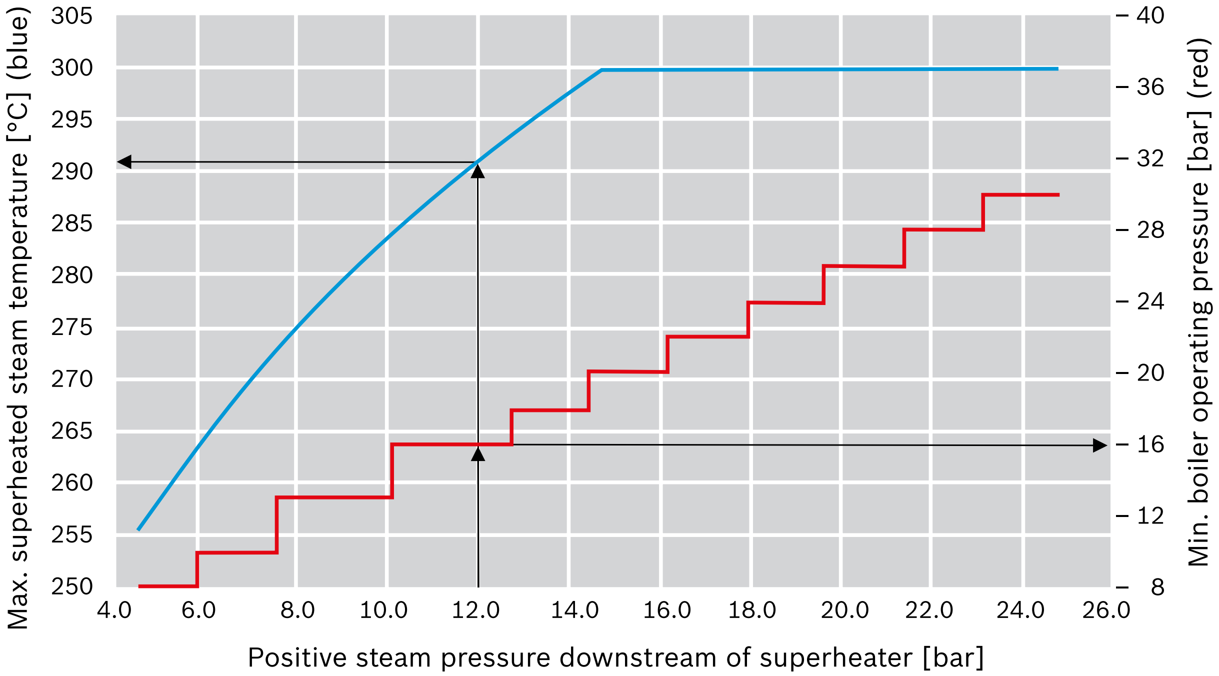

Fig. 74 *Possible superheated steam temperatures and the minimum required pressure stage with reference to the required steam pressure downstream of the super heater*

- Max. superheated steam temperature [°C]
- Min. boiler operating pressure [bar]

Example:

Steam pressure downstream of super heater = 12 bar. Results in: maximum possible superheated steam temperature of 291°C and minimum boiler pressure rating of 16 bar

Construction

The super heater module is mounted on the front reversing chamber. A partition with a flue gas control flap for bypassing of flue gases from the first to the second smoke-tube pass is installed in the front reversing chamber. A fully automatic operation therefore takes place that ensures a controlled superheated steam temperature on the flue gas side. The super heaters are designed to specific customer requirements in order to achieve the superheated steam temperature in a specified boiler load range (e.g. 50 – 100%).

The super heater is started dry at the lowest load. The combustion output is gradually increased once a partial flow of steam through the super heater occurs. Operation takes place once the superheated steam temperature and combustion control has been enabled. To be able to ensure the superheated steam temperature and avoid deposits in the super heater on the water side, demisters are used to reduce the residual steam humidity.

→ Fig. 103, page 192

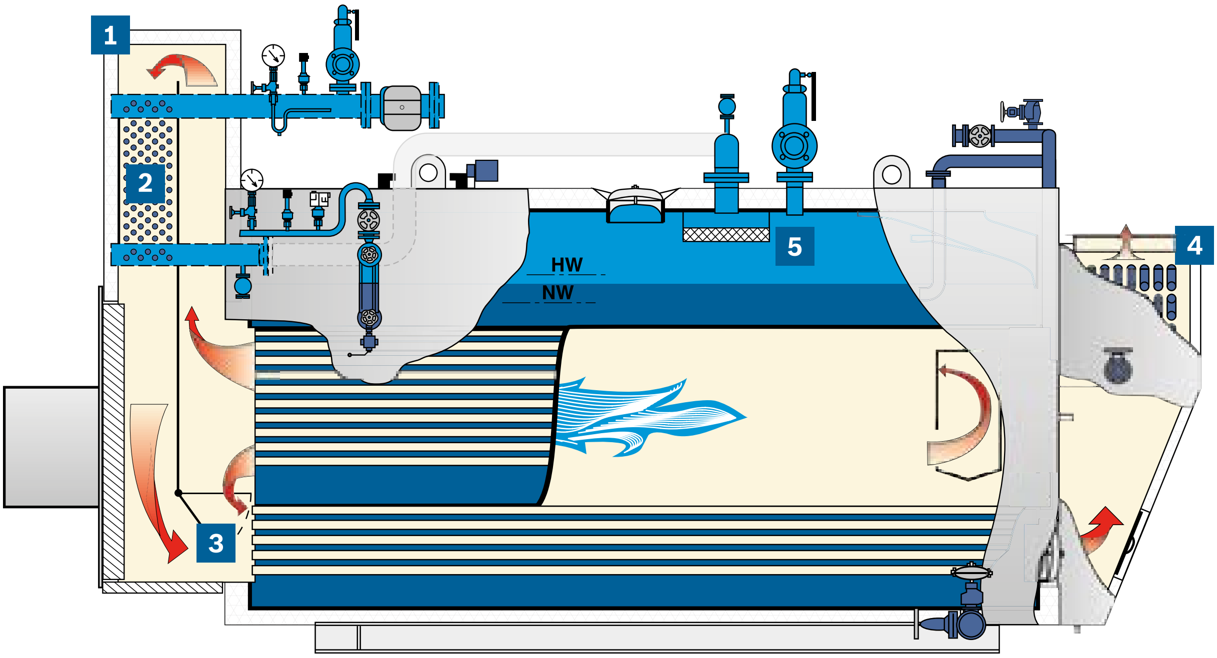

Fig. 75 *UL-S with mounted super heater*

1 Super heater module
2 Super heater tube bundle
3 Superheated steam temperature control damper
4 Economiser
5 Saturated steam feed at boiler with demister

3.9 Boiler feed pumps

The feed pump balances out the steam quantity supplied by the steam boiler and also water lost during surface blowdown and bottom blowdown with an appropriate quantity of feed water. To do this, the water level in the steam boiler is kept constant allowing for fluctuations within a range of roughly 100mm. Due to the regulations governing the operation of steam boilers, special requirements apply from the outset in relation to the design of boiler feed pumps as insufficient water in the boiler is a critical operating condition which must be avoided without fail.

EN 12953-6 does not impose any special requirements on pump rate and delivery pressure, providing two reliable water indicators of a special type are installed, which switch off the heating if the low water (LW) level in the boiler is undercut. Additionally, a minimum distance between the highest flues and the low water mark of at least 50mm must be maintained to ensure that the heating surfaces do not emerge as a result of re-evaporation due to the thermal energy stored in the flues.

As all Bosch shell boilers satisfy these conditions, no special requirements apply for feed pumps.

In addition to the obligations arising from the regulations, feed pumps must also satisfy the requirements for economic operation. This includes in particular keeping the water level in the boiler as constant as possible and maintaining a uniform flow rate of feed water through the existing economiser so the flue gas heat can also be continuously released to the feed water.

Likewise, the electrical output for driving the pumps should be kept as low as possible and the throttle losses via control valves minimised.

Various pump module designs are available in order to satisfy these requirements. The pumps used are vertical, high-pressure multi-stage centrifugal pumps with fully encapsulated air-cooled motor. Pumps with a drive output of up to 22kW can be equipped with an integrated inverter module for speed control. They are specially designed for use in shell boilers.

Pump characteristic map and system characteristic curves

A boiler equipped with economiser with m_S = 4,000kg/h nominal steam output and p_m = 13.3 bar average operating pressure is used as an example and explanation of the characteristic map of a speed-controlled boiler feed pump.

→ Fig. 76, page 161

The permissible range of the pump characteristic map (dark grey background) is defined on the left by the minimum flow rate curve V_{min}. This is obtained from the minimum quantity required to cool the pump.

The pump characteristic map is defined on the right by the maximum flow rate V_{max}, at the top by the 100% speed curve and at the bottom by the minimum heads of the individual speed curves.

The four system curves are drawn in (coloured dotted lines) to indicate the static pressure the pump needs to overcome at different operating pressures in the boiler and the dynamic pressure component due to the flow pressure losses via the pipework, valves and the economiser. As normally only short pipework sections, a few valves and the small flow resistance of the economiser need to be overcome in the boiler house, the dynamic pressure component of the system characteristic is very low. At the maximum flow rate for this boiler of 4.4m³/h this is only Δp_v = 0.53 bar. The static pressure component on the other hand, which is defined by the prevailing pressure in the steam boiler, is p_m = 13.3 bar. The static component therefore far outweighs the dynamic component. It still fluctuates between the minimum burner switch-on pressure $p_{B,on}$ = 12 bar and the maximum pressure specified by the pressure limiter p_{PL} = 15 bar.

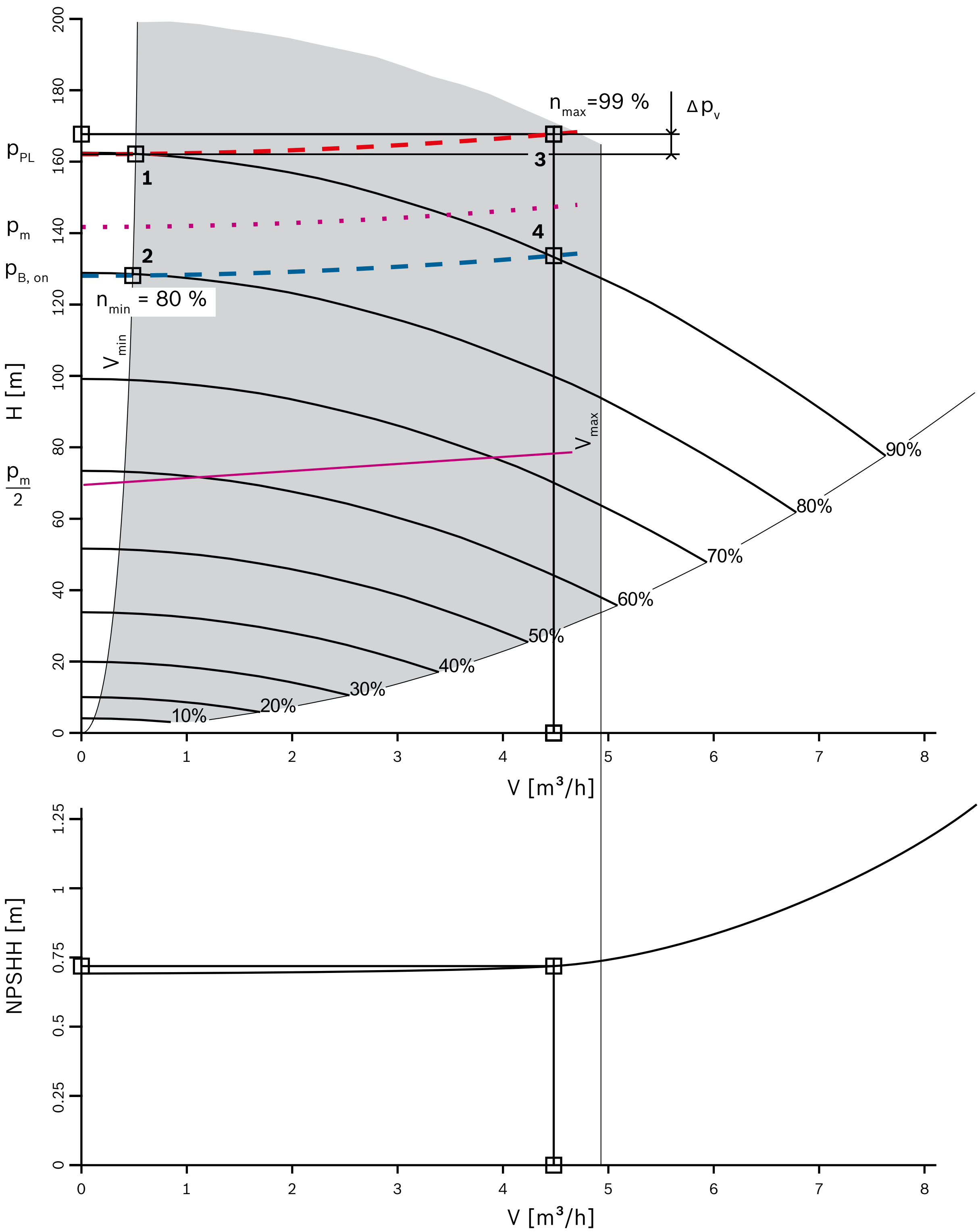

Fig. 76 *Example of a characteristic map of a speed-controlled boiler feed pump*

Energy saving

As the same flow rate is required for the speed-controlled pump and an On/Off pump with control valve, energy savings are only achieved due to the lower delivery pressure and not the lower flow rate, as is the case in hot water systems.

The energy savings therefore vary, depending on the capacity utilisation and actual operating pressure of the system:

- By a few percentage points with higher capacity utilisation and operation at configured pressure
- By up to 60% during frequent operation with reduced operating pressure and lower capacity utilisation

Speed control

Due to the dominance of the static back-pressure, the speed control must limit the maximum and minimum pump speed according to the boiler pressure and therefore keep the current operating point within the range of the pump characteristic map (area highlighted in grey).

→ Fig. 76, page 161

A comparison between points 1 and 4 shows just how difficult this is. While the pump only just delivers the minimum flow rate (point 1) at 90% of the pump speed with p_{PL} = 15 bar, it already delivers the full nominal feed water flow rate (point 4) at the same speed with $p_{(B,on)}$ = 12 bar.

The system characteristic for the reduced operating pressure $p_{m/2}$ demonstrates this even more emphatically.

NPSH (net positive suction head) value

The NPSH value states the minimum static pressure at the pump intake port at which cavitation does not yet occur. This value is predefined by the design of the pump which depends on the flow rate and increases very sharply with higher flow rates. The range to the right of the maximum flow rate of 4.9m^3/h therefore cannot be used without risking damage to the pump due to cavitation.

Pump module PM

With the pump module, the boiler feed pump is mounted on a bracket and delivered ex works fully assembled with pressure display, shut-off valves, filter valves and non-return valves. To safeguard the operational availability of the boiler system if the feed pump develops a fault, two pump modules with fault response switchover are frequently installed.

Pump module with speed control

The feed pumps are also equipped with an inverter module. Because the frequency control is matched to the boiler operation, the motor speed of the pump can be steplessly controlled. This changes the pump curve which means the flow rate of the pump can be adapted to the current operating conditions in the boiler with regard to operating pressure and water level. This saves electrical drive energy, especially when the pressure in the boiler is reduced and in partial load.

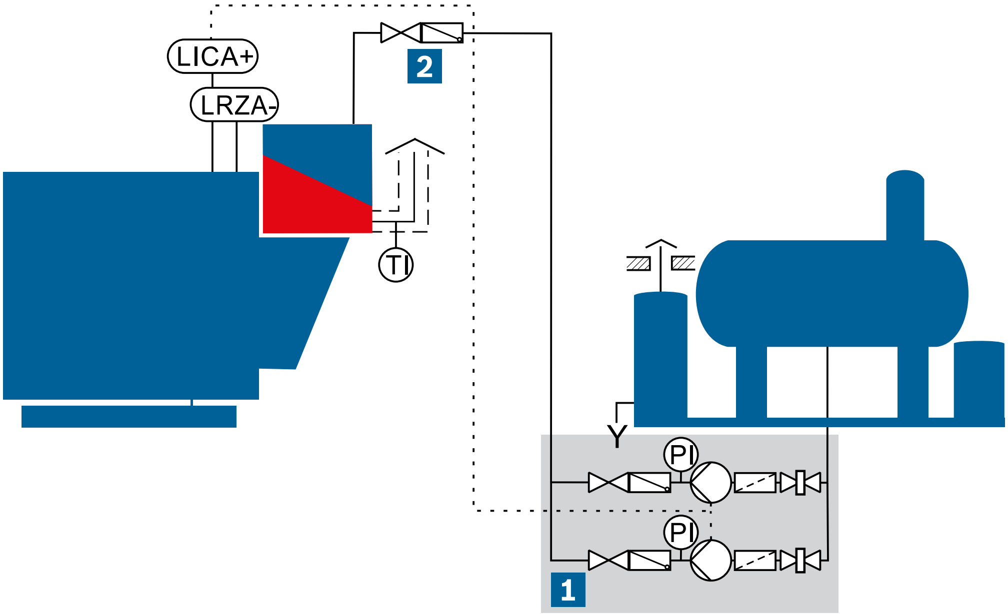

Fig. 77 *Schematic diagram of a pump module with all valves*

1	Feed water control module
2	Shut-off assembly upstream of boiler
PI	Pressure indicator (pressure gauge)
TI	Temperature indicator
LICA+	Level transmitter
LRZA-	Low water level limiter

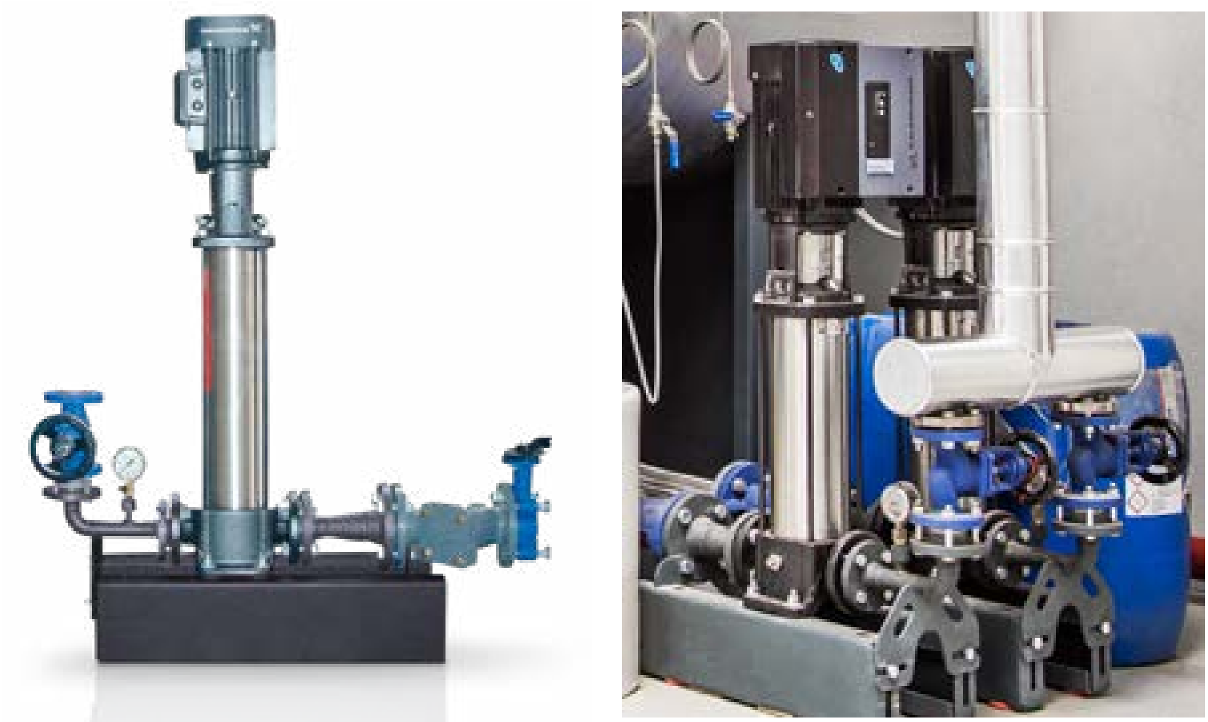

Fig. 78 *Pump module and double module*

Benefits:

- Especially low investment costs
- Especially low operating costs
- Pump curve can be matched to different operating pressures
- Smooth start and therefore no pressure surges when switching the pump on and off
- Reduced risk of cavitation during operation because of lower flow rates

To consider:

- The control ratio of V_{min} to V_{max} should be at least 1:4
- When using economisers, the smallest frequency control range of the feed pump should whenever possible cover the part load control range of the burner. If necessary, a speed-controlled feed pump can also be combined with a feed water control valve.

Example and explanations of a characteristic map of a speed-controlled boiler feed pump

A speed-controlled boiler feed pump of a boiler equipped with economiser with m_S = 4,000kg/h nominal steam output and p_m = 13.3 bar average operating pressure is used as an example.

Pump module with/without speed control and supply control

If a speed-controlled feed pump is not installed, or if the speed-controlled pump cannot cover the necessary control range, a modulating control with the feed water control module RM is recommended for all boilers equipped with modulating burners and flue gas heat exchangers. The module ensures longer flow times in the flue gas heat exchanger and therefore optimum heat recovery from the boiler flue gases. At the same time, this also secures the minimum quantity required for the feed pump cooling via the feed water control module. The preassembled module is used in a suitable location in the feed water pressure line.

The feed water control module for stepless boiler feed consists of a feed water control valve, a drainage unit, a dirt trap and a bypass with corresponding shut-off valves.

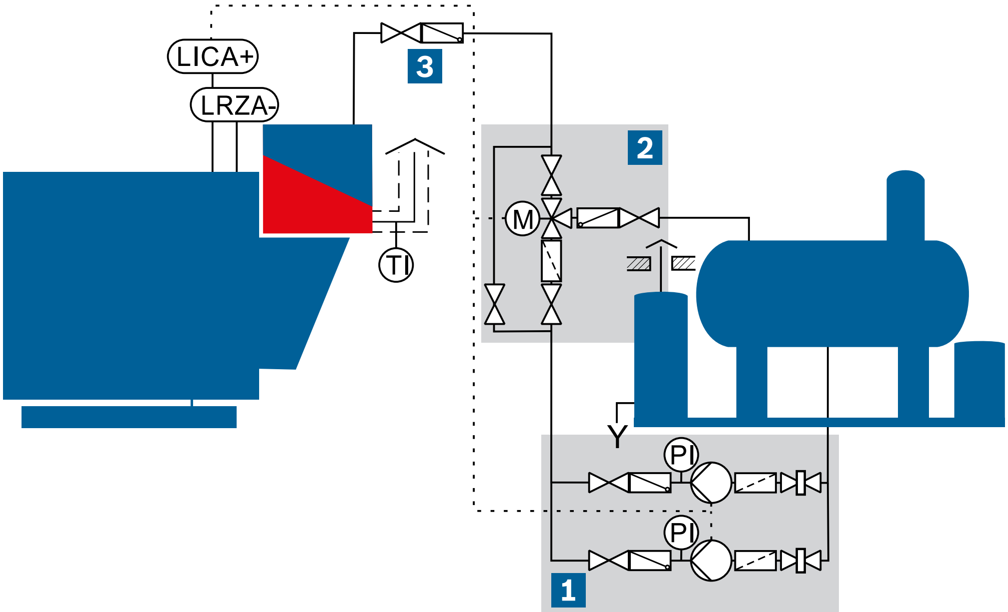

Fig. 79 *Schematic diagram of a pump module and a feed water control module with all valves*

1	Pump module	**PI**	Pressure indicator (pressure gauge)
2	Shut-off assembly upstream of boiler	**TI**	Temperature indicator
3	Feed water control module	**LICA+**	Level transmitter
		LRZA-	Low water level limiter

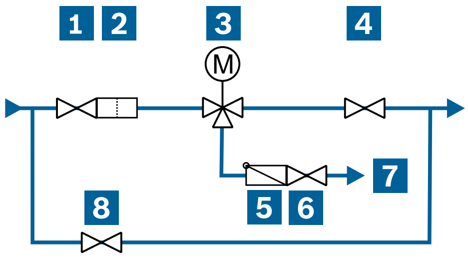

Fig. 80 *Feed water control module*

1 Shut-off valve
2 Dirt trap
3 Feed water control valve with pump bypass
4 Shut-off valve
5 Non-return valve
6 Shut-off valve
7 Pump bypass to feed water vessel
8 Bypass shut-off valve

Benefits:

- Secure minimum flow rate for cooling of feed pump
- Increased efficiency of flue gas heat exchanger
- Reduced number of pump switching operations
- Constant boiler water level

3.10 Boiler control

The boiler control continues to play a decisive role in ensuring safe, reliable and economic operation.

The safety requirements of the various regulations for installation and safe operation of boiler systems must therefore be observed. However, in addition to safety and reliable operation, further energy management requirements, such as data logging and continuous optimisation of boiler operation, are just as important. Furthermore, all the options for managing production from a central automation system should be available as operation. Overall economic performance is only possible through internal communication between the steam consumers and steam generators.

The basic tasks of the control cabinet are:

- Safety functions
- Control functions
- Operation and fault messages
- Data logging and evaluation
- Control interface
- Third-party maintenance

Since 2001, Bosch Industriekessel GmbH has been the first boiler manufacturer to use PLC-based control systems as standard in shell boilers. The concept became a resounding success on the market and has in the meantime become standard equipment.

The control systems are continuously under further development. A high degree of operating data transparency and connectivity is achieved using touchscreen displays with intuitively-operated graphical user interface in combination with the programmable logic controllers.

In addition to controlling the boiler, a number of additional control tasks must also be performed in a boiler system. These are dealt with together with the networking of controls in the chapter System control.

→ Technology – Chapter 4.6: System control SCO, page 206

Control systems

Fig. 81 *Bosch switchgear*

Nowadays, hardware from the field of programmable logic controllers which has been tried-and-tested in industrial applications is used more or less everywhere in state-of-the-art control systems to carry out the necessary control tasks at the boiler and in the boiler house.

The devices perform all control functions of the boiler or boiler system and can communicate with other controls (e.g. burner management systems, separate controls of boiler house modules and higher-level process control systems) via bus systems or networks. Due to the very high demands in terms of reliability, the safety chain is normally implemented using conventional contactor and relay technology.

All control software is stored on a micro memory card. This dispenses with the need to use back-up batteries or EPROMs to safeguard against voltage failures. The devices are compact, modular and are screwed onto a profile rail to form a robust EMC-compliant assembly. Depending on the requirements, optional devices such as additional inputs and outputs or a communication processor, e.g. for Profibus DP, can be combined for interfacing with the central automation system. Additional options are available such as an Industrial Ethernet network for connection of several control modules or preparation for the remote access MEC Remote.

→ Products – Chapter 6.6: MEC Remote, page 374

→ Products – Chapter 6.4: MEC Optimize, page 371

→ Technology – Chapter 4.6: System control SCO, page 206

The complex and stringent demands for safe boiler operation are met using factory-tested software function modules which are specially tailored to the relevant boiler and boiler system controls. The customer benefits from systems with a wide range of variants in which the individual software modules have already been used and tested many times over in practice. Special individual programming is only occasionally carried out in exceptional cases.

3.11 Boiler control BCO

Fig. 82 *Boiler control BCO – example of display for steam boilers*

A graphic TFT display with touch-sensitive interface is used for display and operation. Its extremely long service life, together with its light and contrast intensity makes it eminently suitable for the most demanding industrial applications. The graphic menu structures as well as the status indicators and process value archive are stored on a Multimedia Card (MMC) which is inserted into the control unit.

Graphical user guidance with outstanding operating data transparency

Fig. 83 *Examples of user guidance at the boiler control BCO*

To make operation easy, the design of the symbols, graphics and user guidance on the touchscreen displays is based on the latest insights in ergonomics and operability. All available control functions can be called up intuitively and the actual and set values displayed or modified in the colour display.

Many operating conditions, operating data and measurements of the boiler system are already indicated in the graphic display of the boiler control BCO with the standard equipment. This always includes the operating hours of the boiler and the burner and the number of burner starts, among other things. All specified switching points, switching differentials and limit contacts can be displayed. Important process data is stored on the memory card of the boiler or system control within a defined interval. The archive has a rolling structure: once the memory is full, the oldest process data is deleted and the newest data is archived. These can then be shown graphically as curves in the displays. The process archive can also be read out by the customer service. The data can be further processed in text or table processing software. Analysis of fuel consumption, steam or temperature progressions can therefore be easily displayed. The high degree of transparency in relation to operating data allows the control parameters to be easily optimised which in turn reduces energy consumption, pollutant emissions and general wear and tear of the boiler system.

Functions in boiler systems

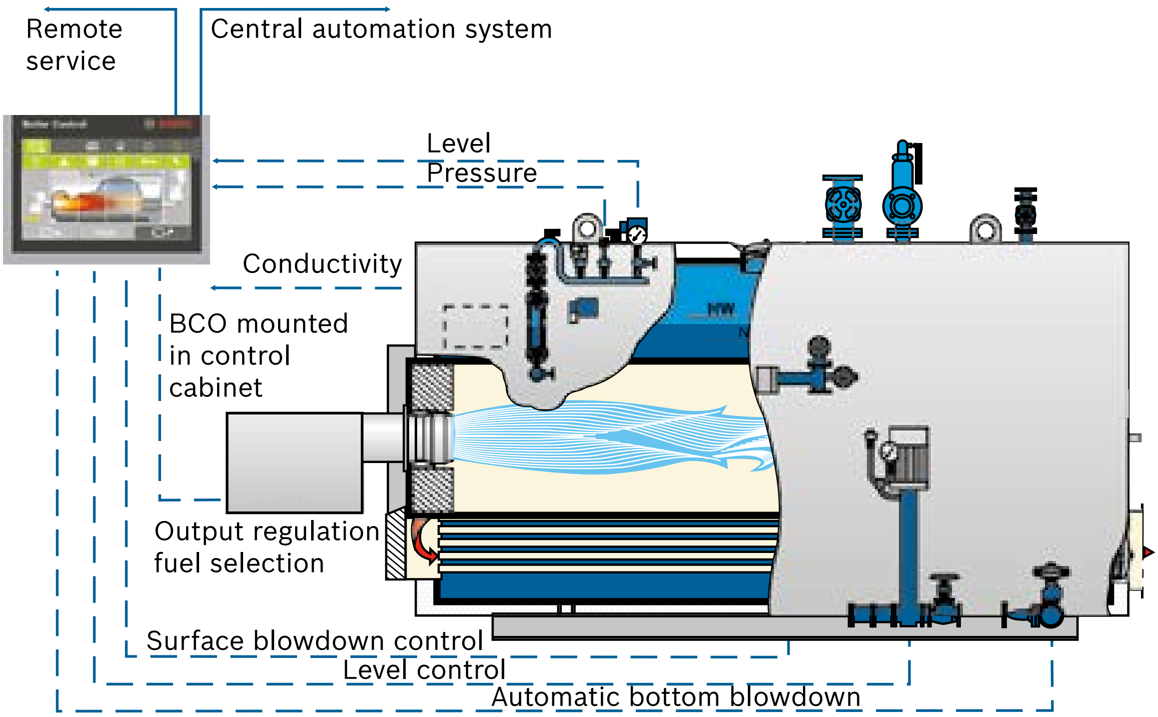

Fig. 84 *Standard functions of boiler control BCO for steam boilers*

Boiler control BCO for steam boiler systems

In addition to the standard output, level, water quality, blowdown and safety chain control functions that feature as standard in every steam boiler, the boiler control BCO can also be extended to include the following additional options and functions:

- Automatic starting from cold
- Measurement and control of flue gas temperature for boiler with economiser
- Measurement and control of superheated steam temperature for boilers with super heater
- Measurement of steam, feed water and fuel flow rates
- Automatic feed pump changeover via pressure, time or fault
- Time-controlled heat maintenance mode with pressure reduction
- Display of operating hours, start frequency, number of cold starts over time
- Detection of unfavourable start-up conditions
- Detection of soiling on the water and flue gas side or unwanted condensation
- Generation of service messages according to requirements
- Display of energy losses as a result of bottom blowdown and surface blowdown
- Display of fuel and water consumption over time
- Display of steam removal rate over time
- Display of boiler load profile over time

- Interfacing with higher-level control systems
- Remote maintenance via MEC Remote
- Interfacing with a central automation system

→ Technology – Chapter 3.2: Heat maintenance system, page 145

→ Technical report FB029: automatic start-up control for steam boilers

Condition Monitoring (CM)

CM allows customers to monitor their systems to ensure they are running efficiently and are operating normally. To do this, the system data are analysed, evaluated and displayed transparently according to a traffic light model.

→ Efficiency – Chapter 4.3.2: Condition Monitoring, page 296

3.12 Compact steam boiler control CSC

The control for the smaller steam output range of up to 4,000kg/h is a convincing product due to the ease of handling and is supplied ex works with all the important functions for semi-automatic boiler operation.

Fig. 85 *Compact control cabinet of CSC for steam boilers in the smaller output range*

The compact programmable logic control CSC is the ideal solution for steam boilers with outputs up to 4,000kg/h. It comes with all the important standard functions for convenient control and operation. Compared to the boiler control BCO which is designed for more complex systems, the CSC is an affordable alternative for standalone steam boilers.

Benefits:

- Attractive price-performance ratio for steam boilers with steam outputs of up to 4,000kg/h
- Colour touch display for straightforward operation and clear visualisation of operating conditions
- Flexible installation and space saving as the CSC is supplied ex works already installed on the boiler or as wall-mounted control cabinet pre-wired and function-tested
- Power electronics for fuel supply, feed water pump, bottom blowdown and surface blowdown
- Ideal water conditions due to fully automatic conductivity-controlled surface blowdown and bottom blowdown

Equipment, standard functions:

- Low water and high water level limiter
- Pressure limiter for maximum positive pressure
- Water level control, 2-step or stepless
- Boil-dry protection device for feed pump
- Output control, 2-step or stepless
- Alarm and fault messages with message memory

Optional equipment:

- External high water function
- Backup pump controller
- Conductivity control and limitation
- Automatic bottom blowdown and surface blowdown
- Heat maintenance via the combustion system
- Output control with two fuels

Construction:

The programmable logic controller is equipped with an intuitive touch display. It is integrated into a boiler control cabinet and permanently mounted on the boiler complete with wiring to the sensors, actuators and burner. Wall-mounted installation of the control cabinet is available as an option.

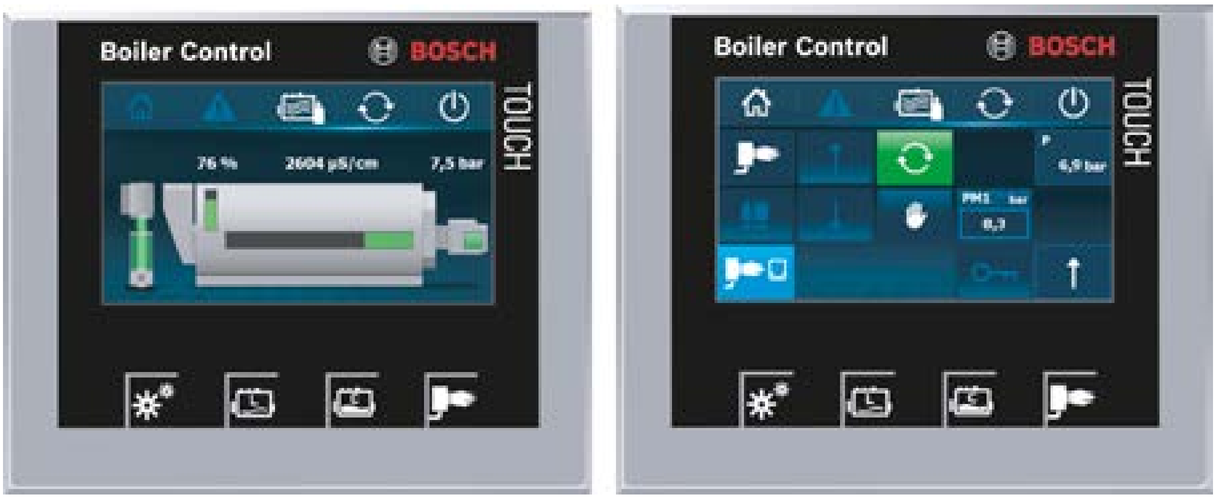

Fig. 86 *Examples of user guidance at the boiler control CSC*


BOSCH

4 Boiler house

The boiler house is a building or part of a building in which one or several steam boilers are installed. The auxiliary systems required for operation of the steam boiler are also normally installed in the same room.

These are specific systems for:

- Water treatment
- Water disposal
- Treatment, distribution and storage of steam and condensate
- Monitoring of the water quality
- Automation and control technology
- Heat recovery

Special regulations apply in this area.

→ Planning – Chapter 6: Legislation, page 63

The following diagram shows an example of the water-steam mass balance. The mass flow rates must be set up for every boiler house individually depending on the system components and operating conditions and are essential to any planning.

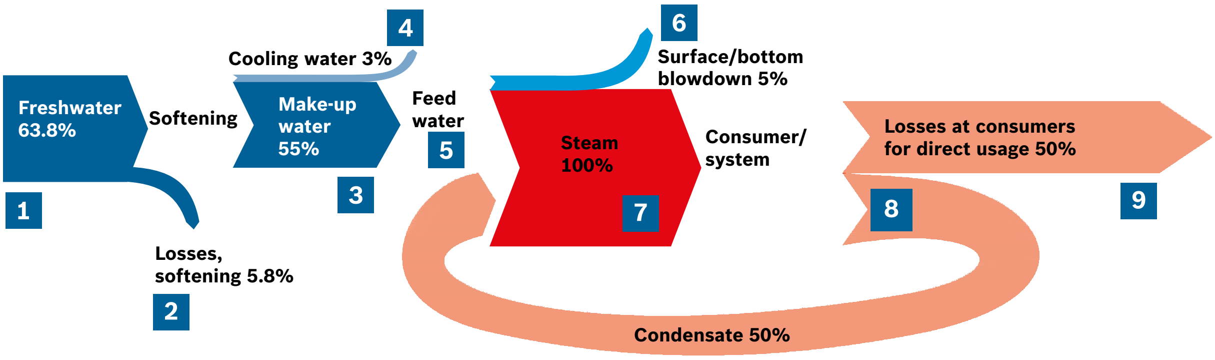

Fig. 87 *Mass balance in steam system (values shown are examples)*

1 Freshwater for softening
2 Losses during softening due to the regeneration
3 Make-up water for deaerating
4 Cooling water for the bottom blowdown vessel
5 Feed water to the steam boiler
6 Losses due to bottom/surface blowdown
7 Steam to the consumers
8 Condensate
9 Losses at the consumers (e.g. due to direct use)

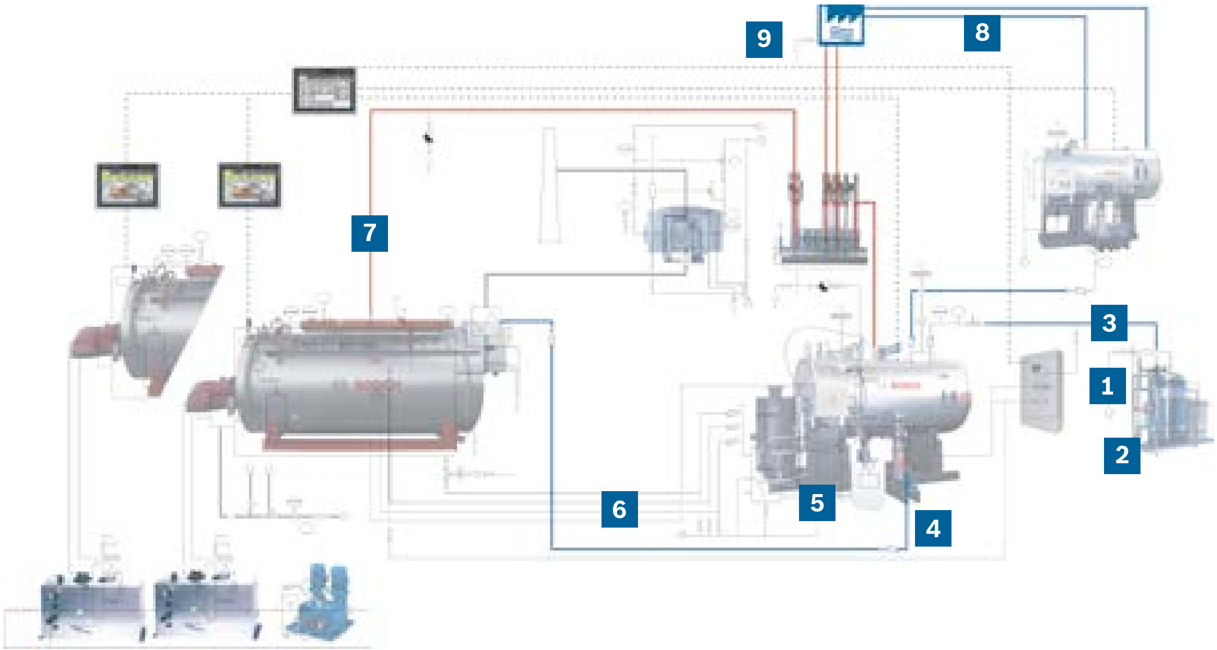

Fig. 88 *Example of a boiler house*

- **1** Freshwater for softening
- **2** Losses during softening due to the regeneration
- **3** Make-up water for deaerating
- **4** Feed water to the steam boiler
- **5** Cooling water for the bottom blowdown vessel
- **6** Losses due to bottom/surface blowdown
- **7** Steam to the consumers
- **8** Condensate
- **9** Losses at the consumers (e.g. due to direct use)

4.1 Water treatment

Correct water treatment is one of the most important fundamental prerequisites for safe and long-term operation of a boiler system. Strict requirements therefore exist in relation to the water quality of boiler systems.

The terms used in connection with boiler systems and their corresponding synonyms for the various water flows are explained briefly below.

Term	Explanation
Freshwater (raw water)	Untreated water that is obtained from the following sources: • Public system (mains water) • Own well • Spring This water is fed in to fill the system and replenish water lost and is normally admitted at temperatures of around 10°C.
Softened water (hardness-free water, soft water)	Water from which calcium (Ca^{2+}) and magnesium ions (Mg^{2+}) have been removed using an ion exchanger.
Partially demineralised water (permeate or demineralised water)	Water which contains more or less no salts. It has a conductivity of < 50 µS/cm and is normally recovered from softened water by reverse osmosis.
Demineralised water (deionised water)	Water which contains no salts whatsoever. It has a conductivity of < 1 µS/cm and is normally obtained by a combination of anion and cation exchangers.
Make-up water	Softened, partially or completely demineralised water which is fed into the feed water vessel for deaeration.
Oxygen-free condensate (high-pressure condensate)	Condensate which accumulates in closed tanks at pressures > 0.2 bar.
Feed water	Softened, deaerated and chemically conditioned water which is fed to the boiler via feed pumps.

Tab. 11 *Terms for the various water flows with explanations*

Errors made during water treatment, in the analysis accompanying the water treatment and insufficient monitoring of water quality are still the most common reasons why operation is disrupted or the steam boiler system is damaged.

For this reason, wide-ranging rules and regulations have been adopted at European level which precisely define the requirements for feed water and boiler water quality.

i

EN 12953-10 sets out specific guidelines for the appearance, conductivity, pH value, overall hardness, acid capacity and iron, copper, silicic acid, oil/grease, phosphate and oxygen concentration. The water should also be free of organic substances.

→ Technical report FB026: modern water treatment and water analysis

These requirements in relation to the feed water admitted to steam boilers and the boiler water lead to the reduction or elimination of the following causes of damage and faults:

- Corrosion
- Deposits on the water side
- Foaming of boiler water
- Sludge formation

The freshwater must be treated to ensure that the water values are complied with and thus avoid damage due to an increased concentration of problematic substances in the water.

Various measures are taken during the water treatment, depending on the output of the boiler system, condensate accumulation rate and ingredients in the available freshwater, to ensure the water is suitable for use during boiler operation.

The following illustration provides an overview of the contents of freshwater or condensate, the dangers they pose to the steam boiler and boiler system and the corresponding water treatment measures that must be taken.

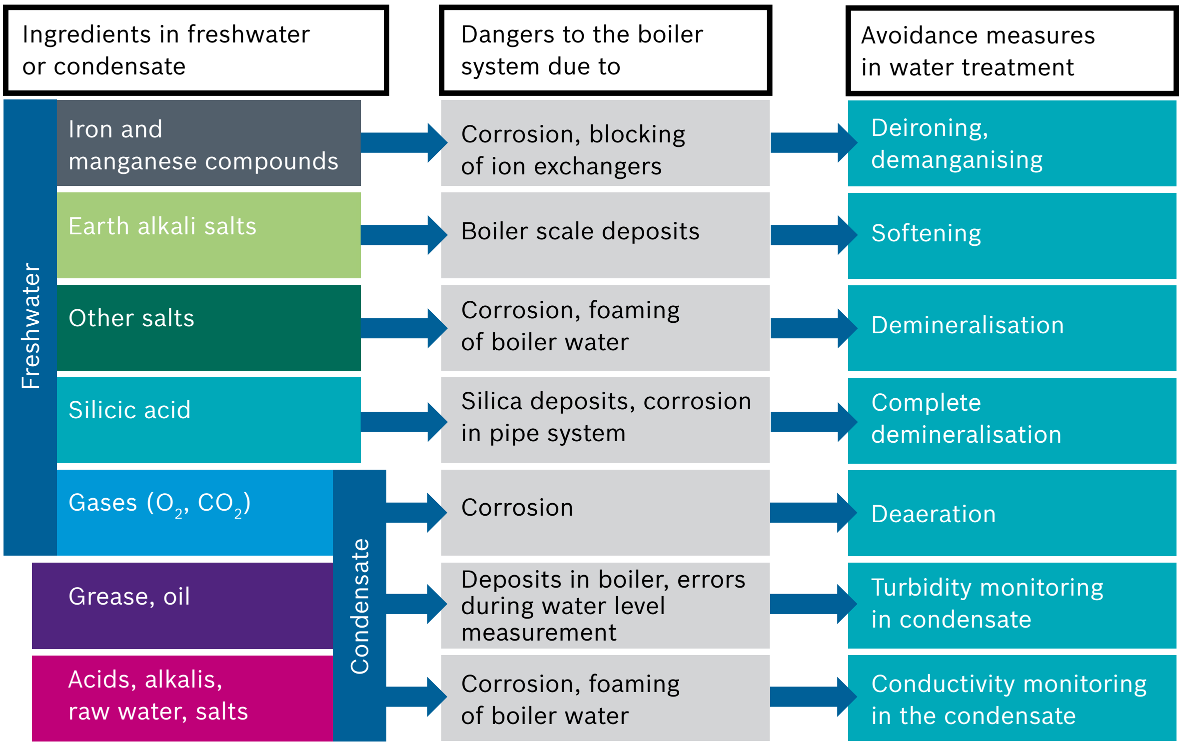

Fig. 89 *Ingredients of freshwater and condensate*

The starting point for designing a water treatment system should always be a detailed analysis of the available freshwater quality.

4.1.1 Deironing and demanganising

During deironing and demanganising, iron(II) (Fe^{2+}) and manganese(II) (Mn^{2+}) ions dissolved in the water are initially oxidised to form higher-quality ions. The oxidation can be carried out using oxygen (O_2), other oxidising chemicals such as potassium permanganate ($KMnO_4$) or via catalysis. The resulting by-products are subsequently filtered off via a filter granulate.

4.1.2 Softening

Among the substances dissolved in water, hardness is especially harmful to the operation of a boiler system. Hardness mainly comprises calcium and magnesium ions (Ca^{2+}; Mg^{2+}). If these so-called alkaline earth metals are present in the feed water, they can precipitate due to the heating in the boiler and form limescale which is deposited as a layer on the heating surfaces.

Fig. 90 *Layer formation in boiler with damage to flame tube*

If the formation of a layer or coating is not identified early on, this will lead to a deterioration in efficiency because the heat transfer is restricted. If the layers continue to thicken, this can lead to overheating of the heating surfaces and damage with serious consequences, which could also mean a total loss of the boiler.

To prevent this, the hardness components must be removed from the water.

Operating principle of ion exchanger

Ion replacement is the most common water softening method. This involves replacing the hardness-forming substances calcium and magnesium with sodium, which is harmless. Ion replacement is a straightforward and efficient water softening method which involves only the small cost of using special regeneration salt.

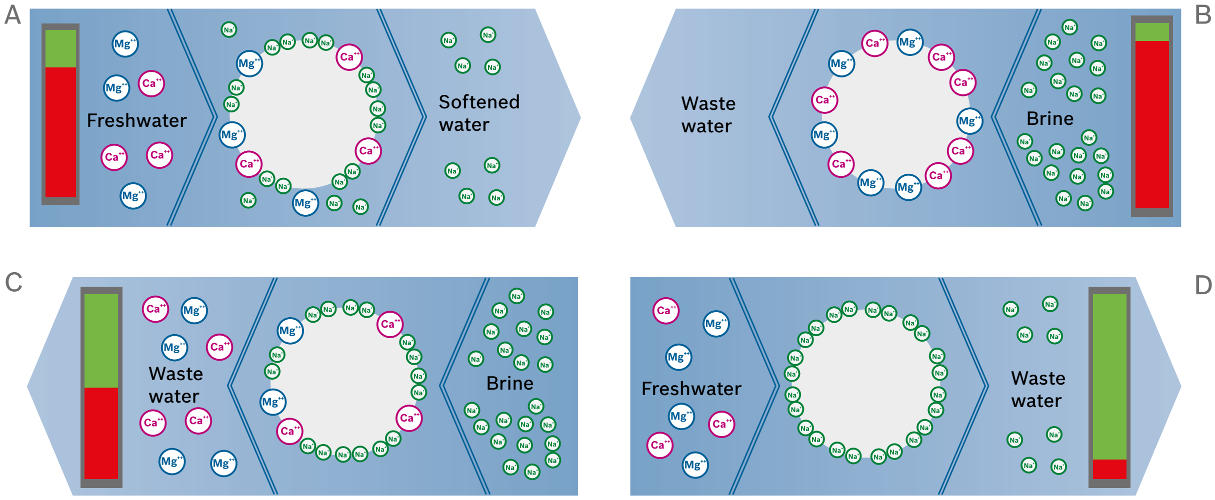

Fig. 91 *Principle of operation of an ion exchanger for water softening*

Operating condition A: softening of water

A chemical balancing reaction occurs during water softening through the exchange of ions. Sodium ions adhere to the exchanger resin in the pressure tank. When the calciferous water flows through the water softener unit, the calcium and magnesium ions in the water are bonded to the exchange resin. Sodium ions are released in exchange.

Operating condition B: start of regeneration

The exchange resin continues to accept new hardness components until it is saturated. The ion exchange resin must then be regenerated. Special softening salt is required for this which dissolves in water to form brine.

The exchange resin is flushed with the brine during regeneration. Due to the surplus sodium in the brine, the resin releases the calcium and magnesium ions once again and absorbs sodium ions.

Operating condition C: end of regeneration

As the resin primarily binds calcium and magnesium ions to it, it cannot be fully regenerated. It is therefore recommended that only water softeners with so-called economic brining are used.

Operating condition D: softening of water starts once again

Once the regeneration process is complete, the ion exchanger is flushed with water and is ready for another water softening cycle.

With larger water softener units it is recommended that dual systems are used. These can be operated on an alternating basis.

→ Fig. 92, page 181

In this way one ion exchanger can produce softened water while the other regenerates. Thus it can be ensured that softened water is always available.

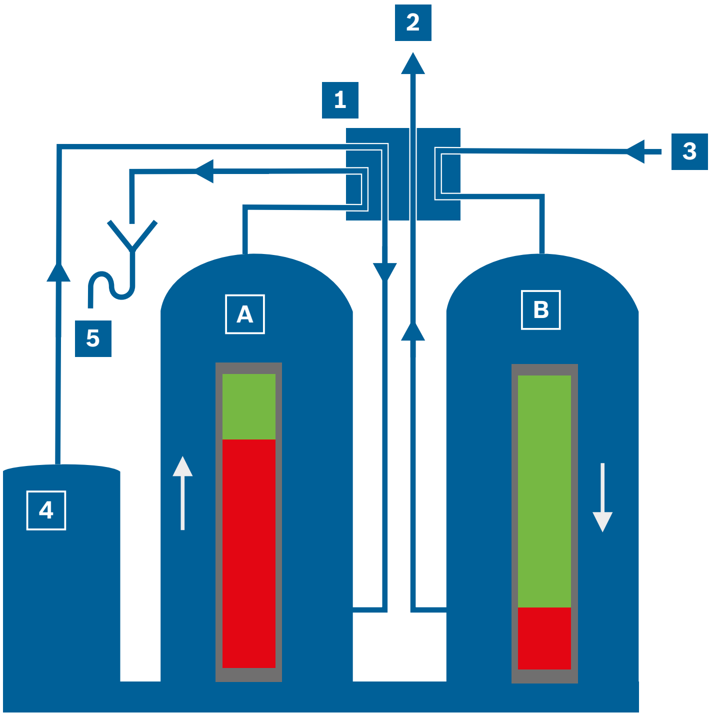

Fig. 92 *Schematic and visual representation of a dual water softener system*

- **A** Operating condition A: ion exchanger is regenerated in the countercurrent direction
- **B** Operating condition B: ion exchanger in operation
- **1** Changeover fitting: showing current flow direction
- **2** Softened make-up water
- **3** Freshwater
- **4** Container for regenerating solution
- **5** Waste water

4.1.3 Demineralisation

Water in the boiler evaporates leaving the salts dissolved in the water behind which means the salt concentration in the remaining boiler water increases. To avoid exceeding the permissible salt concentration, salt must continuously be removed and this is accompanied by energy and water losses.

To reduce the surface blowdown rate, demineralisation of the freshwater is advisable, especially with low condensate accumulation rates <50% and high conductivity in the freshwater. Demineralisation takes place after softening. One of the most common methods is reverse osmosis.

Calculation of surface blowdown rate

The required surface blowdown rate can be calculated based on the conductivity measured in the feed water or the make-up water parameters and condensate accumulation rate (the conductivity of condensate is normally negligible):

$$a = \frac{L_{FW}}{L_{boi} - L_{FW}} \approx \frac{L_{MW} \cdot (1 - c)}{L_{boi} - L_{MW} \cdot (1 - c)}$$

F19. *Equation for calculation of surface blowdown rate*

a	Surface blowdown rate of feed water quantity [%]
L_{FW}	Conductivity in feed water [μS/cm]
L_{MW}	Conductivity in make-up water [μS/cm]
L_{boi}	Permissible conductivity of boiler water [μS/cm]
c	Condensate accumulation rate

In addition to conductivity, the surface blowdown rate is determined by other water parameters such as the silicic acid content SiO_2 or (carbonate) hardness with the limit value 8.2. In this case the biggest value calculated is always decisive for the actual surface blowdown rate.

These parameters can be calculated along the same lines as the above formula for the conductivity:

	Unit	Conductivity	SiO_2	Acid capacity 8.2
Steam quantity	[kg/h]	10 000	10 000	10 000
Surface blowdown rate (as a function of steam quantity)[1)]	[%]	**3.27**	2.56	3.00
Proportion of condensate c	[%]	50	50	50
Proportion of freshwater	[%]	50	50	50
Value in freshwater	[μS/cm]	380	7.5 [mg/l]	0.7 [mmol/l]
Limit, boiler water	[μS/cm]	6 000	150 [mg/l]	12 [mmol/l]
Value in feed water	[μS/cm]	190	3.75	0.35
Surface blowdown quantity	[kg/h]	**327**	256	300
Feed water quantity	[kg/h]	**10 327**	10 256	10 300

Tab. 12 *Calculation of surface blowdown rate*

1) The surface blowdown rate is determined by the biggest value. In this example, the value for conductivity 3.27%.

Reverse osmosis

Reverse osmosis is based on the principle that the diffusion resistance of the pores of the separation membranes is significantly lower for the smaller water molecules than the resistance of the bigger ions dissolved in the water. If the system is in equilibrium, the pressure on the concentrate side (retentate) is higher than the pressure on the pure water side (permeate). This is also referred to as osmotic pressure and is apparent from a difference in height.

→ Fig. 93, page 183, [A]

Demineralisation of the water for technical operations is carried out with the assistance of artificial membranes whereby the natural osmosis process is reversed by means of pressure charging on the concentrate side. Dissolved salts and also organic substances are more or less completely retained during this process.

→ Fig. 93, page 183, [B]

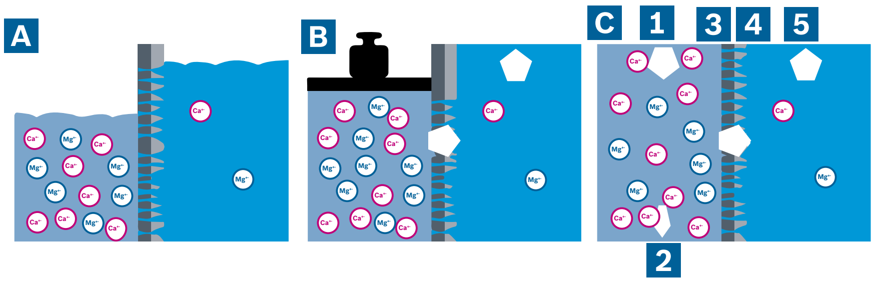

Fig. 93 *Visualisation of osmotic pressure (A), reverse osmosis by pressure charging on the concentrate side (B) and the continuous reverse osmosis process (C)*

A Illustration of osmotic pressure
B Reverse osmosis by pressure charging on the concentrate side
C Process of continuous reverse osmosis
1 Freshwater
2 Retentate
3 Semi-permeable membrane
4 Carrier layer
5 Permeate

Separation process	Strainer filtration	Fine filtration	Particle filtration	Micro filtration	Ultra filtration (UF)	Nano filtration (NF)	Reverse osmosis (RO)
Separation limits	>500µm	5 – 500µm	1 – 10µm	0.1 – 1µm	0.01 – 0.1µm	0.001 – 0.01µm	< 0.001µm
Separable substances	Grains, Sand, Fibres	Larger particles, algae	Small particles, germs, bacteria, viruses	Micro-particles, germs, bacteria, viruses	Viruses and molecular substances	Low-molecular substances and humic substances	Ions
Procedure in water technology	Screening, cyclones, sedimenta-tion, clari-fication	Fabric filter, cloth filter	Multi-layer fast filter, membrane filtration (MF)	Multi-layer slow filter, membrane filtration (MF)	Membrane filtration (UF)	Membrane filtration (NF)	Reverse osmosis (RO)
Separation limits	> 1mm	500µm	10µm	1µm	100nm	10nm	1nm

Tab. 13 *General overview of separation limits and separation methods in water treatment*

The generated pure water is continuously available and the condensate that accumulates can be introduced into the sewer system without further treatment.

The prerequisite for using a reverse osmosis system is that the water is softened beforehand. The water must also be clear and free of insoluble foreign matter and it is especially important that it is also free of organic contaminants to avoid blocking the membranes.

The softened water is admitted to the modules which are equipped with a membrane at a pressure of < 40 bar. Fine water and a very small proportion of small salt ions diffuse through the membrane and form the permeate (latin: *permeare* = penetrate), which is then available as partially demineralised water. The proportion of permeate in the filtered water is 80 – 95%. The rest (5 – 20%) of the original volume of water is the salty concentrate, also referred to as retentate (latin: *retinere* = retain), which is discarded.

The reverse osmosis process takes place while the system is continuously in operation, is virtually chemical-free and removes roughly 98% of the salts so that the conductivity of the permeate is less than 15 µS/cm. The system is monitored throughout this process to make sure it is functioning correctly by measuring the conductivity in the permeate.

In order to keep the systems that perform the reverse osmosis as small as possible, a permeate collection vessel is recommended. This then feeds the deaerator of the feed water vessel.

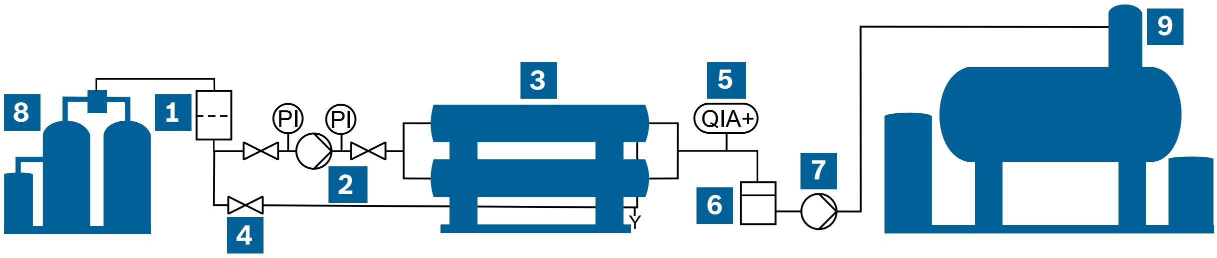

Fig. 94 *Schematic representation of a reverse osmosis water treatment with permeate vessel*

1 Filter
2 High-pressure pump
3 Reverse osmosis module
4 Bypass
5 Conductivity monitoring **(QIA+)**
6 Permeate vessel
7 Permeate pump
8 Water treatment module **WTM**
9 Water service module **WSM-V**

Complete demineralisation

Complete demineralisation of the water with a conductivity of < 0.2 µS/cm is achieved by a complete ion exchange with CO_2 percolator, providing a mixed-bed filter is also installed downstream of the anion exchanger. Cation and anion exchangers are combined in the filter. To optimise the complete demineralisation process and reduce consumption of regeneration agent, weak acidic and weak alkaline anion exchangers are installed upstream of the strongly acidic or strongly alkaline exchangers. The completely demineralised water is also referred to as deionised water.

4.1.4 Thermal deaeration

Corrosive components in the feed water or condensate can damage the feed water vessel, boiler, economiser or the pipework. This is mainly caused by oxidisation or carbonic acid corrosion.

Oxidisation causes pinholes to form at various locations in the base material. Over time the material becomes more deeply eroded. “Pitting corrosion”, a typical pattern of damage, appears.

Fig. 95 *Damage due to oxidation in the boiler and on the pipework*

The outward sign of carbonic acid corrosion (CO_2 corrosion) on the other hand is almost always a relatively uniform surface erosion of the material.

Thermal deaeration is an effective way to keep oxygen and carbon dioxide levels in the feed water permanently below the harmful range. This method makes use of the fact that gases become less soluble in water as its temperature increases. Their solubility falls to virtually zero at 100°C.

The values are based on the equilibrium of the solubility. In order to actually achieve the outgassing, there must be an active exchange between the gases dissolved in the water and the steam space of the feed water vessel which is achieved using trickle or spray deaerators. Here, a large phase limit is generated to facilitate fast transportation of the material into the gas phase. Furthermore, the water must remain in the container for a certain amount of time in order to expel the remaining gases.

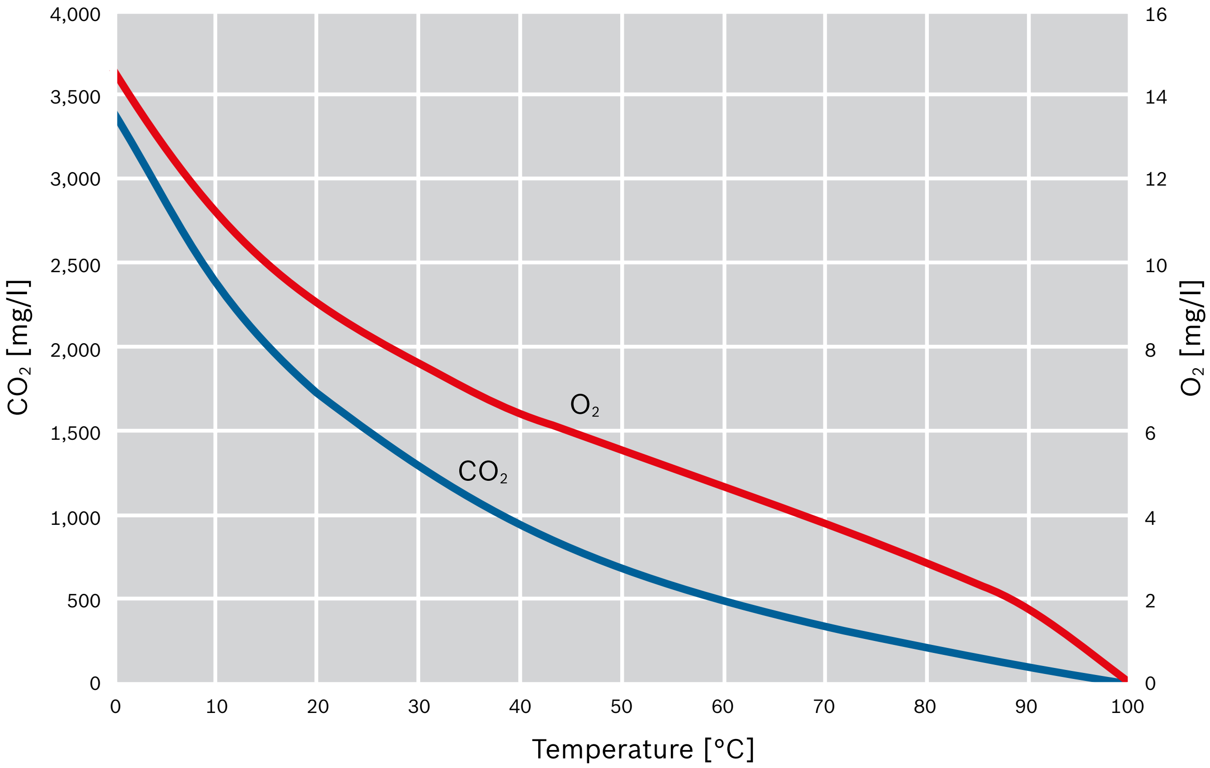

Fig. 96 *Solubility of oxygen and carbon dioxide in water*

Carbon dioxide (CO_2)

Oxygen (O_2)

Fig. 97 *A water service module, consisting of feed water vessel with trickle deaerator, feed pump modules, blowdown expansion vessel, dosing tanks and corresponding control cabinet*

Freshwater or oxygenic condensate is introduced at the top in the deaerator dome and finely distributed, either by spray nozzles or trickle trays. It is heated up to boiling temperature by heat-up steam which flows through the deaerator in the countercurrent direction from the bottom to the top. The gases released during heat-up are removed together with the necessary exhaust vapours at the top end of the deaeration dome.

The majority of heat in the exhaust vapour can be transferred to the make-up water via an exhaust vapour heat exchanger (VC) and is therefore retained by the steam system.

→ Efficiency – Chapter 3.2: Exhaust vapour, page 280

→ Products – Chapter 4.8: Vapour cooler VC, page 350

Full deaeration

Full deaeration occurs when the maximum oxygen content of 0.02mg O_2/l and maximum CO_2 content of 1mg CO_2/l can be reliably maintained at operating pressures of 0.1 – 0.3 bar and therefore temperatures above 100°C.

Chemical oxygen binders are only used to a very limited extent in this case to ensure the feed water contains no oxygen whatsoever.

	Spray deaerator	Trickle deaerator
Room height	++ Very compact	– Deaerating dome extends upwards
Investment costs	+ Slightly lower	– Slightly higher
Operating conditions deviate from design conditions (condensate flows)	– Partial load barely possible	++ Very good partial load behaviour
Use of make-up water continuous control[1)]	– Partial load barely possible	++ Very good partial load behaviour

Tab. 14 *Comparison between spray deaerator and trickle deaerator*

1) Recommended for heat recovery with make-up water

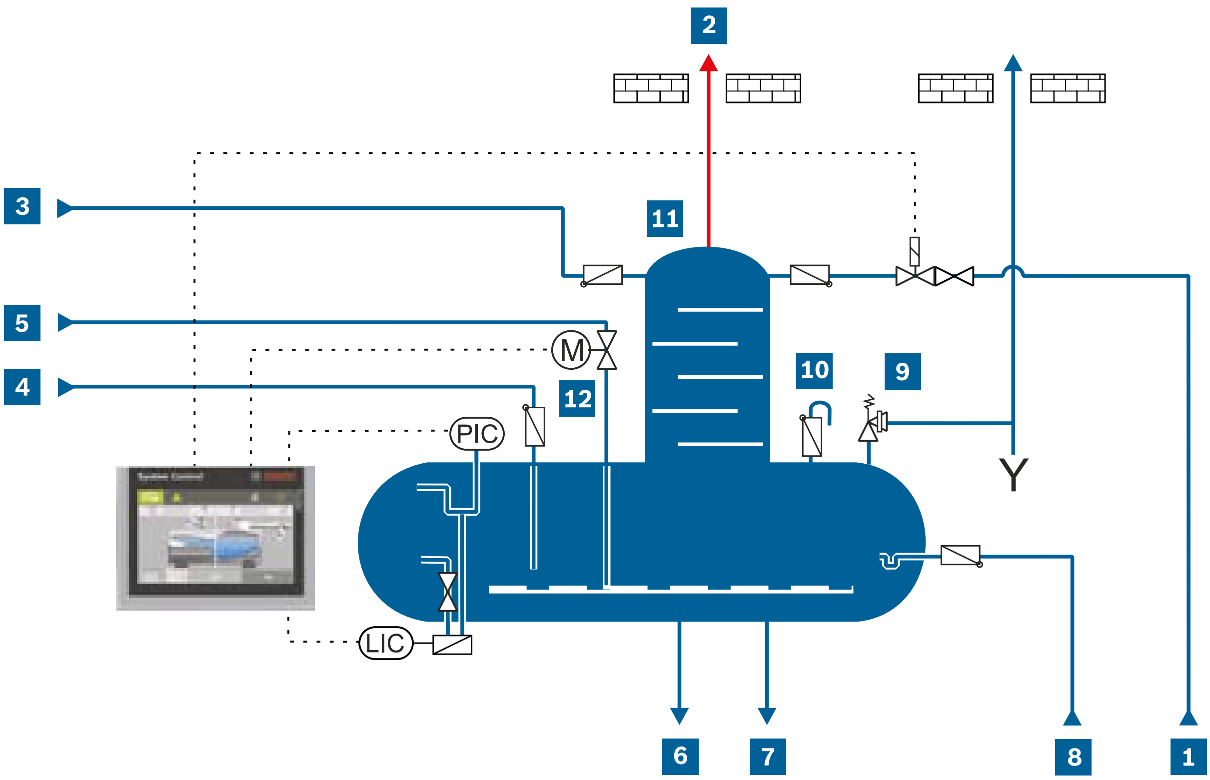

Fig. 98 *Piping and instrumentation flow diagram for full deaeration with trickle deaerator*

LIC Level transmitter

PIC Pressure transmitter

1 Make-up water
2 Exhaust vapour
3 Oxygenic condensate
4 Oxygen-free condensate
5 Heat-up steam
6 Feed water
7 Drain
8 Dosing
9 Safety valve
10 Anti-vacuum valve
11 Trickle deaerator
12 Heat-up steam control valve

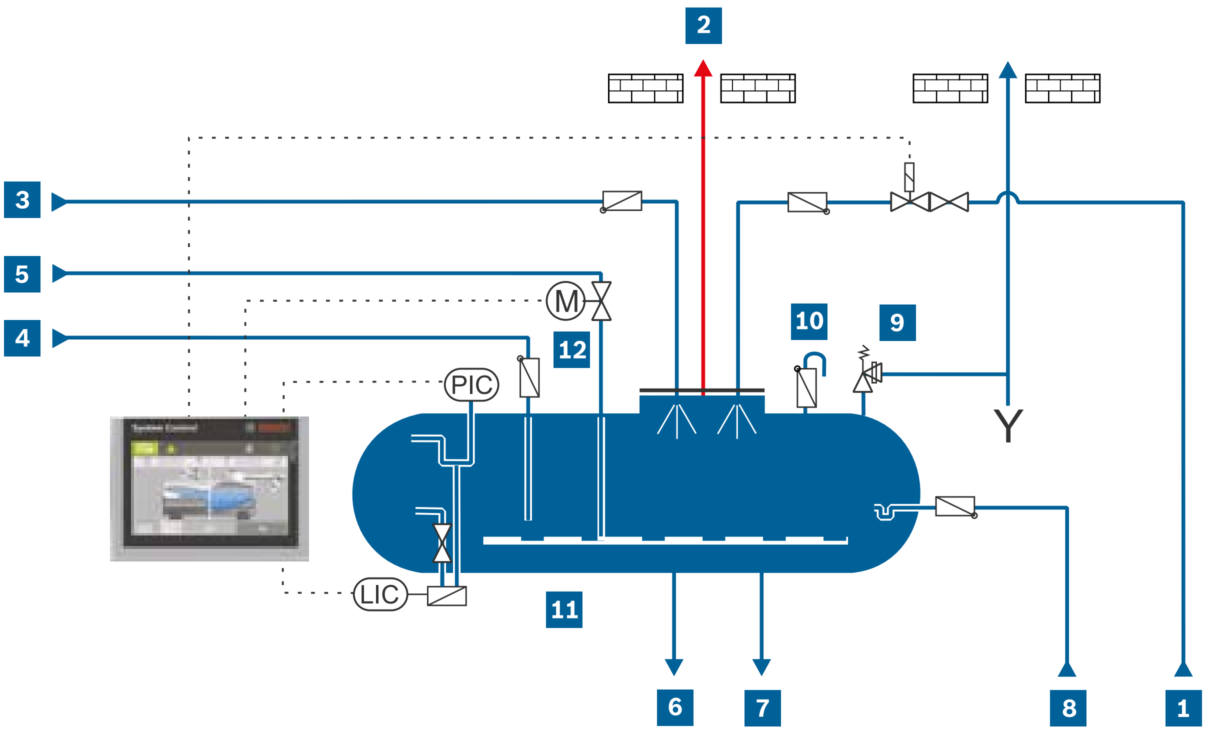

Fig. 99 *Piping and instrumentation flow diagram for full deaeration with spray deaerator*

LIC Level transmitter
PIC Pressure transmitter

1 Make-up water
2 Exhaust vapour
3 Oxygenic condensate
4 Oxygen-free condensate
5 Heat-up steam
6 Feed water
7 Drain
8 Dosing
9 Safety valve
10 Anti-vacuum valve
11 Spray deaerator
12 Heat-up steam control valve

Partial deaeration

If the deaeration only takes place at around 90°C, this is referred to as partial deaeration as a residual quantity of the bonded gases can still remain in the water. In this case, use of chemical oxygen binders must be intensified in order first and foremost to chemically bind the remaining oxygen in the feed water to prevent corrosion in the boiler and rest of the steam system.

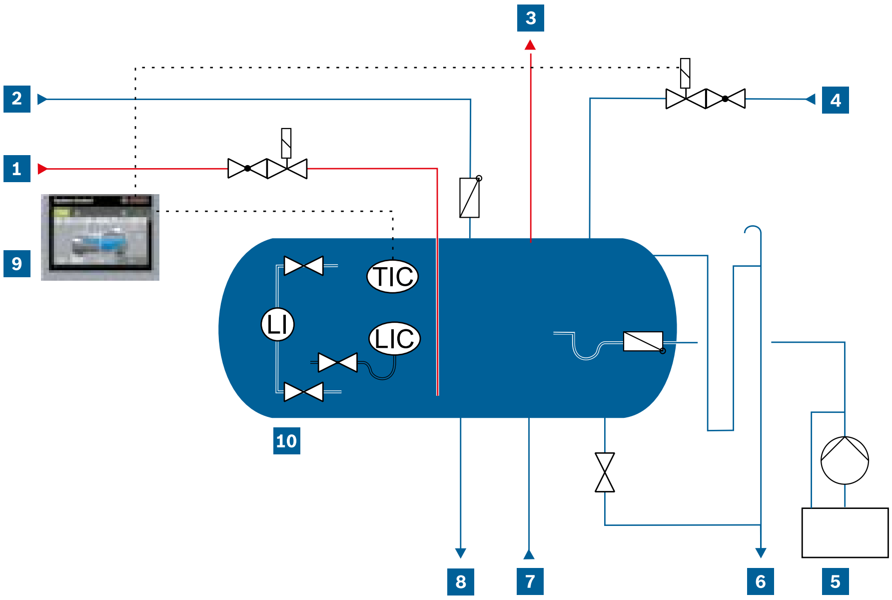

Fig. 100 *Feed water supply – partial deaeration*

LI Level indicator
LIC Level regulator
TIC Temperature controller

1 Heat-up steam pipe
2 Condensate feed line
3 Exhaust vapour pipe
4 Make-up water
5 Chemical dosing
6 Drain line and overflow
7 Feed pump bypass
8 Feed water line
9 Control system
10 Feed water vessel

4.1.5 Chemical dosing

To make absolutely sure the required water qualities are achieved and monitored, additional treatment must be carried out to improve specific feed water and boiler water characteristics.

This chemical dosing helps ensure the following:

- Binding of residual oxygen
- Reduction of corrosion by setting the pH value
- Stabilisation of residual hardness
- Prevention of deposits and limescale formation

This involves adding the dosing agents to the feed water vessel so that a sufficient reaction time of roughly 30min is achieved.

Sodium sulphite is normally used as an oxygen scavenger agent and trinatrium phosphate is used to bind the residual hardness and raise the pH value.

→ Technical report FB026: modern water treatment and water analysis

4.2 Water disposal

The conditions for introducing waste water to the public sewer system are normally defined by the local authorities. In Germany, the pH value of the waste water is normally between 6.5 – 10 and it is normally introduced into the sewer system at a temperature of 35°C.

4.2.1 Hot waste water

The hot pressurised waste water from the boiler during bottom blowdown and surface blowdown must be cooled before it is introduced into the sewer system. This takes place in a so-called bottom blowdown vessel into which hot waste water is admitted via two connectors (one connector for waste water over and under 100°C respectively). Expansion steam accumulates in the vessel which is discharged through the roof into the atmosphere. The remaining waste water is cooled to the permissible temperature at which it can be introduced to the sewer system by adding cool water.

Fig. 101 *Blowdown expansion and cooling module BEM*

1 Through-roof expansion steam pipe
2 Temperature measuring sensor
3 Connection for cooling water (incl. temperature control valve)
4 Outlet for drainage
5 Connection for waste water <100°C
6 Drain to sewer
7 Connection for waste water >100°C

As waste water carries a great deal of energy which can be used at temperatures of around 100°C, use of a heat recovery module should be considered, especially in view of the low amortisation time.

→ Efficiency – Chapter 3.1: Surface blowdown and bottom blowdown, page 277

4.2.2 Water disposal – flue gas condensate

Flue gas condensate forms from time to time when starting the boiler system from the cold state and continuously during utilisation of calorific value with a condensing heat exchanger. This condensate is acidic (ph value < 4) and, to comply with the conditions for introduction of waste water into the public sewer system, must be neutralised before being discharged into the sewer.

Depending on the quantity of condensate, systems containing neutralisation granules or liquids are used for this.

Fig. 102 *Flue gas condensate neutralisers (left: granule-based system, right: liquid-based system)*

4.3 Steam treatment, distribution and storage

4.3.1 Steam drying

The so-called steam quality is determined by the amount of residual moisture in the steam flow. It is advantageous if the water content is as small as possible. Steam dryers can separate the small water droplets carried along in the steam. This also removes salts or contamination they contain from the steam.

A steam baffle plate is already installed at the steam feed connector of steam boilers for this purpose. The deflection of the steam flow separates the water droplets which fall back into the water chamber. This already reduces the residual moisture content to 1 – 3% during normal operation. This is sufficient for most applications.

Further reduction in the steam moisture is only required if the load fluctuations on the consumer side are very rapid or if a super heater module is used. A demister equipped with a special wire mesh can be used for this and is also located below the steam feed connector. The residual moisture can then be reduced to roughly 0.1%.

Fig. 103 *A demister, as installed in the steam boiler below the steam feed*

Due to the heat losses in the steam pipe, the steam moisture along the pipework increases which is why a steam dryer can be used directly upstream of steam consumers, especially when using steam for drying purposes. In steam dryers the moist steam is admitted tangentially into the dryer and the centrifugal forces push the heavier droplets outwards against the wall where they are separated. The steam is then deflected through 180° in the bottom section where the smaller water droplets are separated and then flows out with a residual moisture content of <0.5%.

4.3.2 Steam pressure reduction

A reduction in steam pressure can occur for several reasons:

- To compensate for pressure fluctuations in the steam boiler which ensures an extremely constant pressure level for the steam consumers
- To separate the boiler output control from sudden load variations at the consumer
- Consumers require different pressure levels
- The maximum permissible positive pressure of the consumers is lower than the one of the steam boiler

The steam pressure is reduced using so-called pressure reducing stations which are motor, pneumatically or medium-controlled. Medium-controlled reducing stations require no auxiliary energy or electrical components but their control quality is occasionally poorer than motor-controlled or pneumatically-controlled valves.

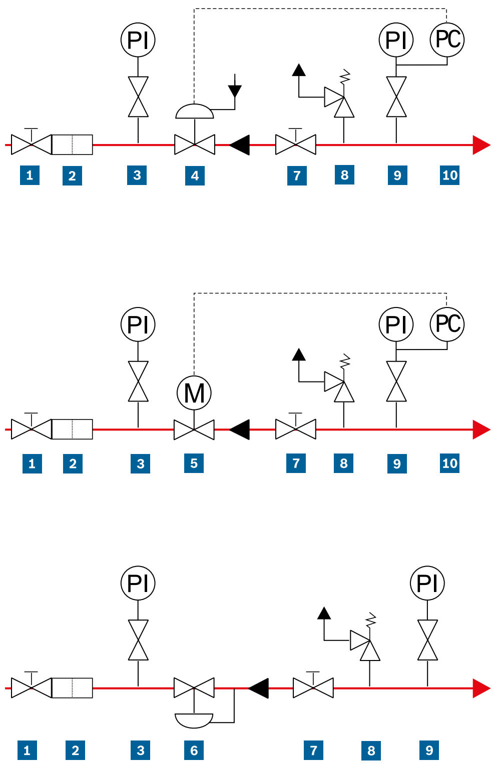

Fig. 104 *Steam pressure reducing station (pneumatically. motor or medium-controlled)*

1 Shut-off valve (primary pressure side)
2 Dirt trap
3 Pressure indicator (primary pressure side)
4 Control valve (pneumatically-controlled)
5 Control valve (motor-controlled)
6 Control valve (medium-controlled)
7 Shut-off valve (secondary pressure side)
8 Safety valve
9 Pressure indicator (secondary pressure side)
10 Pressure transmitter

4.3.3 Steam distribution

Steam distributors are used to combine the steam generated by one or several boilers in a central location (normally the boiler house) then distribute it among the various consumers at the operating premises, as well as the feed water heating.

The steam is also dried, i.e. the residual moisture content reduced, due to the 180° deflection of the steam between the generator and consumer.

The pressure at the steam distributor is also normally measured for the purpose of pressure-controlled boiler sequence control.

Benefits:

- Combining of the steam from the steam generators
- Distribution among the consumers
- Control of boiler sequence control
- Steam drying and dewatering

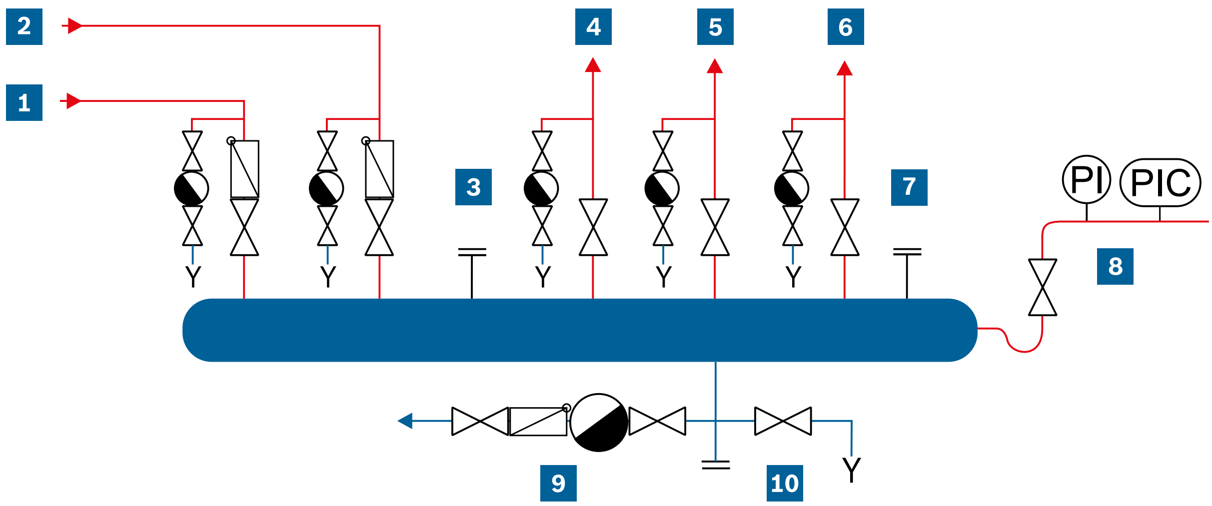

Fig. 105 *Schematic representation of a steam distributor*

1 Supplying steam pipe from boiler 1
2 Supplying steam pipe from boiler 2
3 Reserve connector for additional boiler
4 Outgoing steam line to consumer 1
5 Outgoing steam line to consumer 2
6 Outgoing steam line to feed water deaeration
7 Reserve connector for additional consumer
8 Manostat tube with pressure indicator **(PI)** and pressure transmitter **(PIC)**
9 Condensate pipe to condensate tank
10 Drain

4.3.4 Steam storage

The purpose of the steam accumulator is to store a limited quantity of energy which is available as expansion steam when the pressure is reduced.

→ Technology – Chapter 1.1.7: Expansion steam, page 106

The steam accumulator has the following application area:

- Provides peak load coverage when the capacity of the installed steam generators is briefly exceeded (e.g. during start-up processes of consumers, with autoclaves, a few large batch processes)
- Damping rapid load fluctuations of consumers with heavy cyclical steam demands (e.g. with short recurring steam consumption peaks, many small batch processes)

Fig. 106 *Display of a steam accumulator module*

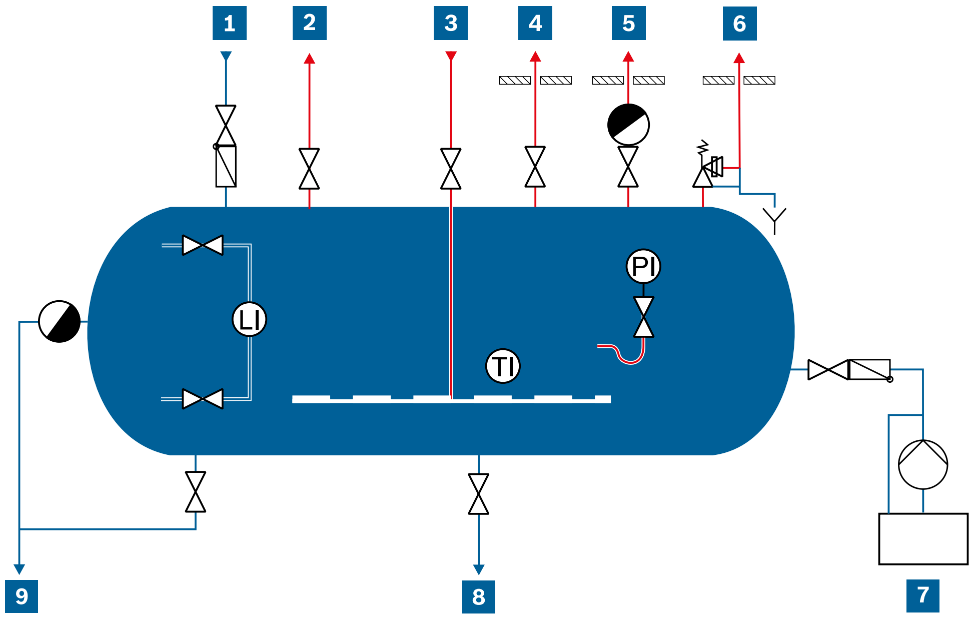

Fig. 107 *Schematic representation of pipework, steam accumulator module SAM*

LI Level indicator
PI Pressure indicator
TI Temperature indicator

1 Feed line
2 Steam pipe to the consumers
3 Heat-up steam pipe
4 Start-up line
5 Air vent line
6 Pressure safeguard blow-off line
7 Chemical dosing
8 Water sampling line
9 Drain line and overflow

When used correctly, a steam accumulator has the following benefits:

For the boiler:

- Reduced fluctuation of boiler pressure. This reduces the mechanical stress and increases the service life of the boiler shell
- Lower switching frequency of the combustion system. This reduces pre-ventilation losses and increases the service life of the boiler.

For the consumers:

- Covers especially high load peaks. The steam boiler can therefore be smaller
- Less water entrainment. This leads to an improvement in steam quality

The steam accumulator is a thick-walled container which is specially designed to cope with heavy pressure-change stresses. As is the case with the steam boilers, it is also subject to regular pressure testing by the approved notified body.

The steam accumulator is filled to 50% of its capacity with boiling water and is heated up to the charging pressure with steam from the boiler.

The accumulator is discharged by opening the shut-off valves on the consumer side. This reduces the pressure in the accumulator. Owing to the reduction in pressure, some of the boiling water evaporates producing what is referred to as expansion steam. The larger the water content of the accumulator and the greater the reduction in pressure the more steam will be produced.

→ Technology – Chapter 1.1.7: Expansion steam, page 106

When heating up again the same quantity of steam is supplied to the accumulator that was previously removed. It is therefore not normally necessary to supply additional feed water to the steam accumulator during operation.

The feasibility of using a steam accumulator can be investigated when planning new boiler systems and also as a retrofitting measure to improve existing processes. When using steam accumulators, special attention should be paid to overall integration into the steam system from steam boiler through to the consumer as the only way to fully reap the benefits is by ensuring optimum interaction of all components. The following figure shows which process and system parameters are decisive for the steam accumulator.

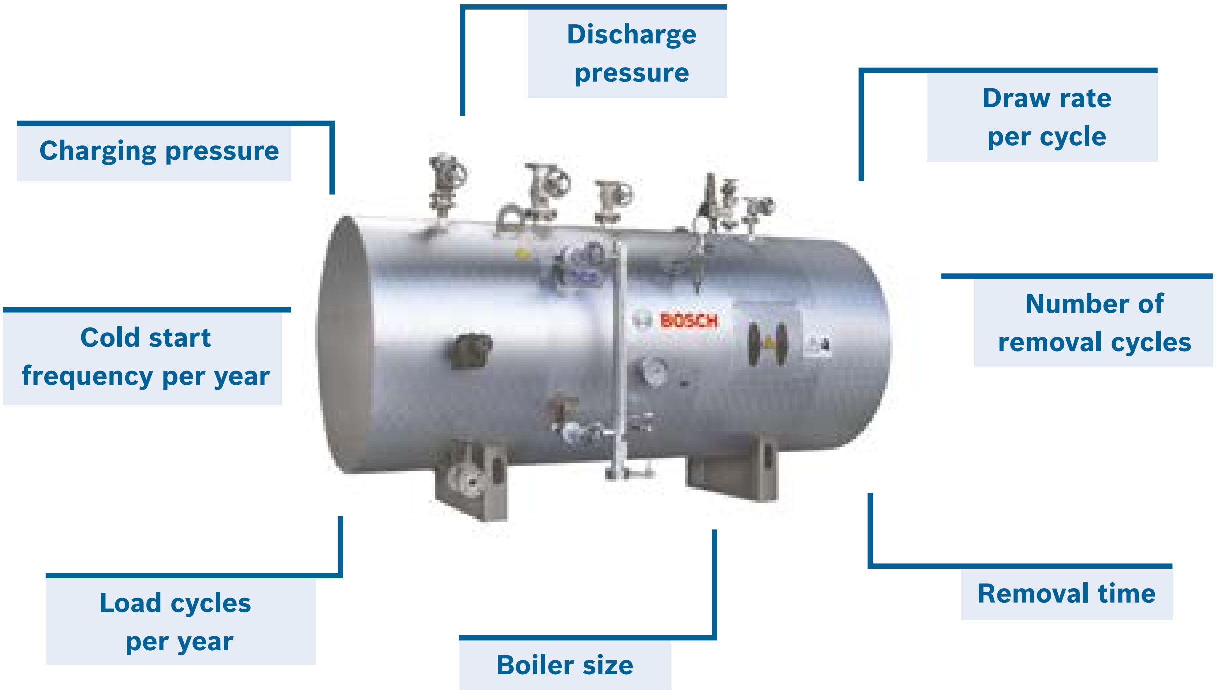

Fig. 108 *Influencing parameters in the planning and sizing of a steam accumulator*

Exceedance of the installed output of the steam generator (example 1)	Damping of a cyclical steam demand (example 2)
• Boiler 9,000kg/h	• Boiler 9,000kg/h
• Consumer peak 15,000kg/h, roughly 350kg in total over a period of 260s	• Consumer peak 11,500kg/h, roughly 28kg in total per peak over a period of 51s, repeated every 92s
• 20m³ steam accumulator filled to 65% capacity with water	• 5m³ steam accumulator filled to 50% capacity with water
• A residual moisture content in steam of up to 5% is permitted	• Residual moisture content in steam <2%
• Accumulator charged after 700s	–
• Accumulator charging pressure 13 bar and discharging ≤ 9.3 bar	• Accumulator charging pressure 12 bar and discharging ≤ 10.5 bar
Simplified and idealised calculation	Simplified and idealised calculation

Tab. 15 *Examples of applications of a steam accumulator*

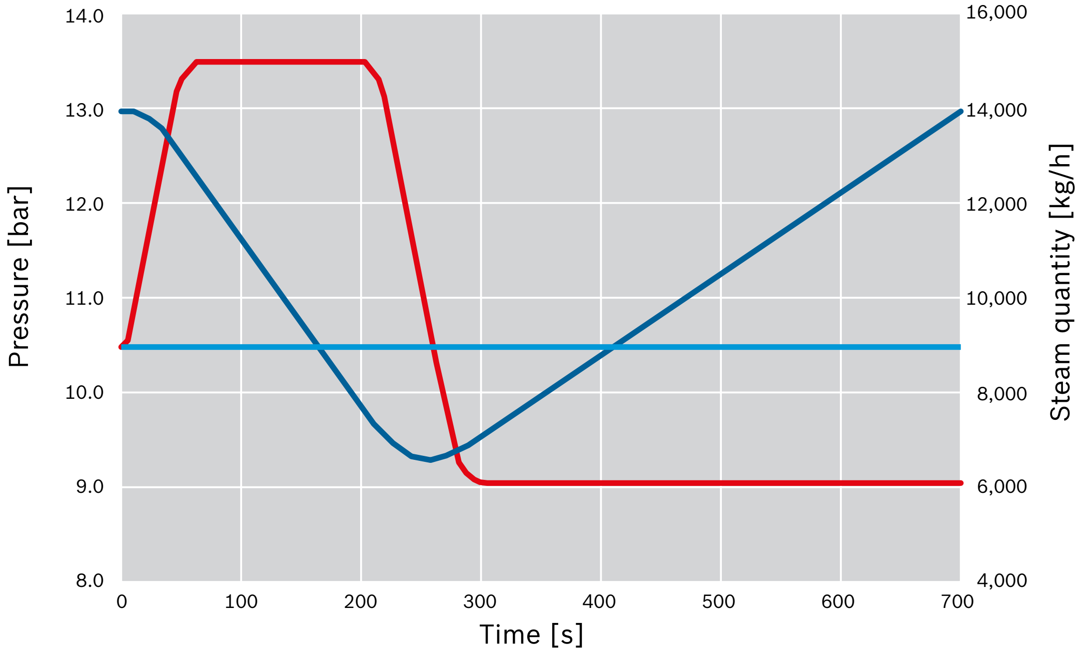

Fig. 109 *Pressure progression in a steam accumulator (***example 1***)*

Pressure in the steam accumulator

Steam removed by consumer(s)

Boiler steam output

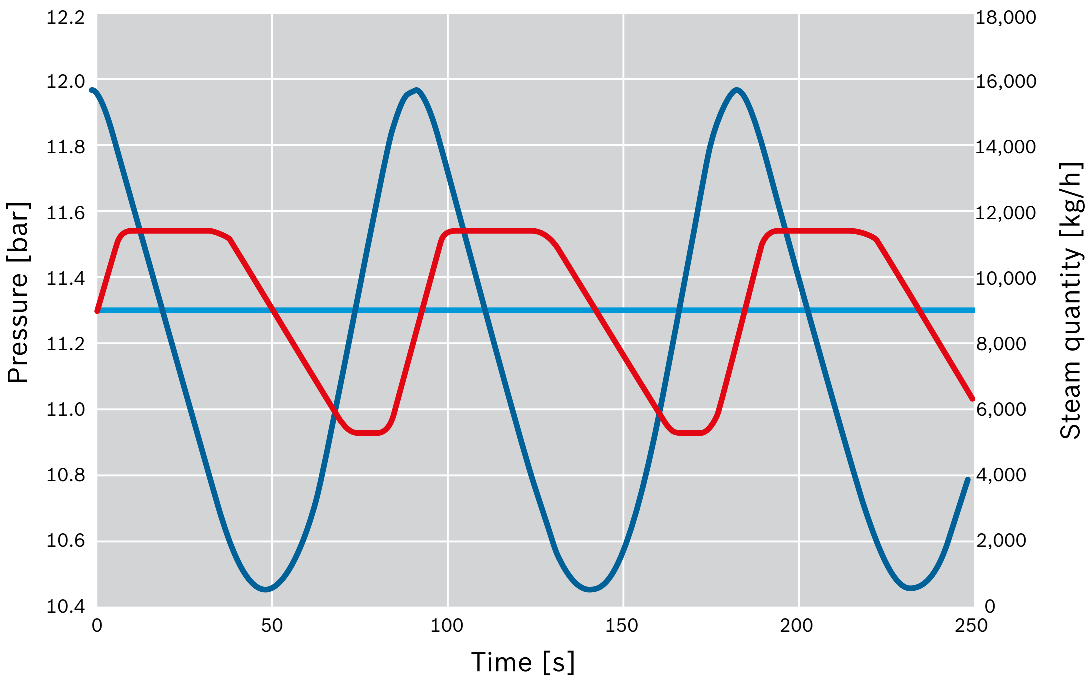

Fig. 110 *Pressure progression in a steam accumulator (***example 2***)*

Pressure in the steam accumulator

Steam removed by consumer(s)

Boiler steam output

4.4 Condensate management

Wherever steam is used for indirect heating in heat exchangers condensate also forms and should whenever possible be returned to the steam boiler circuit or used for some other purpose.

Reusing accumulated condensate is one of the key measures which can be taken to ensure cost-effective energy-efficient operation of a boiler system.

Condensate has two characteristics that make it particularly valuable:

- **High temperatures**
  The condensate downstream of the heat exchanger is normally only slightly undercooled, i.e. it is at a high temperature. By recirculating the condensate, this energy content remains in the system and does not have to be expended again.
- **Treated water**
  Condensate is already treated hardness-free water with a low conductivity. Returning condensate to the steam circuit therefore saves make-up water. This means that less softening or demineralisation of water is required which reduces the amount of energy and chemicals used and these treatment systems can be sized smaller from the outset.

The condensate can be reused in different ways:

- **As preheated boiler feed water**
  by returning it to the feed water vessel via condensate pipes and tanks or by feeding it directly into the boiler.
- **As hot water**
  for heating of processes at a low temperature level, e.g. for cleaning.
- **As steam**
  by using the expansion steam in a secondary low-pressure steam network for consumers requiring lower temperatures.

Before the condensate can be reused, it must first of all be checked for contamination and collected in a tank. This can be done either in an open or closed condensate collection system.

→ Technology – Chapter 4.5: Water quality monitoring, page 203

The differences between the two systems are highlighted in the following table:

	Open system Low-pressure condensate	**Closed system High-pressure condensate**
Container type	Low-pressure container (0.5 – 1 bar) connected to atmosphere via an air vent line	High-pressure container Pressure in container maintained by heat-up steam or overflow regulator
Oxygen in condensate	Oxygenic condensate (in contact with atmospheric oxygen, renewed deaeration required)	Oxygen-free condensate
Condensate temperature when returned	≤100°C	>100°C
Recirculation	Via feed water vessel	High-temperature feed pumps
Condensate transportation	Condensate pumps	Not required
Steam clouds	Possible (especially with high condensate temperature of consumers)	None
System integration	Straightforward	More complex
Investment costs	Low	Higher
Energy saving	Lower	High
Pipework material	Stainless steel	Steel
Use of condensate	Boiler feed water (recirculation to feed water vessel for deaeration)	Boiler feed water (direct recirculation in the boiler) Hot water
Use of expansion steam	Mainly unused In exhaust vapour heat exchanger for preheating of make-up or process water	In the low-pressure steam network For heating of feed water vessel

Tab. 16 *Comparison of different condensate collection systems*

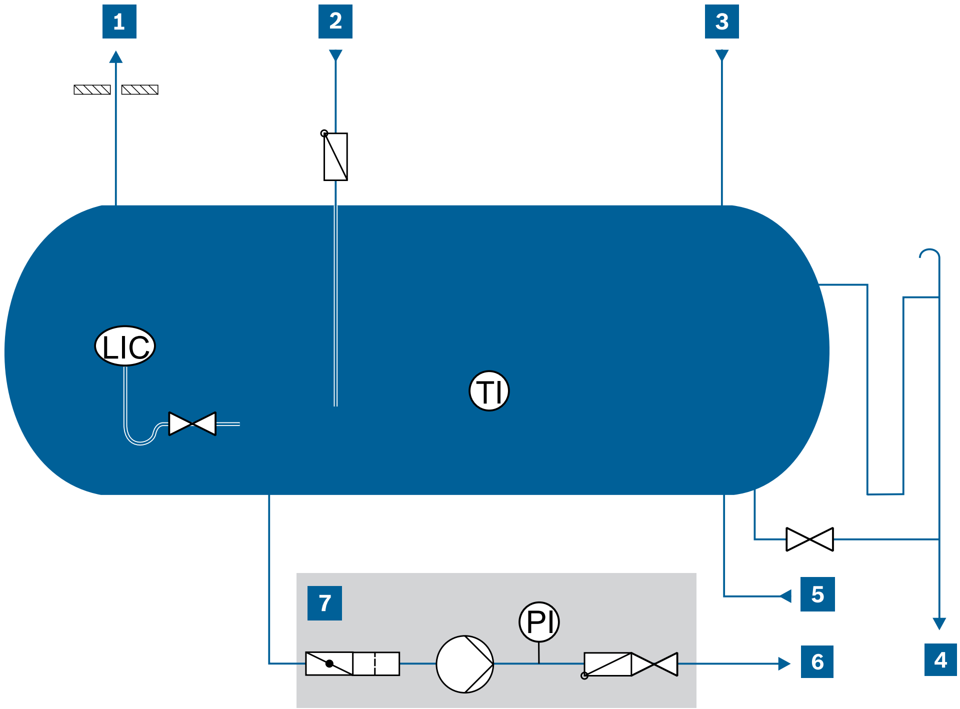

Fig. 111 *Schematic diagram of condensate tank – low pressure*

LIC Level regulator
TI Temperature indicator
PI Pressure indicator

1 Air vent line
2 Condensate pipe leading directly to feed water module
3 Condensate pipe, unpressurised
4 Drain line and overflow
5 Pump bypass pipe
6 Line to boiler
7 Condensate pump module

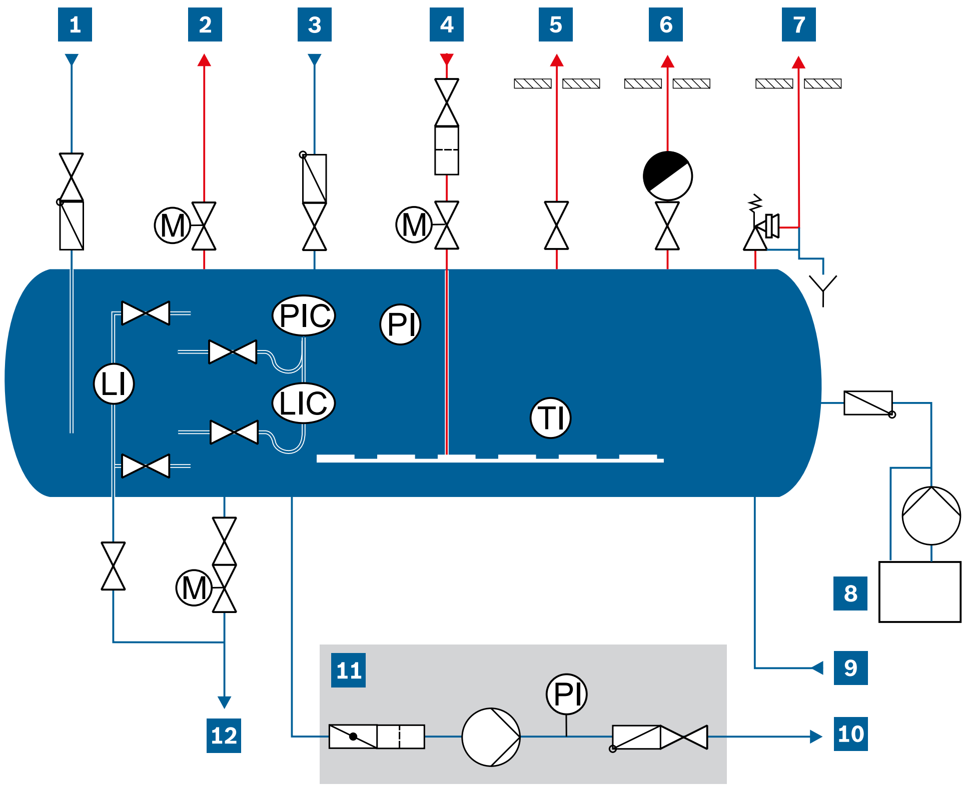

Fig. 112 *Schematic diagram of condensate tank – high-pressure*

LI Level indicator
LIC Level regulator
M Motor
PI Pressure indicator
PIC Pressure regulator

1. High-pressure condensate feed line
2. Overflow steam discharge line
3. Make-up water feed line
4. Heat-up steam pipe
5. Start-up line
6. Air vent line
7. Pressure safeguard blow-off line
8. Chemical dosing
9. Pump bypass pipe
10. Line to boiler
11. High-pressure condensate pump module
12. Drain line

4.5 Water quality monitoring

Water quality is a critical factor for trouble-free and safe operation of a steam boiler system.

It must be monitored in the following areas:

- Boiler
- Feed water
- Make-up water
- Condensate

This is why both continuous in-process checks and periodic inspections of the water quality at various points in the system are carried out:

- In the boiler (via pH, conductivity and oxygen analysis)
- In the feed water (via pH, conductivity and oxygen analysis)
- In the make-up water (via analysis of silicic acid and continuous anaylsis of hardness)

→ Technology – Chapter 2.2: Equipment and control, page 121

4.5.1 Condensate

When recirculating condensate, there is a danger of condensate which has become contaminated as a result of product ingress in the heat exchanger entering the steam boiler. This can cause considerable damage which can be prevented by monitoring the water quality. In doing so a distinction is made between substances:

- that affect the electrical conductivity of the condensate and are monitored via conductivity electrodes
- that cause cloudiness or light refraction which is monitored using what is referred to as a turbidity meter

4.5.2 Conductivity monitoring

Invasion of foreign matter in the condensate system that increases the conductivity can be quickly and reliably detected and signalled by a conductivity monitoring system (e.g. alkalis, acids, freshwater, water from boiling baths). Necessary measures are automatically introduced. These systems operate with automatic temperature compensation to ensure that temperature fluctuations do not lead to fault messages.

They are used in steam boiler systems, e.g. to monitor condensate or feed water.

If the conductivity in the condensate of roughly 50 µS/cm is exceeded, the condensate should be immediately discarded (e.g. via a three way valve). This excludes the possibility of contamination of the feed water, and subsequently also the steam boiler, before it enters the feed water vessel. The boiler operation itself therefore does not have to be interrupted and troubleshooting in the condensate system or heat exchangers can be carried out without any time pressure. However, it should be observed that the conductivity sensor detects all condensate flows.

4.5.3 Residual hardness monitoring

The softened water is monitored by a residual hardness monitoring device. Poor regeneration or overrunning of the water softener could lead to hardness invasion in the downstream system components. To prevent this the residual hardness is monitored either continuously or intermittently. If the limit of 0.01mmol/l is exceeded for a certain period, a fault display automatically appears in order to protect the downstream system components.

4.5.4 Turbidity monitoring

If there is also a danger of oil, grease or other emulsions finding their way into the condensate system, a turbidity monitoring system must be installed in addition to a conductivity monitoring system. The particle content of foreign matter is continuously monitored using optical measuring methods. Whenever possible, this should be installed upstream of the condensate tank as fresh steam or re-evaporation can affect the measurement. If the set value is exceeded, it also makes sense to discard the condensate in this case until the turbidity falls below the set value once again.

4.5.5 Continuous water analysis

Fig. 113 *Water analyser WA*

Smooth boiler operation depends on good water quality. The water analysis device measures and monitors the following parameters continuously:

- pH value in the boiler water
- pH value, oxygen content and conductivity in the boiler feed water
- pH value and conductivity of the condensate or steam accumulator water content

All data is transferred to the system control SCO via the bus system. All relevant water parameters, together with the boiler water conductivity and conductivities of the individual condensate flows, are therefore available in the system control SCO. Demand-based control tasks can be carried out fully automatically. When defined limits are exceeded, all parameters are transferred to the fault memory of the system control SCO of the plant control. The data can also be recorded continuously. This can be transferred via the bus system to a higher-level control system for further processing.

Functions of the water analyser are:

- Stepless activation of the dosing system for oxygen binder
- Stepless activation of the dosing system for alkalisation
- Activation of exhaust vapour valve including display of saved exhaust vapour energy [kWh]

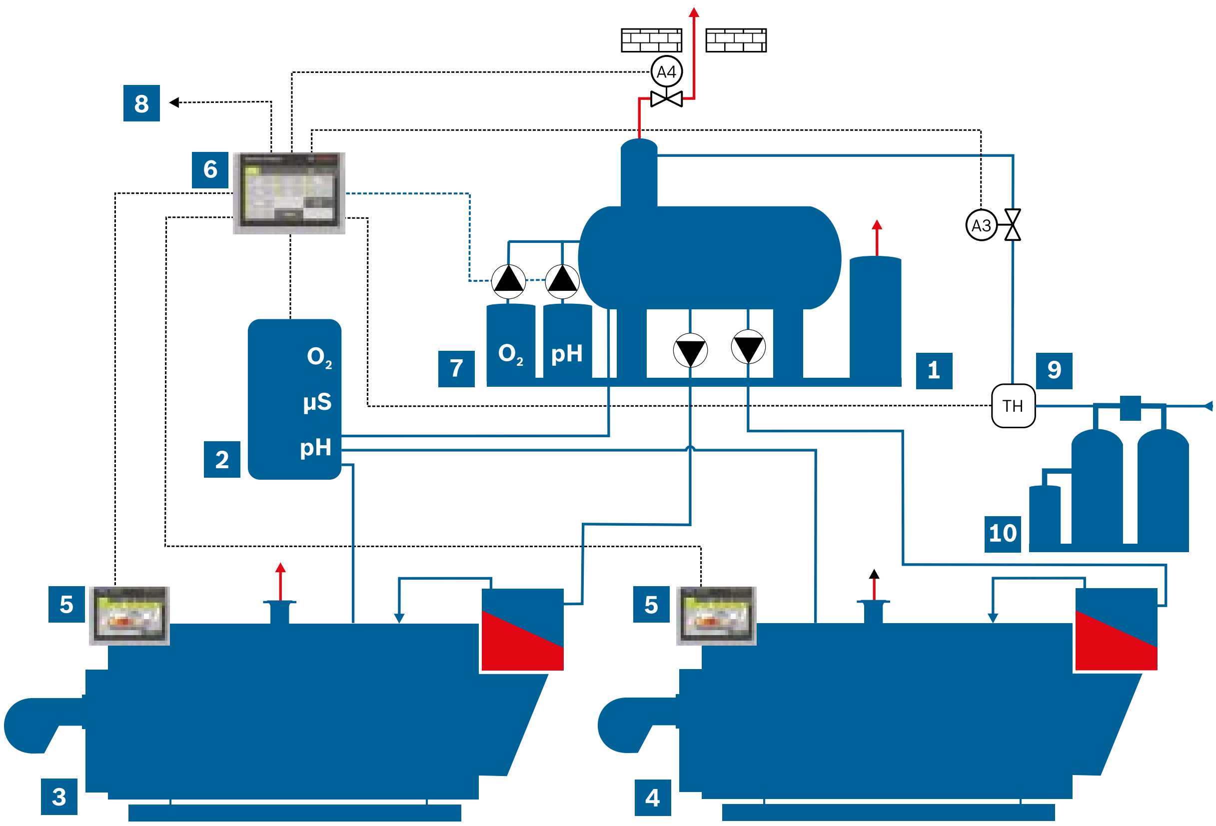

Fig. 114 *Schematic representation of operating principle of water treatment*

- **1** Water service module WSM-V
- **2** Water analyser WA
- **3** Steam boiler 1
- **4** Steam boiler 2
- **5** Boiler control BCO
- **6** System control SCO
- **7** Chemical dosing
- **8** Automation system
- **9** Softcontrol TH (optional)
- **10** Water treatment module

→ Technology – Chapter 4.15: Water analyser WA, page 357

4.6 System control SCO

System control SCO for control of boiler system

The system control SCO combines the controls of steam boilers and/or hot water boilers as well as individual module controllers into a higher-level management system and opens up a wide range of new possibilities. The individual boiler control BCOs, any additional controls and the SCO communicate via a high-performance bus system. This dispenses with the need for complex wiring work and isolation of signals. The connection to higher-level visualisation and automation systems can be established via various automation system protocols, e.g. Profibus, Modbus TCP/IP and BACnet. As an option, the system can be monitored remotely via MEC Remote.

Construction

High-performance programmable logic control with operator interface as TFT colour display with touch-screen.

Equipment

- Sequence control of multi-boiler systems
- Integration of water analysis
- Integration of deaeration systems
- Integration of condensate systems
- Integration of foreign matter monitoring systems
- Integration of oil supply systems
- Extremely wide range of pressure and temperature controls
- Reserve pump control with automatic changeover for several boilers

Benefits at a glance

- Straightforward interfacing with higher-level visualisation and automation systems
- Integrated monitoring and safety functions to prevent maloperation
- Comprehensive storage of operating parameters and system status messages
- Interfacing with MEC Remote possible: operating parameters and system status messages can be accessed via an optional VPN router
- Intuitive operation using graphic symbols and representations on touchscreen displays

→ Products – Chapter 6.4: MEC Optimize, page 371

Fig. 115 *Cross-component system control SCO – example of display*

WCO water control for control of water service module

This particularly low-cost control for the water service module offers all basic control functions for full or partial deaeration systems.

Construction

The programmable logic controller is equipped with a user-friendly text and graphic display and control keys. It is integrated into a control cabinet and permanently mounted on the water service module complete with wiring to the sensors and actuators.

Equipment, standard functions:

- Pressure or temperature control of deaeration system
- Level control of deaeration system (multi-step or stepless including boil-dry protection and high water function)
- Display of measured value curves (pressure or temperature, level)

Equipment, optional

- Temperature control of blowdown, expansion and cooling module BEM
- Spray pressure monitoring for spray-type deaerator systems
- Temperature indicator of feed water vessel
- Activation of exhaust vapour valve to avoid exhaust vapour losses in standby mode

Benefits at a glance

- Attractive price-performance ratio for control of complete water service module
- User-friendly operation via text and graphic display with control keys
- Data transfer via Ethernet or Profibus DP

Master Energy Control MEC Remote for remote maintenance

The Bosch MEC Remote (Master Energy Control) remote maintenance system is the replacement for the former teleservice for industrial boilers. This provided Bosch Industrial Service with direct support access to boiler systems.

The new MEC Remote now also allows operators to conveniently and reliably monitor their systems remotely using standard Internet-ready terminal devices.

MEC Remote is therefore the ideal solution for companies:

- where supervisors and relevant personnel cannot be on site continuously
- with multi-boiler systems that are subject to mandatory oversight
- with standby service at the weekends

Bosch boiler controls are compatible with commercially available automation systems. MEC Remote can also be used with systems without automation system interface.

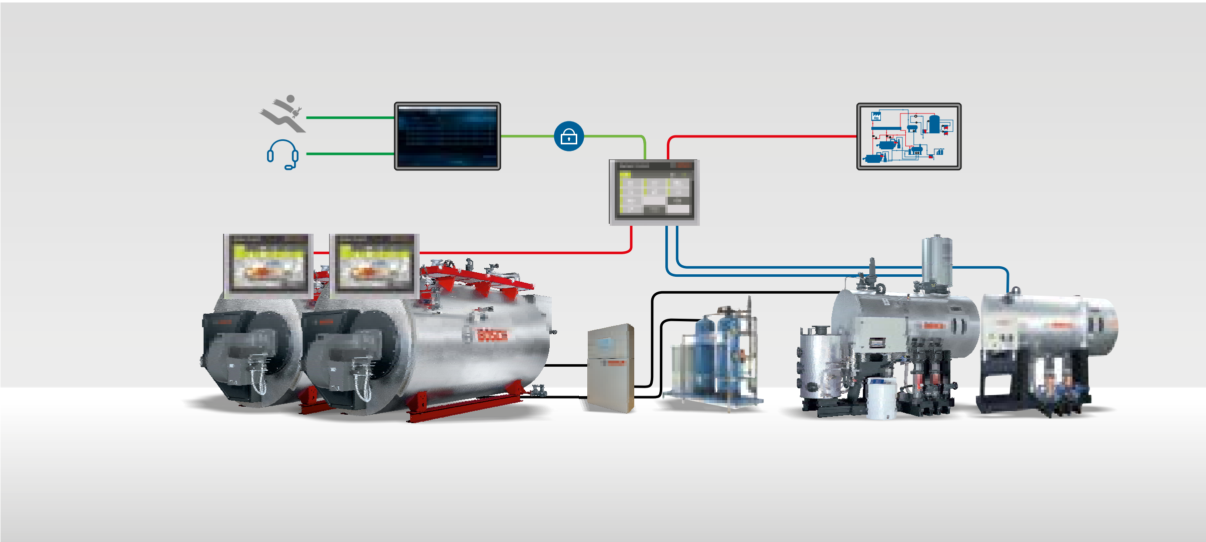

Fig. 116 *MEC Remote – remote access for maintenance and visualisation of system data*

Thanks to a general map several systems around the world can also be monitored at the same time. In combination with MEC Optimize, the operator can on request be automatically notified about abnormalities and faults in the form of a short message to his mobile phone or e-mail. This significantly reduces the supervision effort for systems with high reliability requirements (e.g. during continuous operation).

→ Controls and connectivity brochure

A further benefit for operators is the optional remote support which is available from Bosch Industrial Service. The Bosch experts can perform advanced parameter settings, programming (PLC) and troubleshooting directly via the remote maintenance system. When components fail, the service experts can analyse and narrow down the cause remotely then travel with the right equipment to the operating location. This can reduce boiler downtimes and service costs to a minimum.

One of the most important requirements for the remote connection is maximum security. This is ensured by the ingenious role concept which controls the access rights and authorised control interventions. The remote access itself has a multi-level security concept. The external data connection can be enabled or disabled in the boiler house on the hardware side via a key.

In addition to logging in with username and password via encrypted data transfer (https) a mobile TAN procedure is used. As is the case with online banking, the access data is sent on the operator's mobile phone. Instead of being stored in a Cloud, the operating data of the industrial boiler is stored locally on the system. The security concepts for MEC Remote were devised by ESCRYPT GmbH. A regular security audit is performed by Cirosec GmbH.

Fig. 117 *SCO and MEC System control cabinets*

5 Peripherals

5.1 Pipework

When installing pipework systems, the terms nominal diameter (DN) and nominal pressure (PN) are used to identify characteristics of pipework for the purpose of defining compatible parts, e.g. flange connections. Nominal diameter and nominal pressure are standardised according to the geometrical increment.

When sizing pipework, i.e. defining the nominal diameter and nominal pressure for pipework and valves, a balance must always be struck between the technical requirements, such as keeping the pressure loss or heat loss as low as possible, and the associated investment and operating costs. The optimum overall cost balance between investment and operating costs that emerges is different for every pipe and system. Owing to the curve characteristics in the minimum range of the total costs, two nominal diameters often lie within the optimum range.

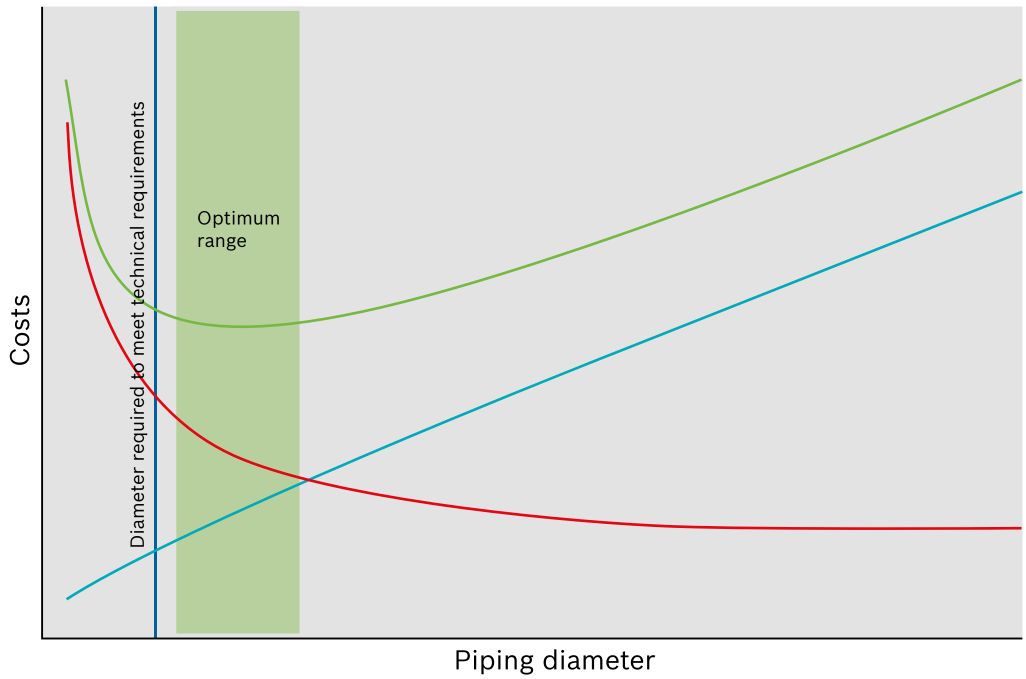

Fig. 118 *Example of schematic cost trend for pipework dimensioning*

- Total costs
- Operating costs
- Investment costs

The following steps must be observed when designing pipework:

- Define nominal diameter
- Define nominal pressure
- Select material
- Define spans
- Consider thermal expansion
- Take special characteristics of the medium into account during installation

As many system-specific, technical and commercial individual parameters would need to be considered for a detailed analysis, pipework is normally designed for the permissible flow speed according to economically sound principles and technical necessities based on experience. Depending on the medium and use, the recommended values have proven to be practise-compliant in many systems.

Medium	Area of application	Recommended speed
Steam	0 – 1 bar	20 – 25m/s
	1 – 40 bar	30 – 40m/s
Water	Suction line	0.4 (0.25 – 0.6)m/s
	Pressure line	2 (1.5 – 3)m/s
Condensate	Steam fraction	15m/s
	Water fraction	2m/s
Flue gas		16.5m/s
Oil	Light fuel oil intake side	0.5m/s
	Light fuel oil discharge side	1m/s
	Heavy fuel oil intake side	0.3m/s
	Heavy fuel oil discharge side	0.5m/s
Natural gas		No specifications (design via pressure loss)

Tab. 17 *Standard design speeds (recommended speeds) for pipework sizing*

Definition of nominal diameter DN

The nominal diameters in the following table are specified without units. They correspond roughly to the inner diameter of the pipework in mm. This is for production reasons as the tools used in the manufacturing of pipes are defined via the external diameter and the clear inner diameter therefore varies depending on the wall thickness. The nominal diameter will normally suffice as calculation variable for rough sizing of the inner diameter.

Nominal diameter DN	External diameter d_1 [mm]
6	10.2
8	13.5
10	17.2
15	21.3
20	26.9
25	33.7
32	42.4
40	48.3
50	60.3
65	76.1
80	88.9
100	114.3
125	139.7
150	168.3
200	219.1
250	273.0
300	323.9
350	355.6
400	406.4
450	457.0
500	508.0
600	610.0
700	711.0
800	813.0
900	914.0
1 000	1 016.0
1 200	1 219.0
1 400	1 422.0
1 600	1 626.0

Tab. 18 *Pipe diameter (EN 10255:2004+A1:2007, EN 1092-1:2013-04, Table A.1)*

The necessary nominal diameter can then be calculated as follows:

$$DN \geq \sqrt{\frac{\dot{V} \cdot 4}{\pi \cdot u}} = \sqrt{\frac{\dot{m} \cdot 4}{\pi \cdot \rho \cdot u}}$$

F20. *Equation for calculation of required nominal diameter*

DN	Nominal pipe diameter [mm]
$\dot{V}$	Flow rate [m³/s]
$\dot{m}$	Mass flow rate [kg/h]
ρ	Density [kg/m³]
u	Recommended speed according to table 17 [m/s]

$$\sqrt{\frac{\dfrac{1{,}000\ \frac{kg}{h}}{3600\ \frac{s}{h}} \cdot 4}{\pi \cdot 4.65\ \frac{kg}{m^3} \cdot 40.0\ \frac{m}{s}}} \cdot 1000\ \frac{mm}{m} = 44\ mm \leq DN\ 50$$

B9. *Example calculation for determining the required nominal diameter*

To optimise nominal diameters which have been designed according to a permissible recommended speed, it may be advisable in individual cases, e.g. if the pipework is very long, to recalculate and optimise the nominal pipe diameter using special design programs.

Defining the nominal pressure PN

The nominal pressure is a standardised pressure stage for pipework and valves. It represents a parameter for the mechanical and dimensional characteristics of a component. Components with the same nominal diameter and same nominal pressure are compatible. The nominal pressure corresponds the maximum permissible positive pressure [bar] at a reference temperature of 20°C.

However, in addition to the material, the maximum permissible positive pressure of a component depends first and foremost on the temperature. At higher temperatures, the maximum permissible operating pressure falls below the nominal pressure. Pipework or valves can then not be operated at the nominal pressure.

The pressure-temperature assignment of flanges is based on the material groups. The following materials and groups are customary in the area of steam boilers:

Material group	Material type	Material number	Material
3E0	Unalloyed steels with guaranteed strength characteristics at higher temperatures	1.0352	P245GH
3E1	Unalloyed steels with defined characteristics ≤400°C, upper yield point >265 N/mm²	1.0460	P250GH
4E0	Low alloy steels with 0.3% molybdenum	1.0426	P280GH
12E0	Standard carbon content, stabilised with Ti or Nb	1.4541 1.4550 1.4941	X6CrNiTi18-10 X6CrNiNb18-10 X6CrNiTiB18-10
15E0	Standard carbon content, alloyed with molybdenum, stabilised with Ti or Nb	1.4571 1.4580	X6CrNiMoTi17-12-2 X6CrNiMoNb17-12-2

Tab. 19 *Material groups according to EN 1092-1:2013-04 Table 9, G.2.2, G.3.2, Table D.1*

The following diagram shows the pressure-temperature curves for different nominal pressure stages. In this case also observe the information in the chapter Tools – Pressure-temperature assignment, which contains the tables for the diagram.

→ Tools – Chapter 5.4.2: Pressure-temperature assignment, page 408

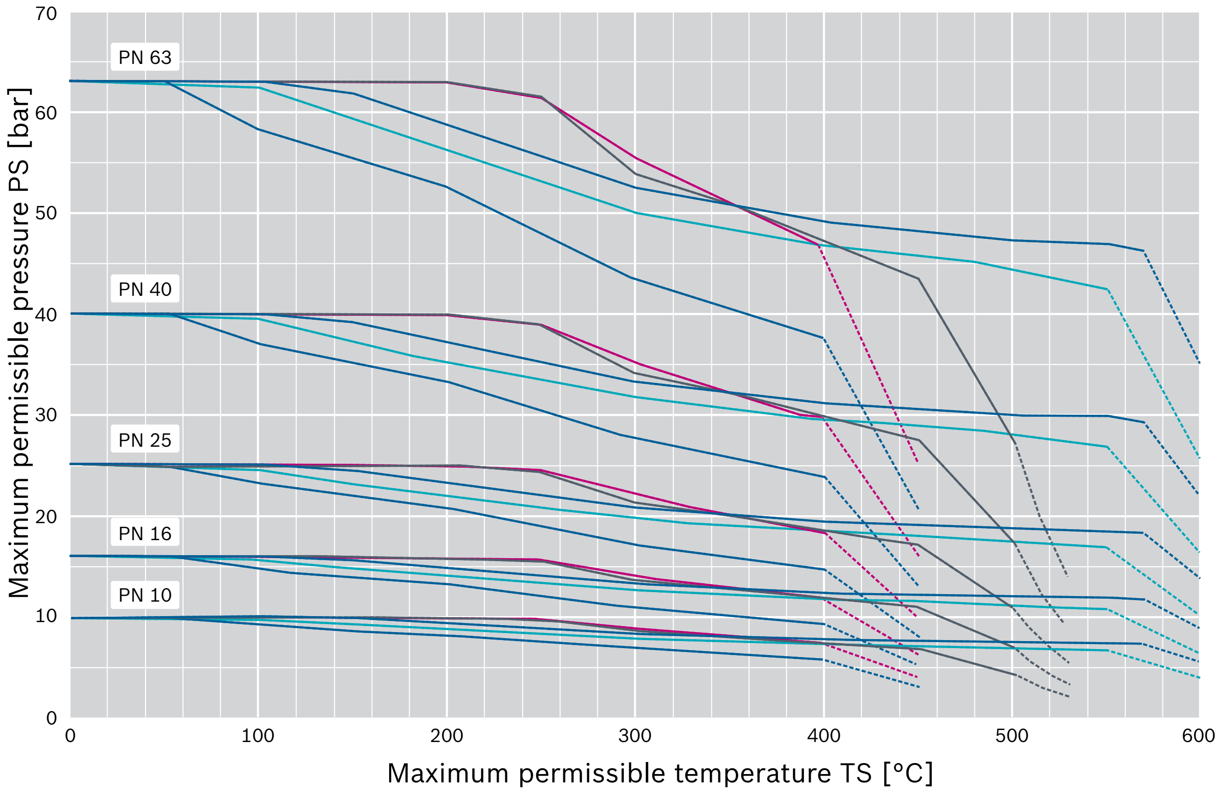

Fig. 119 *Pressure-temperature assignment for flanges according to EN 1092-1*

3E0
4E0
15E0
3E1
12E0

Defining the material

The following table states only the minimum requirement for material selection. Other materials can be also used where special installation conditions, customer requirements or national or local regulations apply.

Materials containing copper must not be used for any pipework to and from the steam boiler, in the condensate and make-up water area.

Application area	Pipework material
Steam pipes	Steel or stainless steel with inspection certificate
Feed water lines	Steel
Safety valve blow-off pipes	Steel
Ventilation and drain lines	Steel
Seat drainage (safety valve)	Copper or stainless steel
Softened water	Plastic (cold) or stainless steel (following heating)
Osmosis water	Stainless steel

Tab. 20 *Minimum requirement for material selection*

Definition of spans

It must be ensured through a sufficient number and correct construction of holders that pipework does not deform beyond acceptable limits due to weight forces (own weight, content, valves and insulation) and other forces acting on it (e.g. at deflections).

Requirements for pipework are explained in EN 13480-3.

→ EN 13480-3

Pipework and flanges for water and steam

DN	Ø valves	PN 40 S	Max. span L1[1)]
10	17.2	2.0	–
15	21.3	2.0	–
20	26.9	2.3	–
25	33.7	2.6	2.9
32	42.4	2.6	**3.2**
40	48.3	2.6	3.5
50	60.3	2.9	3.9
65	76.1	2.9	**4.7**
80	88.9	3.2	5.4
100	114.3	3.6	6.2
125	139.7	4.0	**6.9**
150	168.3	4.5	7.5
200	219.1	6.3	8.6
250	273	7.1	9.7
300	323.9	8.0	10.6
350	355.6	8.8	11.1
400	406.4	11.0	11.8
500	508	14.2	**12.5**
600	610	16.0	13.2

Tab. 21 *Pipework spans (holder-to-holder distance)*

1) Requirements for span L1:
- According to EN13480-3:2014 – filled with water, thickness of insulation 80mm
- With additions through interpolation
- L1 limitation of deflection, up to DN 50 = 3mm deflection, from DN 65 = 5mm deflection
- For details see EN13480-3

Thermal expansion

Substances expand when they are heated and contract when they cool down again.

This effect must be taken into account at many points in a boiler system, especially in locations where high temperatures can occur during operation.

The following points must for example be taken into account during planning and installation:

Location	Use of – to absorb the elongation
Piping	Pipework compensators
• Steam	• Expansion legs (L-legs)
• Flue gas	• Expansion bends
• Surface/bottom blowdown	• U-bends (with long straight pipework)
• –	• Friction bearing
Boiler and container	Friction bearings on feet and base frame Expansion joints and expansion legs on incoming and outgoing pipework

Tab. 22 *Location and types of measures used to absorb thermal expansion*

The following equation can be used to calculate the linear thermal expansion:

$$\Delta l = l \cdot \alpha \cdot \Delta T \quad \text{bzw.} \quad \frac{\Delta l}{l} = \alpha \cdot \Delta T$$

F21. *Equation for calculating linear thermal expansion*

Δl	Linear thermal expansion [mm]
l	Length [mm]
α	Expansion coefficient [mm/m]
ΔT	Temperature difference [K]

Expansion coefficients of different steels

Low alloyed steel (ferritic):
$\alpha \approx 1 - 1.3$ [mm/m · 100K] = $10 - 13 \cdot 10^{-6}$ [1/K]

Stainless steels (austenitic):
$\alpha \approx 1 - 1.8$ [mm/m · 100K] = $10 - 18 \cdot 10^{-6}$ [1/K]

The leg length required to absorb thermal expansion must be determined according to the general codes of practise.

Minimum distance to structure and adjacent pipework

A clearance of at least 50 – 100mm should be maintained in order to install the pipework and insulation and also carry out repairs. The frequently used technical standard for insulation work DIN 4140 recommends a minimum clearance of 100m.

To minimise the clearances, flange connections should have an offset arrangement on pipe bridges.

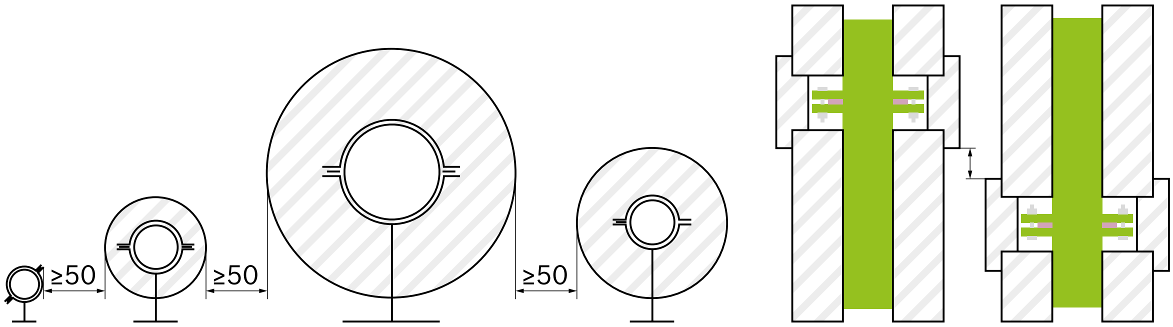

Fig. 120 *Functional clearances of pipework on pipe bridges and offset arrangement of flange connections*

5.2 Steam pipes

Steam or condensate hammer

If steam pipes or items of equipment such as heat exchangers are not drained sufficiently, significant damage could occur as a result of steam hammer.

If hot steam or hot condensate comes into contact with cold water, this is accompanied by the sudden breakdown of large steam bubbles. This implosion causes an inrush of water which collides with itself and causes high-pressure peaks.

Steam hammer is primarily caused by insufficient condensate drainage, inappropriate installation or defective devices and incorrect operation.

Drainage

Due to heat loss in the pipework, condensate accumulates in saturated steam pipes which must be collected and removed. There should therefore be a gentle gradient of 5 – 10mm per m pipe length, i.e. 0.5 – 1%, in the flow direction to allow the condensate to flow to the drainage connections.

The drainage connections are then installed as follows:

- In straight pipework regularly every 30 – 50m
- Before every stagnation point (e.g. valves or vertical pipework sections)

These must be able to reliably remove and collect condensate in the pipework so that it can be effectively carried away by condensate drains. With nominal diameters up to DN 100, the drainage connections should be constructed with the same nominal diameter as the steam pipe to allow the condensate that forms when starting up also to be collected. With bigger nominal diameters, the nominal diameters of the collection connections can then be smaller than the nominal diameter of the steam pipe. The collection connections should be 500mm long and the condensate pipes attached laterally to prevent dirt from impairing the functionality of the condensate drain. As a rule, the condensate should not be discharged into the atmosphere due to the significant enthalpy, and instead should be transported via a collecting line to the feed water vessel where it can be reused.

The quantity of condensate to be removed is linked via the evaporation enthalpy to the heat loss in the pipework, valves and other built-in components for the corresponding pipework section. The quantity of condensate can be estimated using the equations in the chapter Planning – Heat losses in steam pipes.

→ Planning – Chapter 3.1: Calculation of consumption, page 36

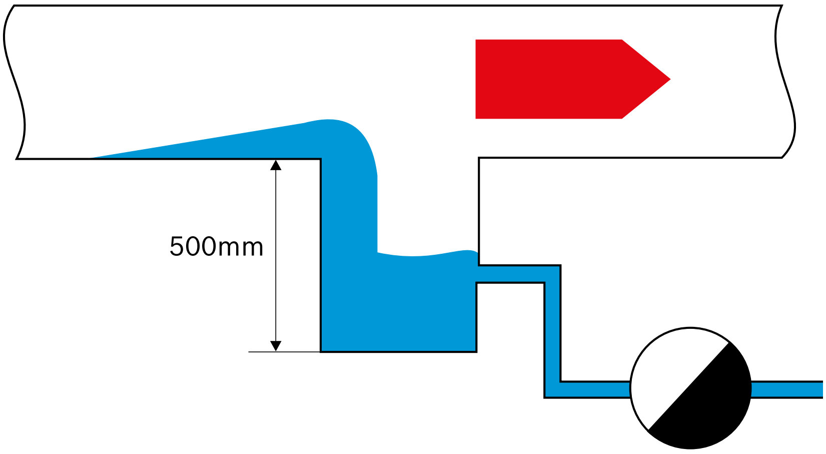

Fig. 121 *Drainage connections*

5.3 Water lines

Pressure line

On the whole, there are no special characteristics to observe in the case of pressure lines. Occasionally a flow speed of ≤ 5m/s is acceptable in short sections of pipework, providing other measures are taken to exclude the danger of water hammer.

Water hammer

Water hammer particularly occurs when closing valves in pipework carrying liquid. Deceleration of the moving water column and low compressibility of liquids causes pressure peaks due to the so-called "Joukowski surge".

Heavy water hammer can be reduced or avoided altogether by increasing the valve closing time and reducing the flow speed.

If electrically-actuated valves (closing time normally > 30 seconds) are used and the recommended pipework speeds (→ Tab. 17, page 212) are complied with, no unacceptably high-pressure peaks due to water hammer will occur.

Suction line

Pipes on the inlet side of pumps are referred to as suction lines. In this case, it is particularly important to ensure that the pressure loss is low to avoid possible cavitation at the pump. This is particularly relevant for pipes in which hot water is transported slightly below the boiling point (e.g. water from feed water vessels or condensate tanks). This pipework is sized for a low flow speed and is kept as short as possible (a few metres) to minimise pressure losses.

Cavitation

Cavitation (latin: *cavitare* = hollow out) occurs as a result of the formation and breakdown of small steam bubbles in liquids.

Steam bubbles occur in locations where the static pressure is low, such as behind impellers in centrifugal pumps. If the static pressure falls below the steam pressure of the liquid, bubbles form and implode shortly afterwards. When this happens, a water jet is produced that strikes the pump blade at a very high speed. Due to the high compressive stresses involved, the material initially hardens and subsequently flakes off thus forming irregular holes in the blades which continue to erode and ultimately destroy the impeller.

The so-called NPSH (Net Positive Suction Head) value of a centrifugal pump specifies the required upstream head of boiling water to prevent cavitation occurring at the impellers. Feed pumps of steam boilers are normally equipped with "Low-NPSH" pumps which only require an upstream head of roughly 0.4 – 1.2m in the operating range.

Each pump should have its own pipework to prevent reciprocal affects.

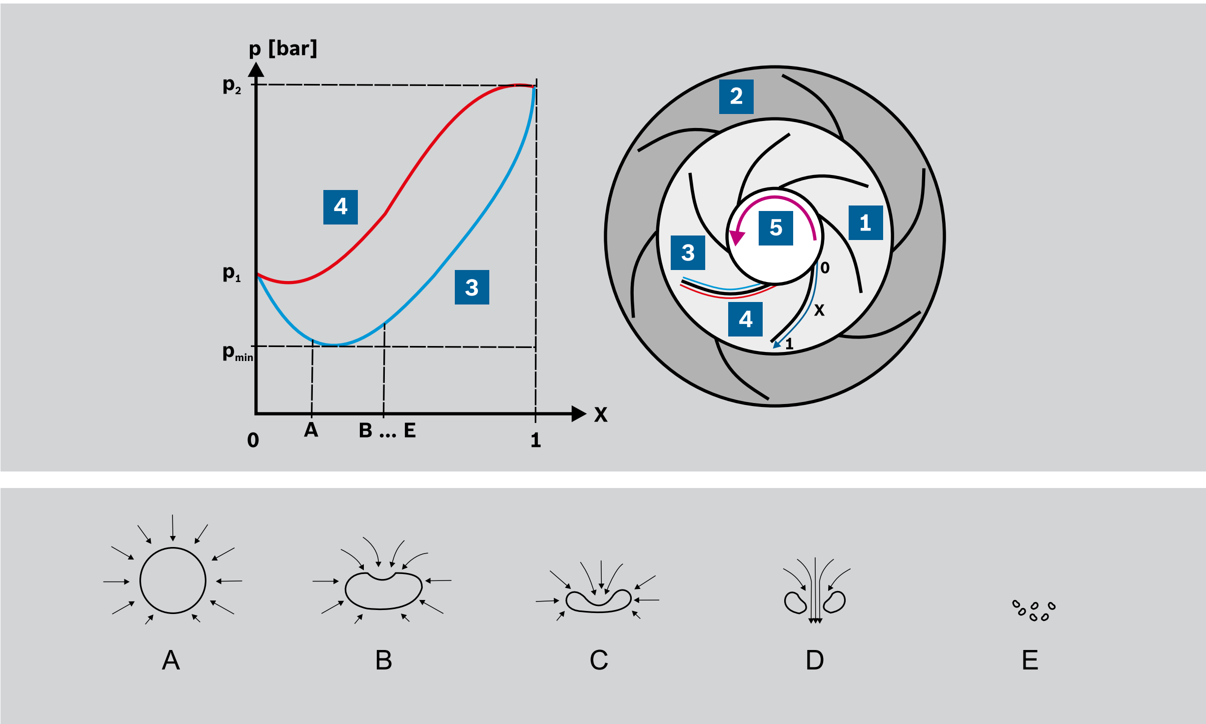

Fig. 122 *Cavitation – flow along pump impeller blade and collapse of gas bubbles*

- **1** Impeller
- **2** Guide wheel
- **3** Suction side, impeller
- **4** Pressure side, impeller
- **5** Rotational direction

- **A** Single bubble
- **B** Start of flattening
- **C** Collapsing gas bubble
- **D** Microjet
- **E** Collapsed gas bubble

5.4 Condensate pipes

Routing of pipework

It is recommended that condensate pipes are installed with a continuous slope of at least 1% in the flow direction to allow liquid condensate to drain off easily and heat exchangers and pipework to be emptied. This makes the heat exchanger start-up process easier and reduces the danger of corrosion.

Water pockets in particular should be avoided as these can lead to steam hammer, especially when starting up the heat exchanger.

Vertical sections in condensate pipes are possible. In addition to the hydrostatic pressure loss, higher flow pressure losses must also be taken into account in this case. Horizontal sections must still be sloped and suitable cold liquid condensate or start-up drainage outlets provided at the lowest points.

As the condensate normally does not accumulate at a sufficient height above the feed water vessel, it should be collected in condensate tanks and recirculated via condensate pumps/siphons.

Sizing

Condensate pipes must on no account be dealt with in the same way as pipes that only carry water. As the volume increases significantly during re-evaporation, both the steam fraction and water fraction must be taken into account during sizing.

If the required cross-sectional area is significantly undercut, this can lead to water droplet erosion on valves and elbows due to the resulting high flow speed.

The area required for the steam fraction and water fraction are derived from the corresponding densities, mass flow rates and recommended speeds.

Water droplet erosion

Water droplet erosion, also known as droplet impingement, refers to erosive wear by liquid droplets. Water droplet erosion is microscopic water hammer.

This occurs when droplets strike a surface at high speed. Although water has a “soft” appearance, the droplets have an abrasive erosive effect due to their incompressibility, high impulse and inertia. This leads to wear of surfaces through continuous exposure.

$$A_{req,S} = \frac{\dot{m}_{Co} \cdot x_{ES}}{\rho'' \cdot u_{Co,S}}$$

$$A_{req,w} = \frac{\dot{m}_{Co} \cdot (1 - x_{ES})}{\rho' \cdot u_{Co,w}}$$

F22. *Equation for calculation of required cross-sectional area of pipework*

By rearranging the equation to make the diameter the subject, the following is obtained:

$$DN \geq \sqrt{\frac{4}{\pi} \cdot A_{req}}$$

$$DN = \sqrt{\frac{4}{\pi} \cdot \dot{m}_{Co} \cdot \left(\frac{x_{ES}}{\rho'' \cdot u_{perm,S}} + \frac{(1 - x_{ES})}{\rho'' \cdot u_{perm,w}} \right)}$$

F23. *Equation for calculation of required nominal diameter of pipework*

DN	Nominal pipe diameter
$\dot{m}_{Co}$	Mass flow rate, condensate [kg/s]
x_{ES}	Ratio of expansion steam when expanding to container pressure [kg/kg]
ρ''	Saturated steam density at container pressure [kg/m³]
ρ'	Boiling water density at container pressure [kg/m³]
$u_{Co,S}$	Recommended speed of steam fraction [15m/s]
$u_{Co,w}$	Recommended speed of water fraction [2m/s]
A_{req}	Required cross-sectional area of pipework [m²]
$A_{req,S}$	Required cross-sectional area of pipework, steam fraction
$A_{req,w}$	Required cross-sectional area of pipework, water fraction

Example:

T_{Co} = 130°C	Condensate temperature before expansion
$p_{Co\text{-}tank}$ = 0.2 bar	Pressure after expansion (container pressure)
x_{ES} = 5.0%	Calculated ratio of expansion steam
$\dot{m}_{Co}$ = 1,000kg/h	Condensate mass flow rate

→ Tools – Chapter 4.2.2: Expansion steam, page 402

$$A_{req,S} = \frac{1{,}000\ \frac{kg}{h} \cdot 5.0\ \%}{0.673\ \frac{kg}{m^3} \cdot 15\ \frac{m}{s}} \cdot \frac{1\ h}{3600\ s} \cdot \left(\frac{1000\ mm}{1\ m}\right)^2 = 1{,}376\ mm^2$$

$$A_{req,w} = \frac{1{,}000\ \frac{kg}{h} \cdot (1 - 5.0\ \%)}{956\ \frac{kg}{m^3} \cdot 2\ \frac{m}{s}} \cdot \frac{1\ h}{3600\ s} \cdot \left(\frac{1000\ mm}{1\ m}\right)^2 = 138\ mm^2$$

B10. *Example calculation for determining the required cross-sectional area of the pipework*

$$DN \quad \sqrt{\frac{4}{\pi} \cdot (1{,}376 + 138)\ mm^2} = 43.9\ mm$$

→ DN 50

B11. *Example calculation for determining the required nominal diameter of the pipework*

5.5 Safety valve blow-off pipe

5.5.1 Blow-off pipe in the steam area

The following criteria must be observed when installing the safety valve blow-off pipe for steam:

- The blow-off pipe must be dimensioned so that an inherent back-pressure amounting to 10% of the excess pressure is not exceeded when discharging.
  - Up to a pipework length of 10m and a maximum of 5 elbows: 2 DN larger than the nominal outlet diameter of the safety valve.
  - If the pipework is longer or a greater number of elbows are used, a detailed calculation of the pressure loss in the pipework is recommended.
- A sloping section of pipe (≥0.5%) must initially be mounted at the valve outlet to create a low point in the blow-off pipe from which liquid can drain off via a device which cannot be shut off.
- If there is a drainage hole in the seat of the safety valve, additional drainage should be provided.
- The blow-off pipe must be isolated from other pipework (e.g. air vent lines, expansion lines, safety valve blow-off pipes) and protected against freezing.
- Blocking of the drainage by dirt or foreign matter must be avoided.
- Harmless discharge of condensate must be ensured.
- The blow-off pipe must be installed and fastened so that the safety valve is not exposed to shear, bending or torsional forces (e.g. by using supports, spring-loaded pipe hangers). The reaction forces when discharging must be taken into consideration.
- The blow-off pipe must terminate harmlessly.

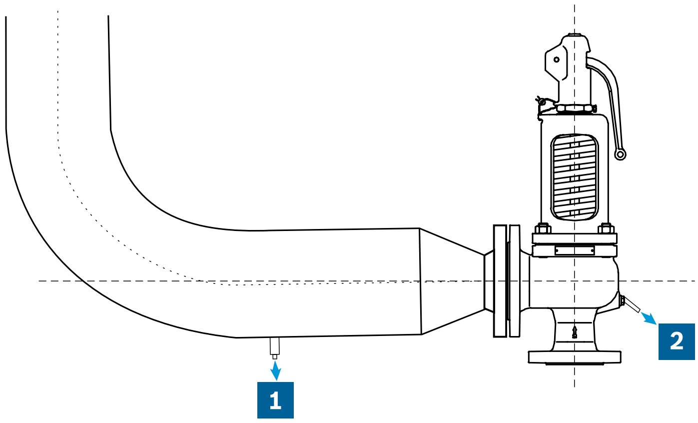

Fig. 123 *Drainage of blow-off pipe and safety valve*

1 Drainage of safety valve blow-off pipe

2 Seat drainage of safety valve

The functional capability of the safety valve and blow-off pipe is verified on site by the approved notified body during acceptance testing of the steam boiler, and normally at full combustion output during real operation.

→ Technical information TI024: requirements for the boiler installation room

5.5.2 Blow-off pipe in the liquid area

The following criteria must be observed when installing the safety valve blow-off pipe for liquids:

- The blow-off pipe of a safety valve which is connected to a water chamber must be equipped with an expansion and water separation chamber.
- The system on the discharge side of the safety valve must be dimensioned so that an inherent back-pressure amounting to 10% of the excess pressure is not exceeded when discharging.
- The section of pipe between the safety blow-off valve and the expansion and water separation chamber must be installed with a slope (≥0.5%).
- If there is a drainage hole in the seat of the safety valve, additional drainage should be provided.
- In doing so, the drain line must be installed with a slope and without constriction.
- Blocking of the drainage by dirt or foreign matter must be avoided.
- The condensate that accumulates in the expansion and water separation chamber must be safely removed and cooled.
- The section of pipe between the safety blow-off valve and expansion and water separation chamber must be installed and fastened so it is not exposed to shear, bending or torsional forces (e.g. by using supports, spring-loaded pipe hangers). The reaction forces when discharging must be taken into consideration.
- High temperatures, flow speeds and flow noise occur when discharging. The blow-off pipe at the expansion and water separation chamber must therefore discharge to the atmosphere in such a way that it cannot pose any danger.
- The blow-off pipe at the expansion and water separation chamber must be isolated from other pipework (e.g. air vent lines, expansion lines, safety valve blow-off pipes) and protected against freezing.

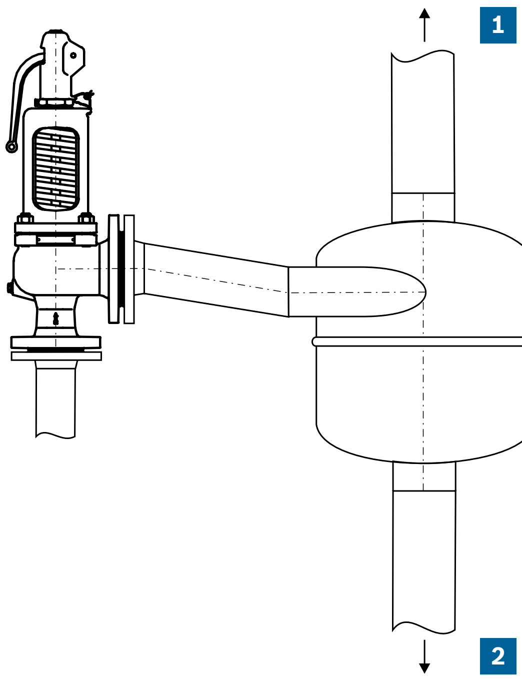

Fig. 124 *Safety valve with expansion and water separation chamber*

1 Blow-off pipe harmlessly through roof

2 Drainage line for harmless discharge and cooling

5.6 Flue gas system

The flue gas system starts where the boiler ends and has the task of removing the flue gases produced during combustion safely to the atmosphere. This includes the exhaust pipes inside and outside the boiler room, the chimney and additional built-in components such as expansion joints, silencers or flue gas dampers.

All components of a combustion system, starting with the burner with corresponding fan through to the boiler, economiser, exhaust pipes, silencers through to the chimney, must be carefully matched. Only then can problem-free operation be ensured on a long-term basis under all operating conditions. If individual components are mismatched or executed incorrectly this leads to vibrations, noises, increased emissions or unstable combustion throughout the entire system.

Flue gas systems must be sized in accordance with the national and local regulations and applicable standards.

General requirements relating to flue gas systems in and on buildings are specified in EN 1443. The flue gas systems must be implemented in accordance with local building regulations.

Apart from building regulations, further standards such as EN 13084-1 apply for freestanding chimneys.

For definitions regarding flow sizing, see the standards EN 13384 for flue gas systems in and on buildings, and EN 13084-1 for freestanding chimneys.

Flue gas ducts must be made of non-combustible materials and be resistant to the effects of flue gas and heat. The material of the entire steam boiler flue gas system must be suitable for temperatures up to 350°C. If the boiler is equipped with a fourth pass or a waste heat boiler for utilisation of the waste heat in flue gases from a CHP module or a gas turbine, the flue gas system must be suitable for the highest temperature that can occur in each case.

Additional country-specific requirements frequently apply for the design of the flue gas system and the height of the chimney. Only the most important functional fundamental planning principles are therefore described here.

Exhaust pipe

The exhaust pipe connects the boiler end to the inlet of the chimney. It should be routed as directly as possible, be aerodynamically efficient and have few elbows in order to keep the pressure loss and heat loss to a minimum. The pipe should not abruptly narrow or widen and instead a maximum transition angle of 30° should be used. The connection of the exhaust pipe to the chimney should always be established by tapping into it at an angle of 30 – 45°.

Requirement	Design
Constant combustion chamber conditions	Designed for +0/-1mbar at boiler end One chimney draught recommended per boiler
Low pressure loss	Short, few elbows and aerodynamically efficient
Low heat loss	Provide insulation
Remove condensate	Condensate drainage nozzle and neutralisation
Ensure unrestricted passage	Provide cleaning and inspection apertures
Emission measurement	Provide emission measurement nozzle
Cleaning and inspection	Provide cleaning and inspection apertures at all deflections
Compensate for thermal expansion	Provide expansion joints
Resistance	Temperature resistant (up to 350°C), condensate resistant, corrosion resistant
Compression strength	Positive and negative pressure
Gas tightness	Gas tightness according to EN 1856
Danger due to insufficient air	Integrate flue gas and supply air flaps with safety-orientated limit switches

Tab. 23 *General requirements for exhaust pipes*

Sizing

The exhaust pipe with all components such as flue gas dampers, expansion joints and silencers can normally be continued up to the chimney with the same nominal diameter as the flue gas connector at the boiler.

When designing the system, a recommended speed of 16.5m/s with reference to the boiler outlet temperature should not be exceeded. As the recommended speed is referenced to the operating flow rate, the flue gas mass flow rate which is normally specified still has to be converted to the operating flow rate.

The ideal gas law can be used for the conversion.

$$\rho_b = \rho_n \cdot \frac{T_n}{T_b} \cdot \frac{p_b}{p_n}$$

F24. *Rearranged ideal gas equation for calculating the operating density of gases*

ρ_b	Operating density
ρ_n	Standard density
T_b	Operating temperature [K]
T_n	Temperature under standard conditions (273.15K)
p_b	Operating pressure [bar]
p_n	Pressure under standard conditions (1.01325 bar)

→ F2: Normal temperature and pressure and standard temperature and pressure, page 27

Example, natural gas H:

$\lambda = 1.15$ Excess air

$\dot{m}_{FG} = 10{,}000$ Flue gas mass flow rate [kg/h]

$\rho_{n,FG} = 1.244$ Standard density of flue gas [kg/m³$_n$]

$T_b = 250 / 523.15$ Flue gas temperature [°C]/[K], downstream of boiler and upstream of economiser

$p_b = p_n = 1.01325$ Ambient pressure [bar] (deviation from the standard condition is disregarded)

$$\rho_b = 1.244 \frac{kg}{m^3_n} \cdot \frac{273{,}15\ K}{523.15\ K} \cdot 1 = 0.427 \frac{kg}{m^3}$$

B12. *Example calculation for determining the operating density of the flue gas*

$$DN \geq \sqrt{\frac{4 \cdot \dot{V}}{\pi \cdot u}} = \sqrt{\frac{4 \cdot \dot{m}}{\pi \cdot \rho \cdot u}}$$

F25. *Formula for calculating the required nominal diameter of the exhaust pipe*

DN	Nominal pipe diameter
$\dot{V}$	Flow rate [kg/h]
$\dot{m}$	Mass flow rate [kg/s]
ρ	Density [kg/m³]
u	Recommended speed according to table 73 [m/s]

$$DN \sqrt{\frac{4 \cdot 10{,}000 \frac{kg}{h}}{\pi \cdot 0.650 \frac{kg}{m^3} \cdot 16.5 \frac{m}{s}} \cdot \frac{1\ h}{3{,}600\ s} \cdot \left(\frac{1{,}000\ mm}{1\ m}\right)^2} = 574\ mm$$

→ Minimum nominal diameter DN 630

B13. *Example calculation for determining the required nominal diameter of the exhaust pipe*

The draught calculation of the chimney manufacturer may also require a larger nominal diameter, especially where short chimneys and long exhaust pipes are concerned.

5.6.1 Flue gas silencer

The purpose of flue gas silencers is to reduce the emission of combustion noise. To guarantee effectiveness of the silencer, it must be designed for the frequencies emitted by the burner, the boiler output and the specified approved noise emissions.

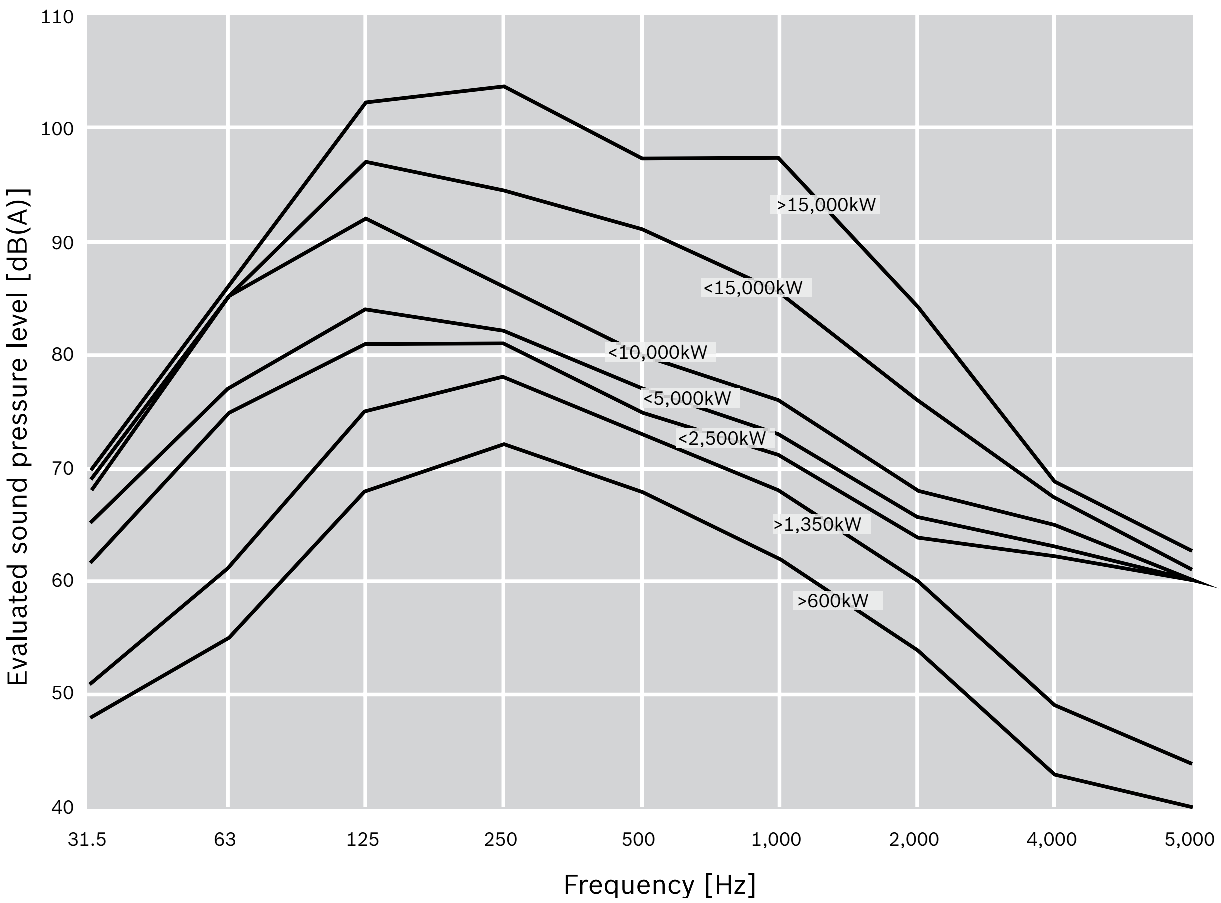

Fig. 125 *A-rated frequency analysis and corresponding total sound pressure level with reference to boiler output*

Boiler output	[kW]	≤ 600	≤ 1,350	≤ 2,500	≤ 5,000	≤ 10,000	≤ 15,000	> 15,000
Empirical value for the total sound pressure level	[dB(A)]	75	81	85	87	94	100	107

The values shown in Fig. 125 are only guide values for a single boiler without flue gas silencer. The measurement was performed 1m from the chimney outlet at an angle of 45°.

The noise produced during combustion is emitted as airborne noise via the surface of the flue gas system and emerges at the chimney head. The noise from a boiler system primarily consists of low frequency sound.

These sound emissions can be effectively reduced with a flue gas silencer. To comply with the prescribed sound emission values when designing a flue gas silencer the frequency spectrum of the flue gas noise at the chimney outlet of the boiler system must be taken into consideration.

The graph in Fig. 125 shows the average sound pressure level of a boiler, measured at the chimney outlet with no flue gas silencer in the flue gas system. As the combustion system (e.g. due to the burner construction or the flow profile that occurs in the combustion chamber) and flue gas system (e.g. due to the number of elbows, length and diameter of the exhaust pipe) have a considerable influence on the resulting values, only guide values can be specified here for the sound pressure level. In the case of the multi-boiler system the sound levels of all boilers must be added up.

When planning the exhaust pipe, it must be considered that to reduce the noise emissions, the silencer must be fairly long, depending on the requirement, and must be installed inside or outside the installation location prior to entry of the exhaust pipe into the chimney.

If the sound emission requirements are exacting, e.g. in the hospital sector, due to the complexity of the topic, it is advisable to consult an acoustics expert regarding the specific design of the flue gas silencer.

Chimney

The purpose of the chimney is to remove the flue gas and pollutants it contains harmlessly to the surroundings by ensuring they are removed in the free air current without disruption and are also sufficiently diluted. It should be in the immediate vicinity of the boiler house to avoid long flue gas ducts and the flue gases should be removed vertically upwards. Obstruction of the free air flow by elbows or rain canopies is not permitted.

Chimney height

The minimum required height for the chimney is defined by the national requirements for air pollution control.

Chimney cross-section and chimney draught

The temperature of the flue gases in the chimney is higher than the outdoor air. This produces a lifting force, the so-called “chimney draught”, in the chimney and rising exhaust pipe sections. This supports the removal of the flue gases and produces a negative pressure in the chimney and sections of the exhaust pipe. The size of the chimney draught is also linked to the temperature difference in relation to the atmosphere via the density.

The chosen chimney cross-section must be large enough to allow the lifting forces to overcome the flow resistance in the chimney from the boiler end. On the other hand, the cross-section should not be too large to ensure the flue gases still exit the chimney at a velocity of at least 6m/s and so that an overly high negative pressure does not exist at the boiler end, especially with very high chimneys.

The calculation for the exhaust pipe should always be performed by a specialist contractor or the boiler manufacturer.

6 Production

6.1 Optimum boiler construction

Optimum design for modern steam supply

Modern steam boilers not only have to work efficiently, they must also handle dynamic pressure demands with a consistently high steam quality. Water content and steam space size are frequently discussed in this context, although other factors are more relevant. Far more crucial for the power reserve and the dynamics with consistently high steam quality are the water quality, the control quality and the height of steam space. Poor water quality leads to an “unsteady” water level and foaming, accompanied by a danger of water entrainment.

The patented arrangement of flame tube and passes in Bosch boilers (Fig. 127) is therefore perfect for maximising the steam space with a low water content. In the event of sudden output peaks, the water level in the boiler increases as more steam bubbles are produced. In these cases the high steam space offers outstanding security against high water shutdowns and minimises water entrainment. In addition, extremely fast reaction to load peaks is reliably achieved by our intelligent three-component control, pilot signals from large scale consumers and by avoiding preventilating (burner start). A wide range of design methods such as Design by Rules and Design by Analysis (e.g. FEM) keep design-related stresses in the boiler shell to a minimum.

Further benefits are:

- Higher steam quality, especially for dynamic requirements
- Low water content allows faster heating from cold start condition
- Most compact design reduces required space, radiation and downtime losses
- Lower combustion chamber load and reduced NO_x emissions

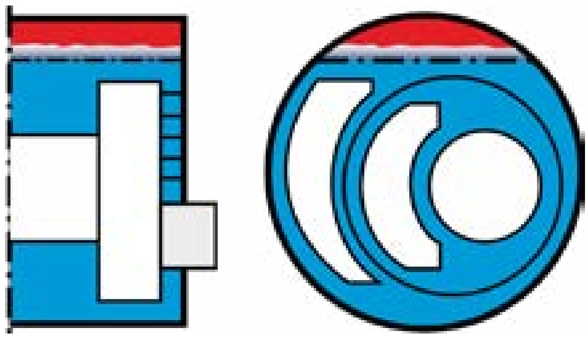

Fig. 126 *Boiler design with side-by-side arrangement of passes*

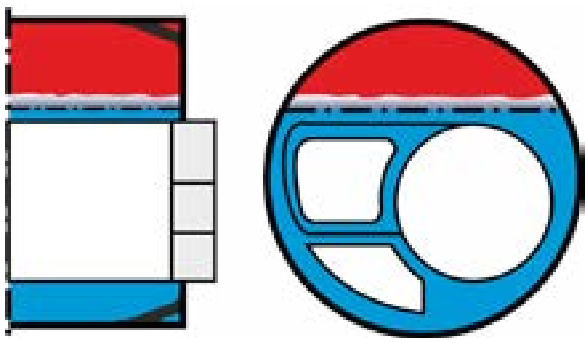

Fig. 127 *Boiler design with optimised steam space by Bosch*

Diagonal stays instead of stud bolts

In other boiler designs the reversing chamber is fixed to the boiler end with stud bolts and there is no direct connection between the flame tube and the boiler end. Especially when heating up, large forces exist in the boiler due to the temperature difference between the cold boiler shell and hot flame tube. With stud bolts these forces can only be transmitted at specific points which leads to unfavourable stress peaks.

Further disadvantages of stud bolt construction are:

- Stud bolts critical when exposed to bending stresses
- Bolts tear off, especially with frequent temperature changes

The design principle of Bosch industrial boilers has been further developed and the stud bolts omitted. The flame tube is anchored to the boiler shell at both ends and can distribute stresses evenly via the boiler base and diagonal stays (corner anchors). To avoid additional thermal emissions, multi-layer Bosch composite insulation with a particularly high insulating effect is used for the boiler inspection door. A further benefit is the lifelong freedom from maintenance, assuming proper operation and commissioning. This UNIVERSAL UL-S design has proved itself in more than 80,000 boiler systems for well over 60 years. A number of these boilers which were initially produced from the early 1950s are still verifiably in operation today.

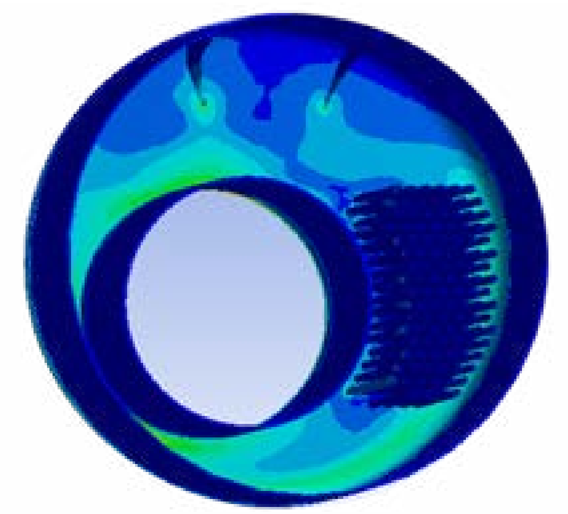

Fig. 128 *Diagonal stays instead of tie rods ensure even stress distribution and a long service life*

6.2 Correct welding of flame tube and smoke tubes

The connections between the flame tubes and smoke tubes and the base are one of the most sensitive areas in high-pressure boilers. These connections must be able to withstand high stresses and temperatures. At Bosch, smoke tubes are therefore welded in by state-of-the-art robots and semi-automatic welding systems are used for flame tubes. Particularly homogenous and robust connections are obtained by carrying out welding fully or semi-automatically. Cooling grooves are also used on the water side at weld seams that are exposed to high thermal stresses. Particularly for thicker sheet metal this provides excellent cooling even in high load condition.

Burner passages however are made without water cooling in order to increase the boiler’s durability. Complicated and costly repairs including a complete hydraulic pressure test are thus prevented. Thanks to Bosch’s special insulation concept in the burner passage, heat emission losses and heat input of our industrial boilers can be minimised. This also increases the robustness and ease of maintenance of the boiler as the insulation material is designed to last the entire service life of the boiler when commissioned and operated correctly.

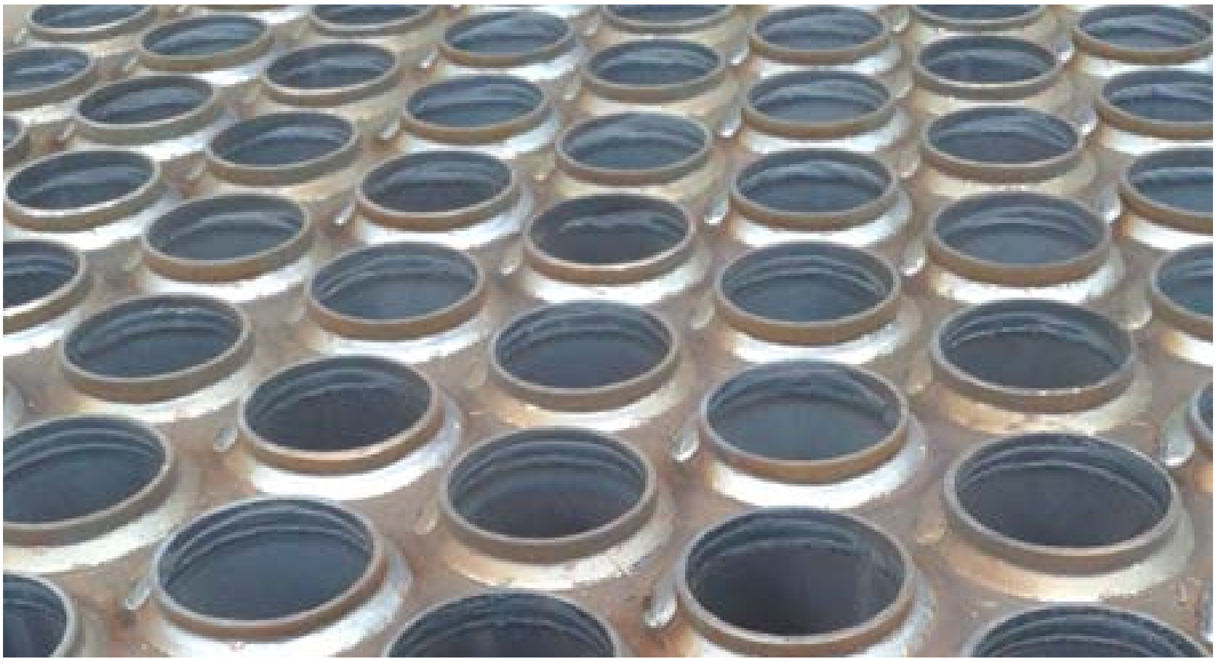

Fig. 129 *Weld seams at inserted smoke tubes*

6.3 Welding with precision

Fig. 130 *Horizontal and vertical boiler shells at the production in Gunzenhausen, Germany*

Thanks to our process cranes with exceptionally high load-bearing capacity and our high production halls, boilers weighing up to 120 tons can be safely, quickly and gently turned and set up in the ideal processing position. By contrast, in older production facilities boilers weighing more than 60 tons, for example, are often welded out of necessity in a sloping position. This can lead to quality problems with the weld seems.

Horizontal welding allows a more homogenous structure to be achieved, a higher penetration depth, notch-free geometries, outstanding welding quality and therefore greater uniformity of the welding process in general.

For the individual assembly of a boiler with flanges and customised equipment, the components are connected manually using the metal active gas welding (MAG) procedure.

To ensure pore-free seams it is essential that the inert gas is not blown away during welding. We ensure this by protecting our work areas with windprotected work stations, special ventilation systems and radiant ceiling heating instead of conventional hot air blowers.

Our globally unique, self-developed corrugated tube machine is able to manufacture fully automatically corrugated flame tubes with up to 9 metres length. The machine is equipped with twelve servomotors and three lasers for monitoring and control. It manufactures corrugated flame tubes with millimetre precision using laser technology. Corrugated flame tubes are a core product in boiler manufacturing and are the components that must withstand the highest stress.

Fig. 131 *The in-house designed fully automatic corrugated flame tube machine*

6.4 Use of welding robots

To ensure a particularly high and consistent quality, the smoke tubes of most of our boilers are welded fully automatically by five robot systems. The special robot used in industrial boiler manufacturing at Bosch (see Fig. 132, page 237) has many advantages compared to welding robots used in conventional applications. No positioning errors occur due to the fully automatic individual tube scanning operation which requires no tool changes. The robot can be used flexibly in combination with a crane and transported quickly and easily to every boiler. The quality of these weld seams is crucial for the long-term durability of the boiler as the smoke tube weld seams are exposed to high stresses.

Fig. 132 *Mobile welding robot used in Bosch industrial boiler production*

6.5 Fewer weld seams, higher quality

Our industrial boiler manufacturing facilities are designed to handle especially wide sheet metal sections up to 3.5 metres. This means that our large boiler shells require fewer weld seams than is usually the case. A weld seam may be perfectly executed but it still cannot compete with the outstanding robustness of continuous, low-stress solid material.

Low-stress material increases the service life

Particularly tight tolerances can be achieved by using laser and plasma cutting machines to cut container and pressure vessel components. Precise angles and minimum heat input are further benefits compared to common gas cutting systems.

Cutting with CNC-controlled plasma systems ensures that less energy is introduced at the cutting points of the panels. Cutting heads which are adjustable up to 45 degrees allow simultaneous joint preparation. All boiler shells and base components are therefore processed at Bosch Industrial using this method.

Smaller sheet-metal parts for boiler components and smaller boiler shells are cut on the fully-automatic CNC-controlled laser cutting system. The workpieces which are obtained through fast, precise, low-stress cutting can be supplied to downstream processes without any reworking and with extremely small joints and burr-free edges.

Fig. 133 *Bending of sheet metals with widths up to 3.5m is possible*


BOSCH

Efficiency

1 Basics

Fuel costs represent the major share of the operating costs of a boiler system. The efficiency and also especially the actual degree of utilisation is relevant for assessing the energetic effectiveness of steam boiler systems.

In addition to the fuel costs, the cost of power, chemicals, water and waste water, spare parts and downtimes must be monitored and optimised.

1.1 Net calorific value, gross calorific value and condensation heat

The net calorific value (H_u or H_i) is the energy released during a full combustion when the flue gas is cooled back to the reference temperature at a constant pressure. In this case the water vapour produced during combustion remains in gaseous form. The net calorific value therefore only specifies the quantity of sensible heat in the flue gases and is directly related to temperature, and not the quantity of condensation heat bound in the water vapour.

The 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 at a constant pressure and the entire quantity of water produced is condensed. The gross calorific value therefore also contains the condensation heat, also referred to as “latent heat”.

→ Technology – Chapter 1.3: Enthalpy, page 110

Depending on the fuel used, the gross calorific value is around 6.8% (fuel oil) to 10.8% (natural gas H) higher than the net calorific value.

Material value	Symbol	Unit	Natural gas L	Natural gas H	Propane	Butane	Fuel oil EL	Fuel oil EL low-sulphur
Net calorific value	H_i	kWh/m³ kWh/kg	8.83	10.35	25.89	34.39	11.89	11.89
Gross calorific value	H_S	kWh/m³ kWh/kg	9.78	11.46	28.12	37.23	12.70	12.70
Ratio	H_i / H_S	%	110.8	110.7	108.6	108.3	106.8	106.8
Dew point	t_{Co}	°C	56.9	57.0	53.1	52.4	48.6	48.6
Acid dew point	t_{Co}	°C	–	–	–	–	124	97
Water generation[1)]	$W_{spec,H2O}$	g_{H2O}/kWh	159.4	158.5	126.9	122.0	100.5	100.5
pH value	pH	–	2.8 – 4.9	2.8 – 4.9	2.8 – 4.9	2.8 – 4.9	1.8 – 3.7	2.3 – 4.5

Tab. 24 *Characteristics of various fuels*

1) With reference to H_i

Some of the water vapour in the flue gas can be condensed due to state-of-the-art heat recovery and flue gas systems made of corrosion resistant materials (e.g. suitable stainless steels). Using this condensing technology, the efficiency can then also increase to over 100% because it is based on the lower net calorific value.

→ Efficiency – Chapter 2.1.2: Condensing heat exchanger, page 263

Efficiency is calculated on the basis of the net calorific value of a fuel as in former times it was essential that the water vapour in the flue gas remained in gaseous form to prevent flue gas condensation and corrosion of the boiler or flue gas system as well as chimney sooting.

However, to use the condensing technology sensibly, the medium must be at a temperature of ≥ 10K below the flue gas dew point temperature, i.e. at a maximum temperature of 45°C with natural gas.

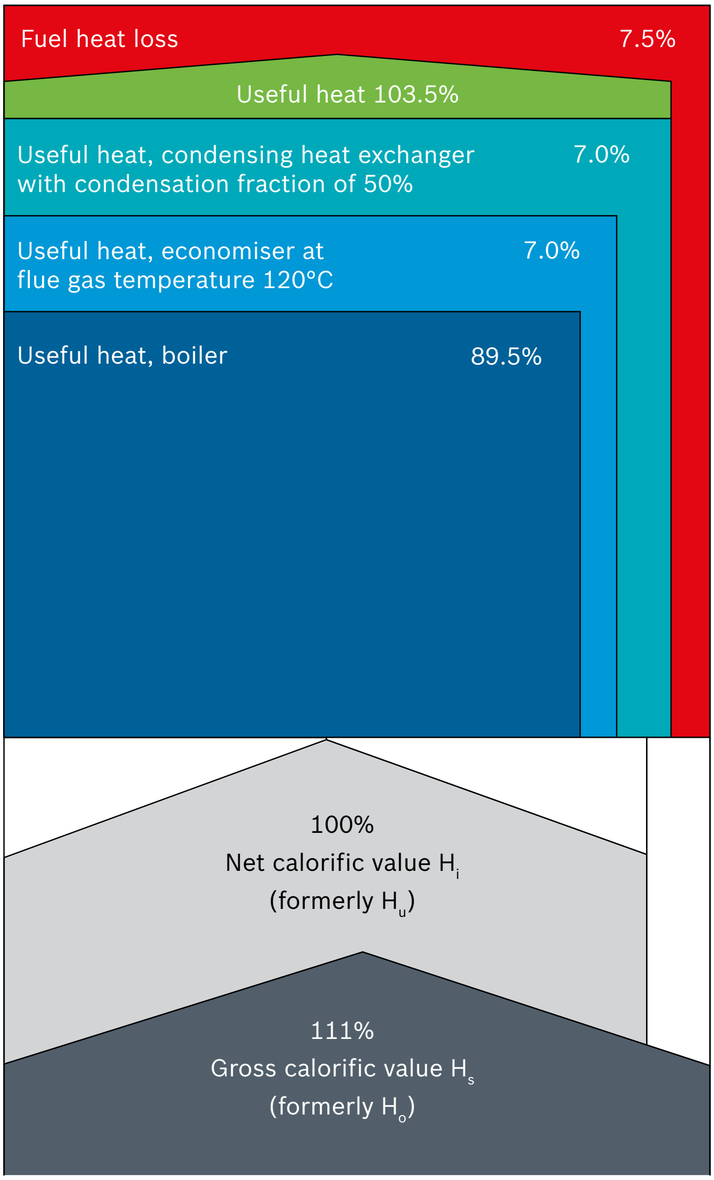

Fig. 134 *Heat balance of a steam generator featuring condensing technology and gas combustion (values are examples)*

1.2 Overview of efficiency measures

If a balance calculation is performed for a steam boiler at a specified load based on the incoming and outgoing material and energy flows, the proportion of energy that cannot be used quickly becomes evident. Fuel, combustion air, feed water and electrical output, e.g. for pumps and fans, is supplied.

The variables in the balance calculation that are removed are, in addition to the useful thermal energy in the steam, proportional losses for the flue gas, surface blowdown or bottom blowdown and thermal losses due to radiation and conduction.

The losses can be minimised by taking suitable measures. When selecting the optimisation measures, priority should be given to those which offer the best cost-benefit ratio. However, this cost-benefit sequence of measures depends on the specific system and also largely on the mode of operation of the overall boiler system. The following table provides an overview of the measures for increasing efficiency. Most of these measures can be combined.

Energy saving measures	Potential savings	→ Page
Economiser	≤7% fuel	→ Page 261
Condensing heat exchanger	≤7% fuel	→ Page 263
Air preheating	≤2.5% fuel	→ Page 265
Feed water cooling	≤1.8% fuel ≤3% fuel at 4-pass boiler	→ Page 267
Brine expansion and heat recovery	≤2% fuel, freshwater, waste water	→ Page 277
Oxygen and/or CO burner control	≤0.5% fuel	→ Page 270
Speed control, fan	≤75% electricity costs	→ Page 270
Exhaust vapour heat exchanger	≤0.5% fuel	→ Page 280
High-pressure condensate system	≤12% fuel, freshwater	→ Page 284
Automatic and continuous water analysis	≤0.5% fuel, chemicals, personnel costs	→ Page 296
Optimisation of control parameters, regular service, maintenance, cleaning	≤3% fuel, extended service life, process reliability	→ Page 298
Osmosis water preparation	≤3% fuel, freshwater, chemicals	→ Page 282

Tab. 25 *Energy saving measures and the resulting savings potential*

1.3 Efficiency

The efficiency is a ratio of benefits to effort which is based on the energetic outputs. In the case of a steam boiler, the efficiency is therefore the quotient of the thermal output released in the form of steam to the thermal output supplied in the form of fuel. The efficiency is a measure of how effectively the energy is converted in the boiler. The efficiency of steam boiler systems is determined by the combustion efficiency and the heat losses due to radiation and conduction on the boiler surface. In this case, it is important for the efficiency to be defined only for a new system at its nominal steam output or for specific partial load steam outputs when the system is in equilibrium.

Losses due to starting up and shutting down, surface blowdown and bottom blowdown, contamination of heating surfaces, feed water treatment and heat losses in further pipework are disregarded.

$$\text{Efficiency } \eta = \frac{\text{Output}}{\text{Input}} = \frac{\text{Thermal output of steam}}{\text{Thermal output of fuel}}$$

$$\eta = \frac{\dot{Q}_S}{\dot{Q}_F}$$

F26. *Formula for calculating the efficiency*

$\dot{Q}_S$ Thermal output of steam [kW]

$\dot{Q}_F$ Thermal output of fuel [kW]

1.4 Combustion efficiency

The combustion efficiency η_f describes the sensible heat yield during combustion of a fuel. It is determined by calculating the thermal losses q_A in the flue gas with reference to the ambient temperature level. Unburnt components of the fuel are not taken into account for oil and gas combustion since in practice they must not occur on a relevant scale.

→ Efficiency – Chapter 1.1: Net calorific value, gross calorific value and condensation heat, page 243

The combustion efficiency is based on the net calorific value of a fuel and is calculated by deducting the flue gas losses from the maximum achievable 100%.

$$\eta_f = 100\% - q_A$$

F27. *Formula for calculating the combustion efficiency*

Excess air

The excess air is the ratio of actual quantity of air supplied to the required stoichiometric quantity of air.

$$\lambda = \frac{m_L}{m_{L,st}}$$

The simplified equation for conversion of the flue gas oxygen content only applies for a flue gas/air ratio of ~ 1.

$$\lambda \approx \frac{21\%}{21\% - O_2}$$

→ Fig. 135, page 249

λ	Excess air
m_L	Actual heat
$m_{L,\,st}$	Stoichiometric heat
O_2	Oxygen [% by vol.]

To calculate the flue gas loss, the percentage of CO_2 or O_2 in the flue gas and temperature differential between the flue gas temperature and ambient temperature are determined. The maximum CO_2 percentages in the flue gas, which depend on the fuel used in each case, and the Siegert factor f, which depends on the measured O_2 content, are also required.

$$q_A = \frac{f}{CO_{2,max}} \cdot \frac{21\%}{21\% - O_2} \cdot (t_{FG} - t_L)$$

F28. *Formula for calculating the flue gas loss*

q_A	Flue gas loss with reference to the combustion output and the lower net calorific value [%]
f	Siegert factor, linear dependency on excess air λ [bar]
$CO_{2,max}$	Maximum CO_2 value in dry flue gas [% by vol.]
O_2	Measured oxygen content in dry flue gas [% by vol.]
t_{FG}	Measured flue gas temperature [°C]
t_L	Reference and combustion air temperature in accordance with EN 12953 part 11 constant 25°C

If only the CO_2 value in the dry flue gas is measured, the following conversion applies:

$$O_{2,r} = 21\% \cdot \left(1 - \frac{CO_2}{CO_{2,\,max}}\right)$$

F29. *Formula for calculating the residual oxygen content from the CO_2 value*

$O_{2,r}$	Calculated oxygen content in dry flue gas [% by vol.]
CO_2	Measured CO_2 value in dry flue gas [% by vol.]
$CO_{2,max}$	Maximum CO_2 value in dry flue gas [% by vol.]

		Siegert factor	**Siegert factor**
Fuel	$CO_{2,max}$	$f_1 = f\ (O_2 = 0\%)$	$f_2 = f\ (O_2 = 5\%)$
Natural gas L	11.67%	0.4792	0.4530
Natural gas H	11.94%	0.4731	0.4469
Fuel oil EL	15.31%	0.4535	0.4342
Fuel oil SA	16.02%	0.4570	0.4389
Propane	13.69%	0.4575	0.4352
Propane-Butane	13.78%	0.4570	0.4349
Butane	13.99%	0.4563	0.4346
Natural gas GZ35	11.12%	0.4871	0.4611
Natural gas GZ41.5	11.67%	0.4604	0.4358
Natural gas GZ50	11.67%	0.4835	0.4569
Medium fuel oil HL Schwechat	15.72%	0.4534	0.4348
Medium fuel oil CLU 3	16.11%	0.4458	0.4285

Tab. 26 *Siegert factors of various fuels*

Calculation of Siegert factor for any given oxygen content in dry flue gas O_2:

$$f(O_2) = f_1 + \frac{f_2 - f_1}{5\% - 0\%} \cdot O_2$$

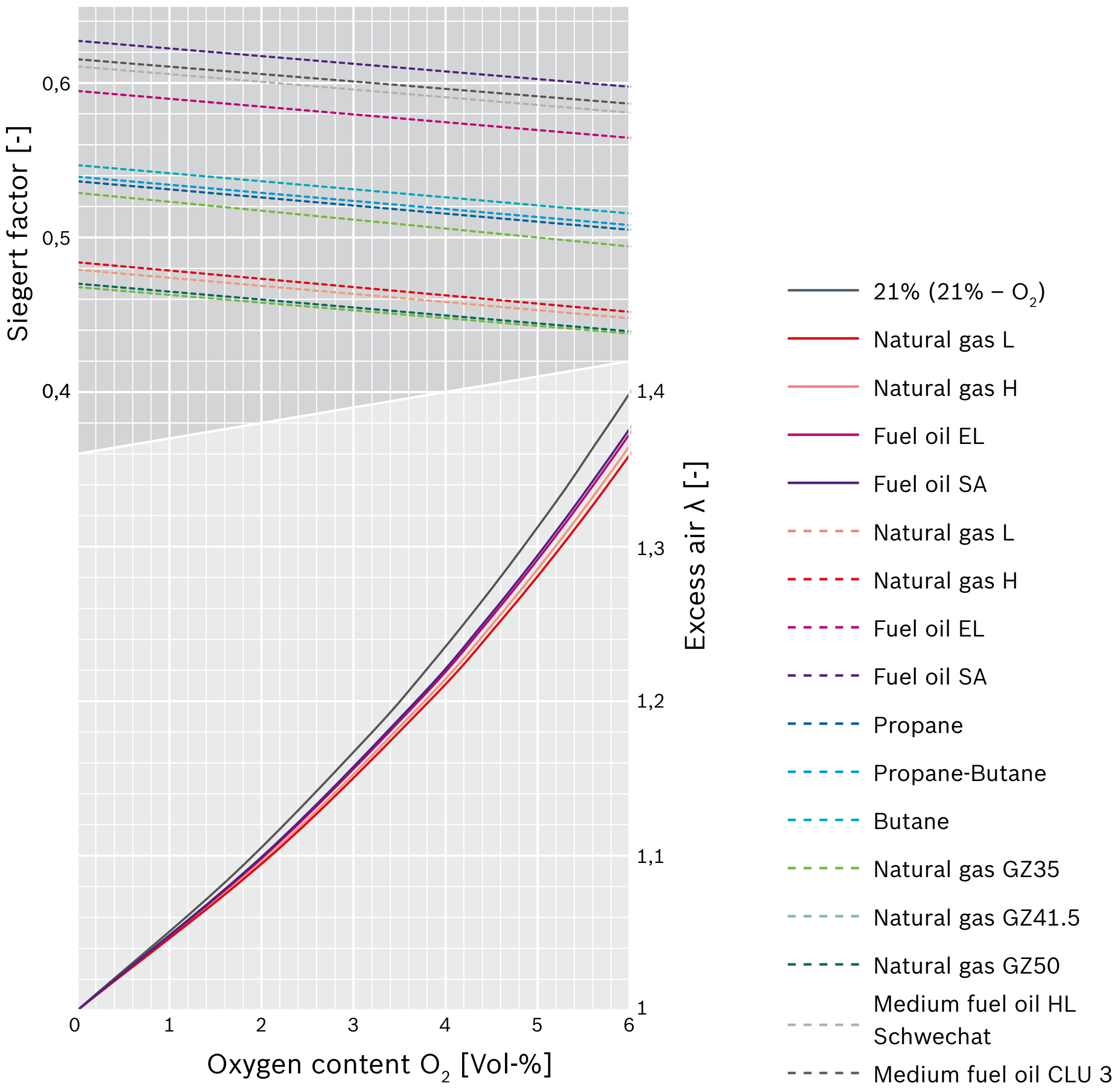

Fig. 135 *Correlation between oxygen content in dry flue gas, excess air and Siegert factor*

Notes:

- For excess air: natural gas GZ 41.5/50, propane, butane, propane-butane coincides virtually exactly with natural gas L and is therefore not shown.
- Medium fuel oil CLU 3 and medium fuel oil HL Schwechat are between the curves of fuel oil EL and SA, and are therefore not shown.

The combustion efficiency increases starting from the full load until roughly 35% partial load with a boiler system. The excess air and therefore the CO_2 content measured in the dry flue gas increases only slightly while the flue gas temperature falls due to more efficient utilisation of the heating surface in the boiler. At a partial load of <35% the greater amount of excess air which is necessary prevails and the combustion efficiency falls again.

→ Fig. 144, page 263

The combustion efficiency is determined during emission measurement by the chimney sweep or customer service, for example. Heat losses due to radiation and conduction on the surface of the boiler are not taken into consideration in this case.

The relationship between combustion efficiency and flue gas temperature with varying excess air is shown in the following diagram for the fuel natural gas H. The higher the flue gas temperature the lower the efficiency.

The diagram also clearly shows that the increase in efficiency is particularly high with less excess air, i.e. low λ values, especially with high flue gas temperatures.

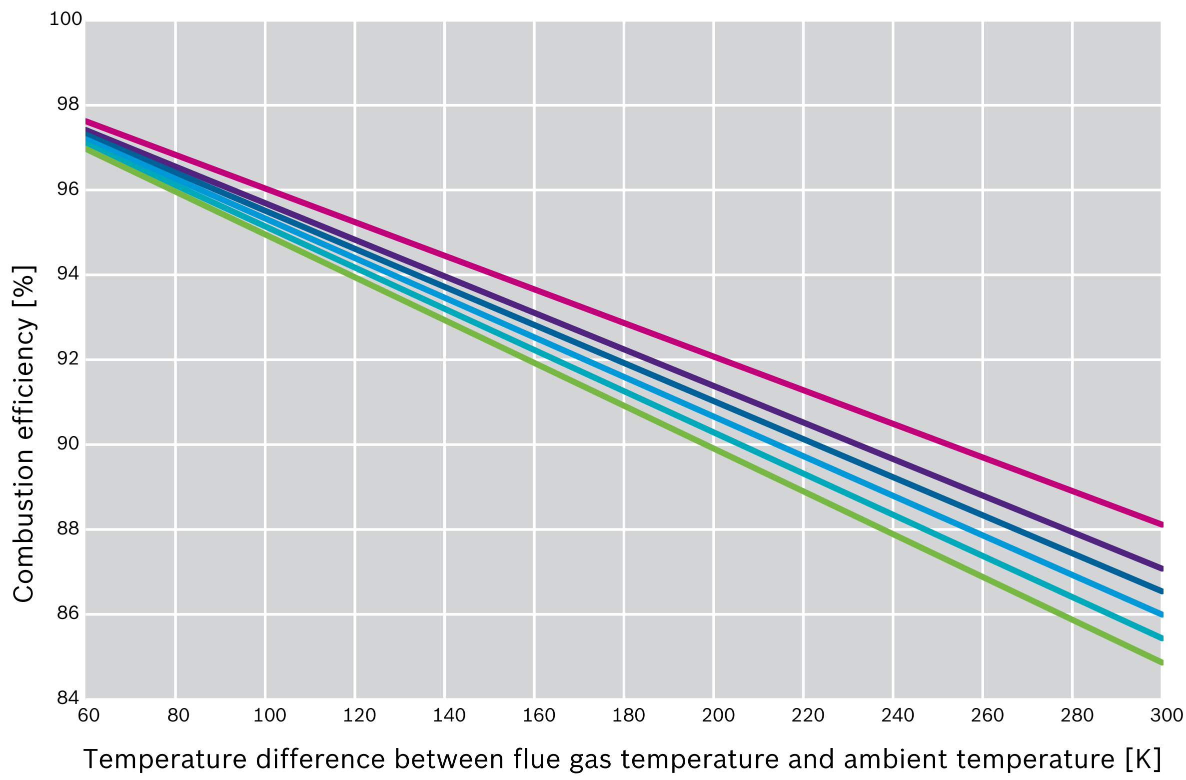

Fig. 136 *Efficiency curve with reference to excess air λ without condensation, using natural gas H as example*

- λ = 1 (O_2 = 0%)
- λ = 1.1 (O_2 = 2.14%)
- λ = 1.15 (O_2 = 3.09%)
- λ = 1.2 (O_2 = 3.96%)
- λ = 1.25 (O_2 = 4.77%)
- λ = 1.3 (O_2 = 5.52%)

1.5 Boiler efficiency

The boiler efficiency η_{boi} is the same as the combustion efficiency minus the heat losses on the surface of the boiler to the environment at the installation room during the burner runtime. It can be calculated as follows:

$$\eta_{boi} = 100\ \% - q_A - \frac{\dot{Q}_{l,boi}}{\dot{Q}_{bu}}$$

oder

$$\eta_{boi} = \frac{(\dot{Q}_{bu} - q_A) \cdot (\dot{Q}_{bu} - \dot{Q}_{l,boi})}{\dot{Q}_{bu}}$$

F30. *Formula for calculating the boiler efficiency*

η_{boi}	Boiler efficiency
q_A	Flue gas loss with reference to the combustion output and the lower net calorific value [%]
$\dot{Q}_{l,boi}$	Heat loss performance of the boiler type [kW]
$\dot{Q}_{bu}$	Current combustion output of the boiler [kW]

→ Technical Information TI005: heat losses due to radiation and conduction

As the heat losses due to radiation and conduction $\dot{Q}_{l,boi}$ generally cannot be easily measured or calculated, the empirical values according to EN 12953 Part 11 are used. These depend on the one hand on the rated output of the boiler type and on the other the temperature of the medium on the water/steam side inside the boiler and therefore the operating pressure.

Heat losses are identical regardless of whether the boiler is at full load or standby mode. For the boiler efficiency this means that the smaller the current burner load is, the higher the consequences of the heat loss. The heat loss performance also occurs during burner downtimes. During downtimes, e.g. at the weekend or overnight, these losses can be minimised by reducing the operating pressure and therefore the operating temperature.

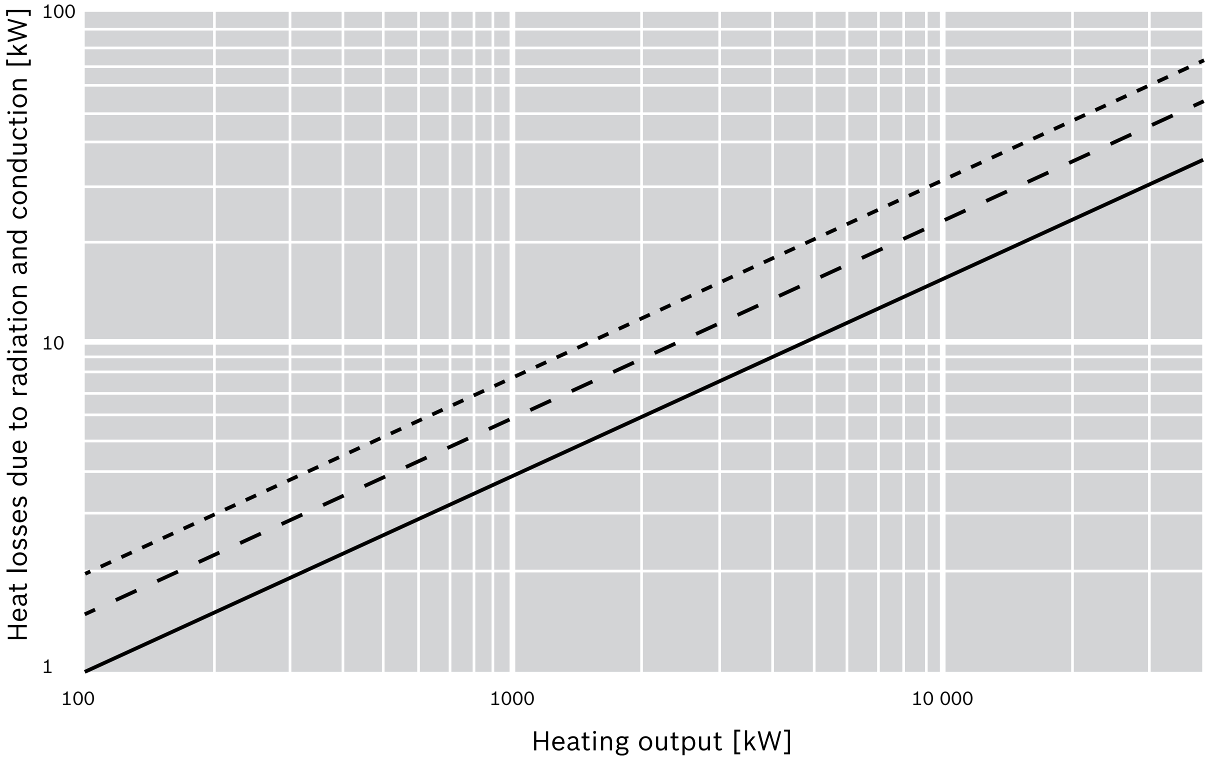

Fig. 137 *Heat losses due to radiation and conduction as a function of the nominal output of the boiler and of the average temperature of the medium in the boiler with an insulation thickness of 100mm*

——— Average medium temperature 100°C

– – – Average medium temperature 150°C

- - - - - Average medium temperature 200°C

In the case of combustion efficiency and boiler efficiency, the nominal load condition and possibly also specific partial load conditions, e.g. at 75%, 50% and 25% of the boiler output, are specified in the manufacturer's documentation. However, a steam boiler system normally operates in all partial load ranges. When the steam removal rate is very low, the boiler system even operates in a mode with longer burner downtime phases.

The boiler efficiency therefore cannot be used exclusively as the yardstick for energy efficiency. In order to be able to more effectively take the corresponding times when a boiler system is at a standstill and when it has activated burner operation into account, the degree of utilisation must be determined as an evaluation criterion.

1.6 Degree of utilisation

The degree of utilisation of a boiler system is a quotient formed of the quantities of heat over a specific period (normally a year). In the case of a boiler system, this is the thermal energy used in relation to the thermal energy supplied by the fuel.

$$\text{Degree of utilisation} = \frac{\text{Output energy}}{\text{Input energy}}$$

$$\eta = \frac{\int \dot{Q}_S \, dt}{\int \dot{Q}_{bu} \, dt}$$

F31. *Formula for calculating the degree of utilisation*

η	Degree of utilisation [%]
$\int \dot{Q}_S \, dt$	Cumulative thermal output of steam over the time [MWh]
$\int \dot{Q}_{bu} \, dt$	Cumulative rated combustion input over time [MWh]

The degree of utilisation is a decisive parameter for the economic efficiency of the system as a whole. It encompasses all losses, i.e. losses that occur during downtimes, when starting up and shutting down the system, during load changes, during surface blowdown and bottom blowdown, in the pipework and containers (e.g. during thermal water treatment).

This important variable can however only be properly measured with heat meters at the consumers and fuel counters and is normally only actually recorded in comprehensive Energy Management Systems.

1.7 Annual degree of utilisation

η_a = annual degree of utilisation [%]

The heat energy $Q_{i,a}$ supplied during a year is determined based on the actual fuel energy used. To do this, the fuel quantity is measured with gas or oil counters and multiplied by the net calorific value.

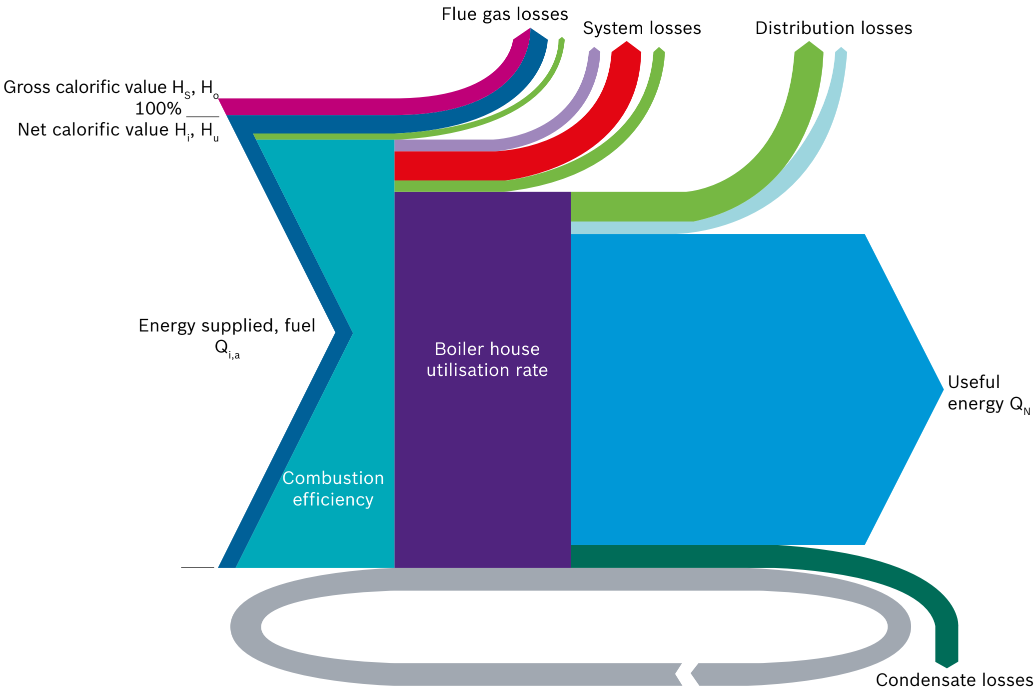

Fig. 138 *Sankey diagram (energy flow diagram) of a steam boiler system*

- Latent heat of the flue gas
- Sensible heat of the flue gas
- Radiation and conduction (including downtime losses)
- Pre-ventilation losses
- Surface blowdown and bottom blowdown, exhaust vapours
- Leaks (at the condensate drains, pipework)
- Missing condensate recirculation and exhaust vapours
- Recirculated condensate

The amount of energy actually used during operation $\dot{Q}_{o,a}$ is determined using a steam meter and a heat quantity calculator. The quantity of heat in the steam is calculated from the quantity of steam and steam pressure, and possibly the temperature of the steam.

When measured and added up over a year and divided by the amount of energy in the fuel, the annual degree of utilisation of the system is obtained.

The annual degree of utilisation of a steam boiler system therefore includes all operational losses of a steam boiler system, such as the flue gas, system, distribution and condensate losses.

A boiler efficiency of 95% may be accompanied by an actual annual degree of utilisation of only 60%. Especially if the average boiler load is very small, the conduction and radiation losses, which generally do not depend on the boiler load, are very high in relation to the fuel heat used. The losses for pre-ventilation of the boiler system during cycling of the burner and for water treatment are added to this.

If the system is frequently only operated in partial load, the losses can occasionally be 20 – 40% of the fuel required for operation of the system.

Annual degree of utilisation η_a = $\frac{\text{Output energy}}{\text{Input energy}}$

$$\eta_a = \frac{Q_{o,a}}{Q_{i,a}}$$

F32. *Formula for calculating the annual degree of utilisation*

a	Based on a year (degrees of utilisation can also be determined on a monthly or weekly basis)
$Q_{o,a}$	Useful energy per year [MWh]
$Q_{i,a}$	Supplied energy per year [MWh]

Boiler efficiency with condensing use

In addition to CO_2, the flue gas produced during combustion of the hydrocarbon chains found in most liquid or gaseous fuels also includes H_2O, i.e. water. At high flue gas temperatures, this water is present in the form of vapour.

However, if the flue gas temperature can be cooled locally to below the dew point, some of the water vapour in the flue gas condenses on the cold heat transfer surfaces and the heat released during this process can be used.

Compared to the formula for a boiler without condensing use, the formula for the boiler efficiency is extended to include the condensation fraction:

$$\eta_{boi,gross\ calorific\ value} = \eta_{boi,dry} + \frac{H_s - H_i}{H_s} \cdot \alpha$$

F33. *Formula for calculating the boiler efficiency with condensing use*

$\eta_{boi,\ gross\ calorific\ value}$	Boiler efficiency with condensing use
$\eta_{boi,\ dry}$	Boiler efficiency without condensation
H_s	Gross calorific value [kWh/kg]
H_i	Net calorific value [kWh/kg]
α	Condensate number (proportion of condensate)

The condensate number specifies the ratio between the quantity of condensate which occurs in practice and the quantity of condensate which is theoretically possible in the flue gas and normally has a value of 0.3 – 0.6, depending on the design.

Efficiencies higher than 100% when using condensing technology are not perpetuum mobile, and can instead be traced back purely to the reference basis of the net calorific value H_i. If the energy used were referenced to the physically correct gross calorific value H_s, 100% would be the maximum efficiency that could be achieved without any losses whatsoever. However, to allow comparisons to be drawn with conventional systems, it has been decided to retain the net calorific value as reference value, also in the case of condensing boilers.

→ Fig. 134, page 244

The difference between the net calorific value and gross calorific value is the latent heat in the flue gas and represents the maximum proportion of heat which can also be recovered due to condensation of the water fraction in the flue gas.

The purpose of the following diagram is to make clear how flue gas condensation increases efficiency and the optimisation in terms of cost-effectiveness.

When using gas as fuel, the efficiency increases in a linear fashion as the flue gas temperature falls until flue gas condensation starts (with a heating surface temperature of roughly 56°C). When condensation in the flue gas starts, the crucial factor is no longer the reduction in temperature, but instead first and foremost the condensation rate α of the water vapour in the flue gas. The diagram shows the different condensation rates of 25, 50, 75 and 100% as dashed blue lines. With a corresponding higher condensation rate, the efficiency continues to increase in jumps.

During this process, the special design of the condensing heat exchanger allows significant quantities of the water in the flue gas to condense at very low water inlet temperatures (e.g. make-up water at 15°C) even when the flue gas temperature measured in the chimney is significantly higher than the flue gas dew point.

In the diagram for natural gas H an efficiency of 100.9% is achieved with a condensate accumulation rate of 34% and a measured average flue gas temperature of 75°C, for example.

→ Fig. 139, page 257

In addition to the quantity of water, the greatest possible distance between the water inlet temperature and minimum dew point is decisive for the condensate accumulation rate. That is shown in the diagram by the red (natural gas H) or purple (fuel oil EL) efficiency curve, which is temperature-dependent.

The area coloured blue represents the technically-achievable flue gas condensation range for steam boiler systems.

1 Example 1:

- Economiser
- Excess air λ = 1.1
- Feed water temperature at Eco inlet 103°C
- Flue gas discharge temperature 126°C

Natural gas H:

- Flue gas discharge temperature 126°C
- Efficiency 95.4%

Fuel oil EL:

- Flue gas discharge temperature 126°C
- Efficiency 95.6%

2 Example 2:

- Condensing heat exchanger
- Excess air λ = 1.1
- Make-up water inlet temperature 15°C

Natural gas H:

- Flue gas discharge temperature 75°C
- Condensate proportion, condensing heat exchanger α = 34%
- Condensate temperature 49°C
- Efficiency 100.9%

Fuel oil EL:

- Flue gas discharge temperature 65°C
- Condensate proportion, condensing heat exchanger α = 34%
- Condensate temperature 41°C
- Efficiency 100.2%

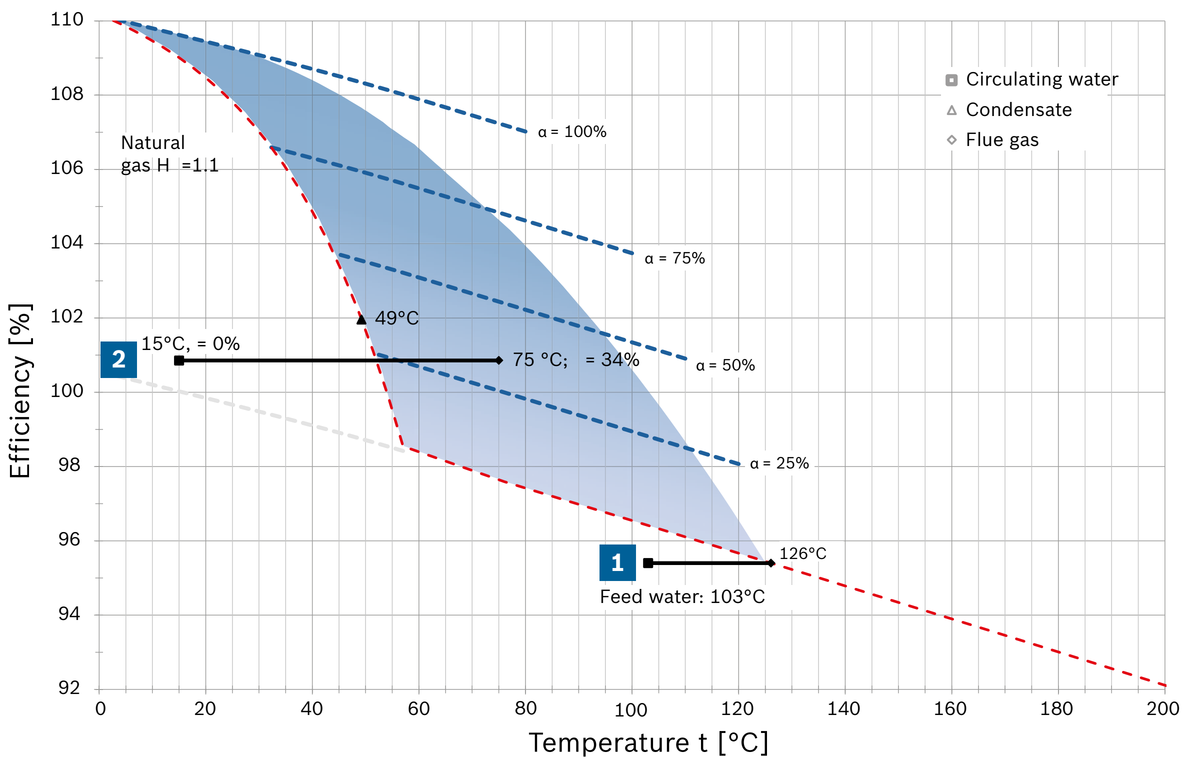

Fig. 139 *Combustion efficiency progression as a function of flue gas temperature with natural gas H (H_i = 10.35kWh/m_n^3, T_L = 20°C)*

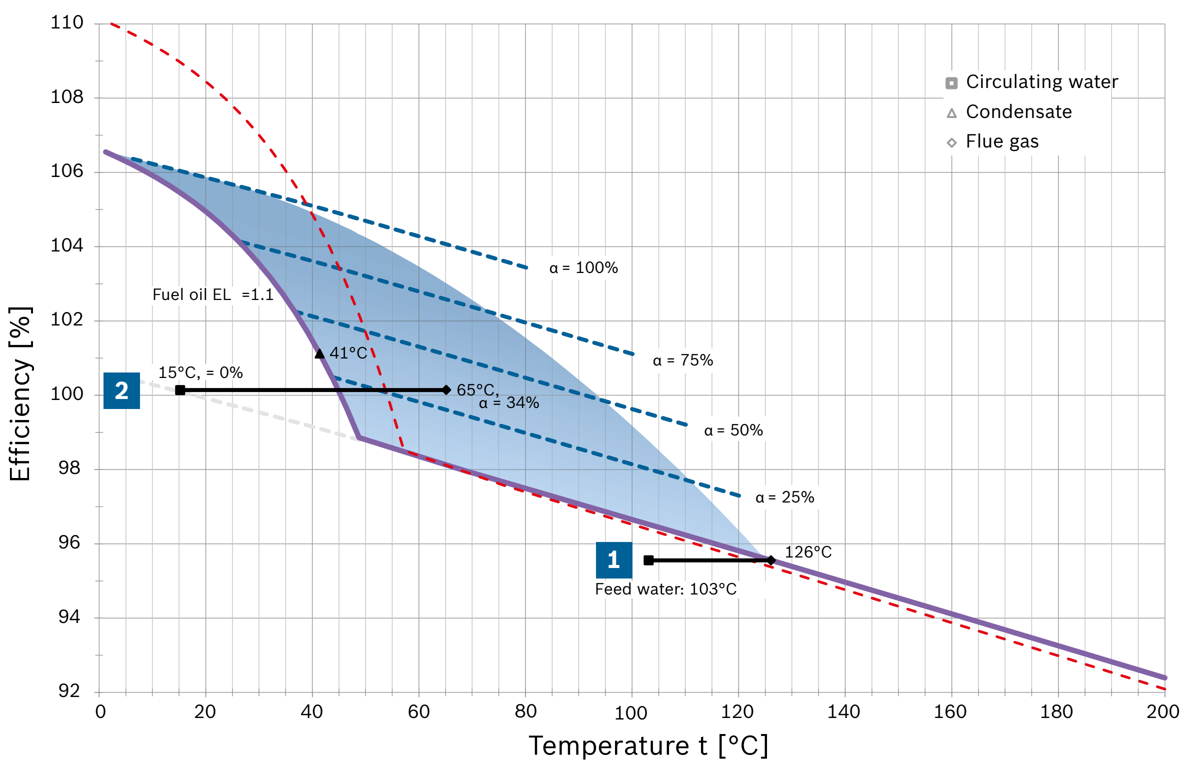

Fig. 140 *Combustion efficiency progression as a function of flue gas temperature with fuel oil EL (H_i = 11.89kWh/kg, T_L = 20°C)*

Especially when using oil as fuel, it must be observed that because the fuel composition is different to gas, the water vapour fraction in the flue gas is significantly lower and therefore the efficiency gain due to condensation is also correspondingly less.

1.8 Analysis of operating costs

To keep the fuel costs of a boiler system as low as possible, the annual degree of utilisation achieved in practice is important. To be able to draw conclusions about the overall operating costs, the cost of the electrical energy required to run the fans and pumps, the waste water and water disposal costs and ultimately also the expenditure for operating, maintenance and inspection costs must also be considered.

The following topics should be considered when performing an overall assessment:

- The energy and mass balance of the boiler
- The energy and mass balance of the complete steam system including water treatment, all pipework, all consumers and the condensate system
- Maintenance and operational effects on the system
- Optimisation options through combination with additional technologies such as combined heat and power or solar heat

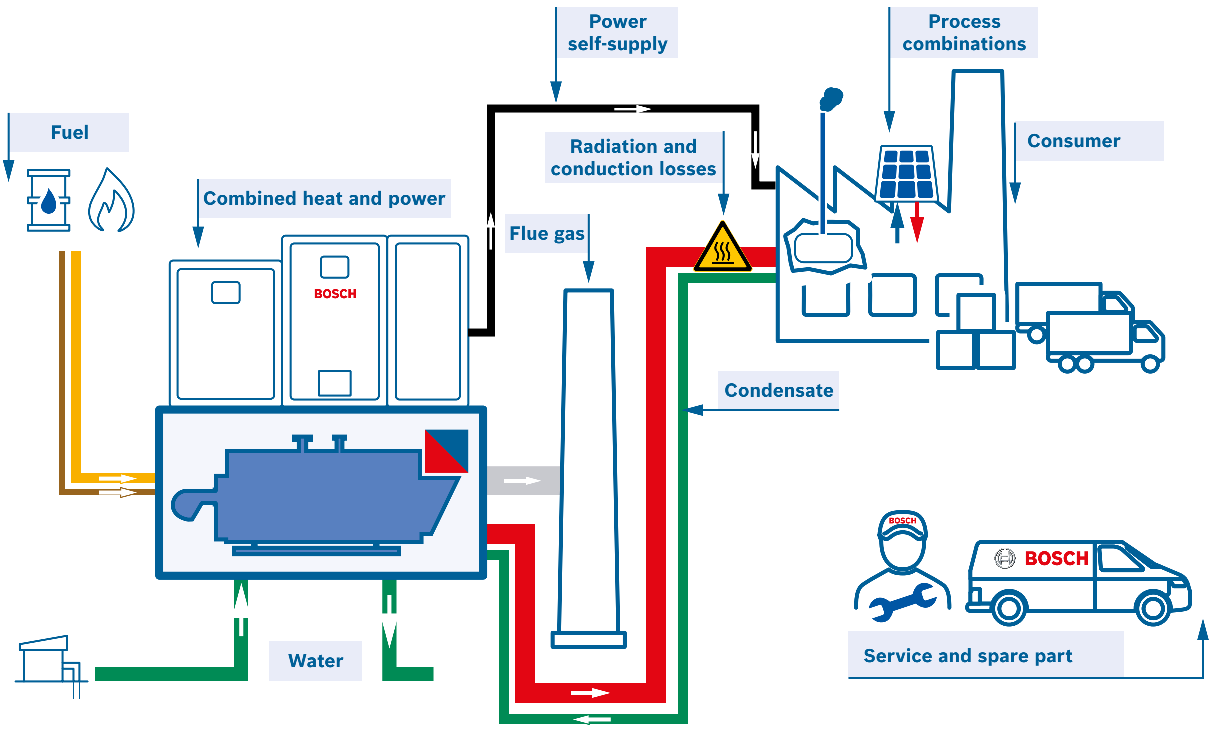

Fig. 141 *Factors influencing the overall assessment of the operating costs of a steam boiler system*


BOSCH

2 Increasing combustion efficiency

2.1 Flue gas temperature or flue gas loss

2.1.1 Economiser

The flue gas temperatures at the boiler outlet are normally roughly 60K above the temperature of the product inside the steam boiler.

→ Fig. 65, page 149

At an operating pressure of 10 bar, which corresponds to a saturated steam temperature of 185°C, the flue gas temperature is therefore roughly 245°C. This corresponds to a flue gas loss of roughly 11%. As shown in the graphic (Fig. 143, page 262), the flue gas loss can be reduced by roughly 1 percentage point, or the boiler efficiency increased accordingly, with each 20°C reduction in flue gas temperature.

Using an integrated or downstream economiser, the flue gas temperature can be reduced to 120 – 140°C, depending on the economiser design, which reduces the flue gas loss significantly. During this process, the heat in the flue gases is transferred to the boiler feed water flowing in countercurrent. The heat removed from the flue gas flow is fed to the boiler via the heated feed water. This increases the combustion efficiency by 5 – 7%.

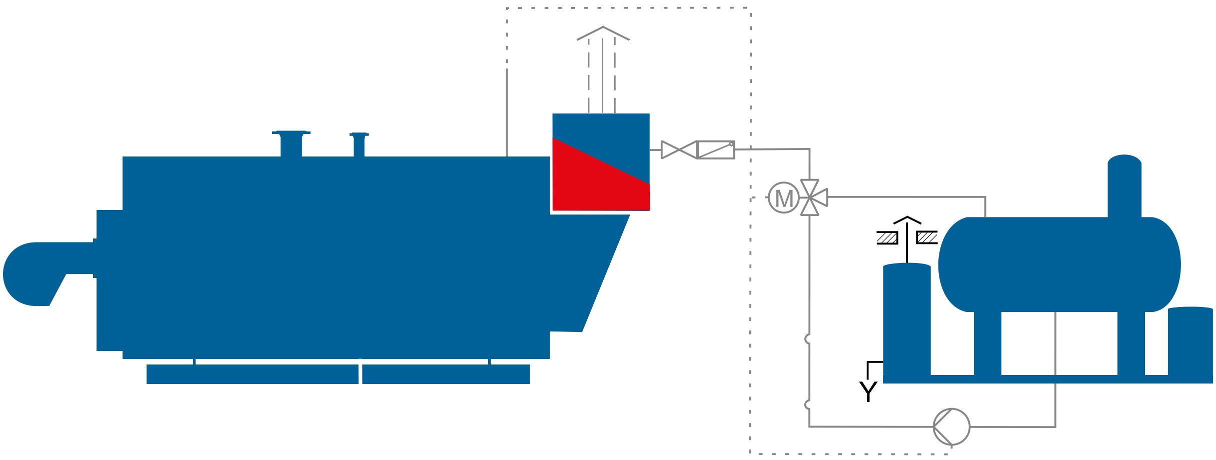

Fig. 142 *Simplified flow diagram of a steam boiler system with integrated economiser*

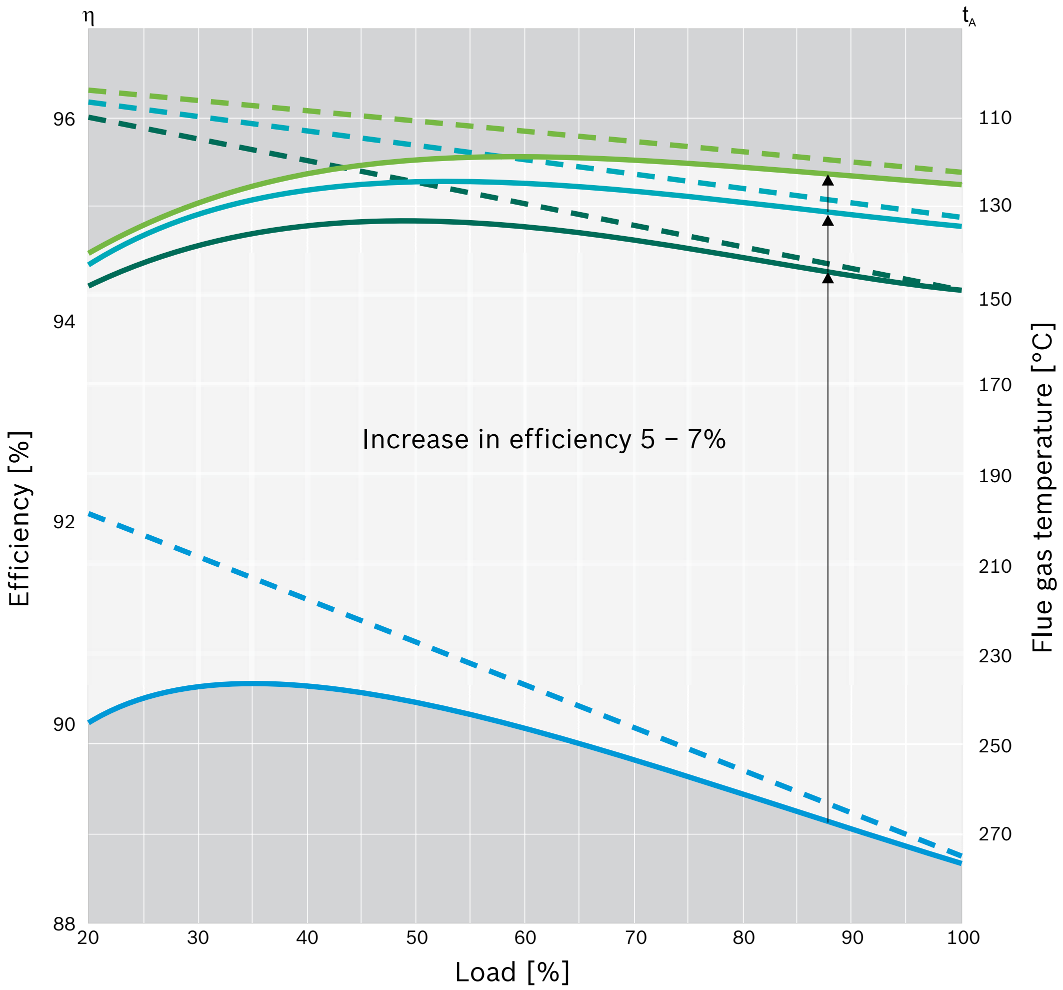

Fig. 143 *Efficiency gain for various exemplary sizes of economiser (increasing from I to III)*

η		t_A	
———	ECO size 3	– –	ECO size 3
———	ECO size 2	– –	ECO size 2
———	ECO size 1	– –	ECO size 1
———	without	– –	without

Unregulated economisers achieve the optimum efficiency gain because in partial load optimum use is made of the available heating surface to cool the flue gas.

→ Technology – Chapter 3.3: Economiser, page 148

If the permissible minimum temperature of the chimney needs to be taken into account, economisers can be designed individually for the various flue gas inlet and outlet temperatures.

On the one hand, in order to achieve a high degree of economic efficiency via a low flue gas temperature and also to comply with a permissible minimum flue gas temperature for the chimney on the other, a stepless feed water controller and a water-side bypass control are necessary boiler components. Nowadays the integrated economiser is a standard feature of a steam boiler in more or less every application. It normally pays for itself within a few months.

2.1.2 Condensing heat exchanger

When using condensing technology, not only the sensible heat which is directly linked to the temperature but also the condensation heat latent in the water vapour is partially removed from the flue gas. Liquid flue gas condensate is produced which must be removed from the flue gas path, neutralised and introduced into the sewer system.

This is made possible without causing long-term corrosion damage using corrosion resistant materials in heat exchangers, moisture-resistant flue gas systems and chimneys made of stainless steel.

Given the right framework conditions, an additional improvement in efficiency of up to 7% is possible. To do this, the condensation economiser is always connected downstream of the dry economiser on the flue gas side.

→ Fig. 144, page 263

As an example, the following graph shows the boiler efficiency as a function of boiler load.

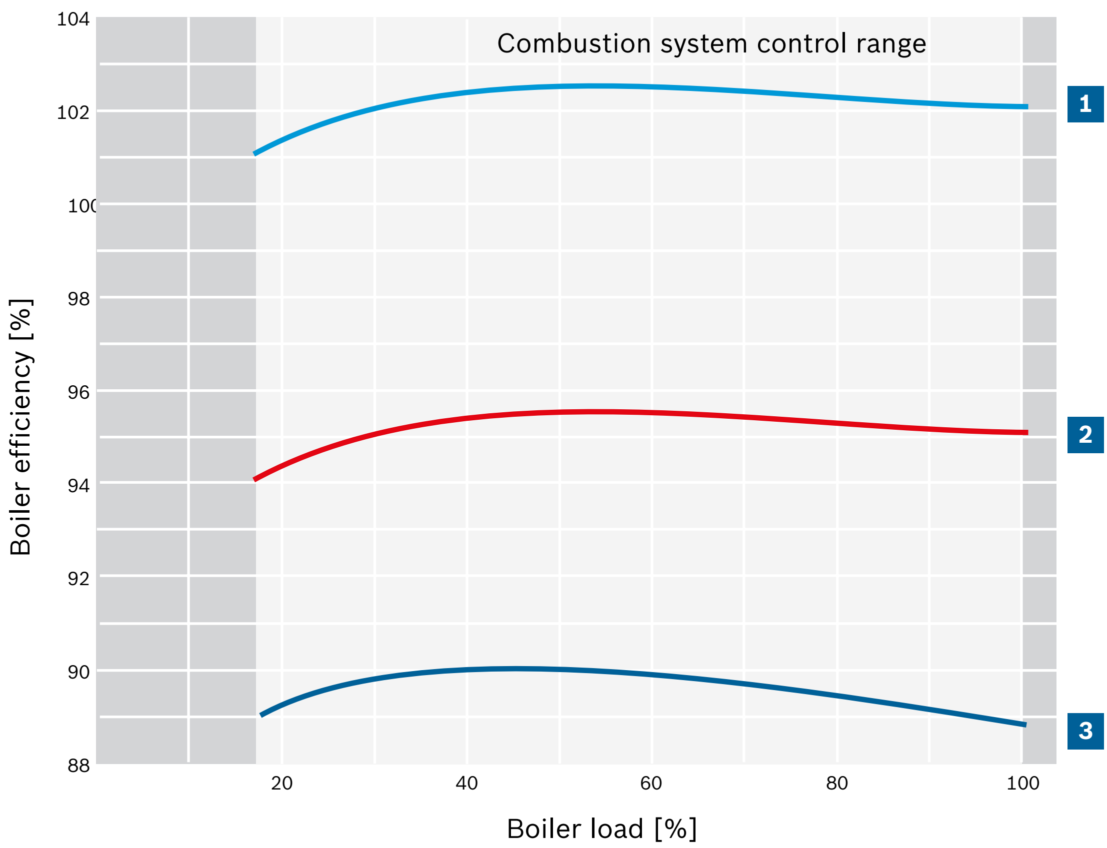

Fig. 144 *Efficiency curve as a function of the boiler load of a boiler without economiser, boiler with economiser and boiler with economiser and additional condensing heat exchanger*

1 Steam boiler with economiser and upstream condensing heat exchanger

2 Steam boiler with economiser

3 Steam boiler without economiser

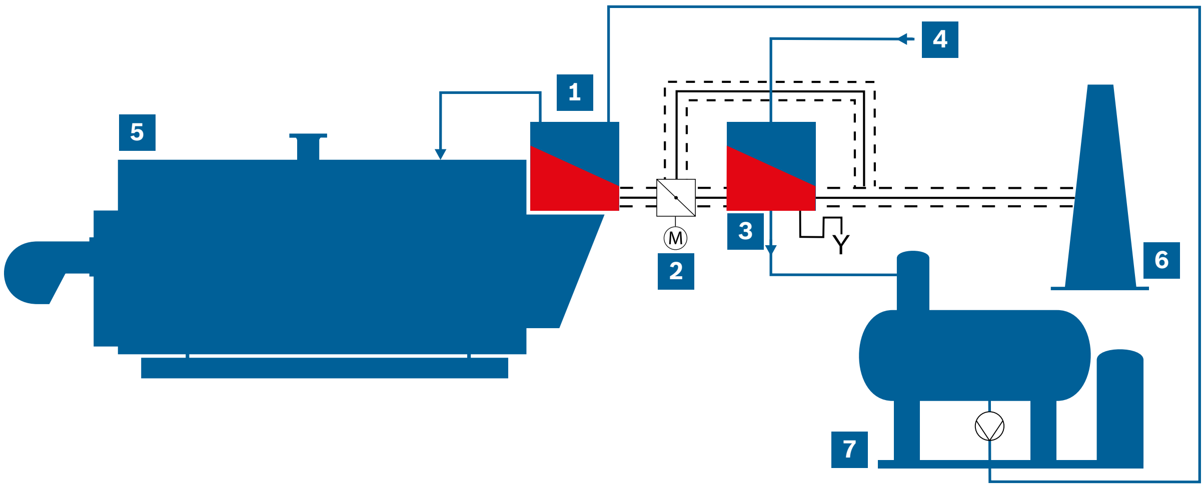

Fig. 145 *Simplified flow diagram of a steam boiler system with integrated economiser and downstream condensing heat exchanger*

- **1** Integrated economiser (steel)
- **2** Flue gas bypass flap
- **3** Condensing heat exchanger (stainless steel)
- **4** Make-up water
- **5** Steam boiler
- **6** Chimney
- **7** Water service module WSM-V

To operate a condensing heat exchanger efficiently, a sufficiently large (>30% of the boiler steam output) and cool (temperature <35°C) water flow is required as a low temperature heat sink. This should be available when the steam boiler is in operation.

→ Fig. 145, page 264

In steam boiler systems, this can be the make-up water used to replenish the feed water vessel.

This especially applies to systems with direct steam heating where no or very little condensate (<50% of the steam output) is recovered (e.g. when manufacturing expanded polystyrene or bread and also for humidification or drying). In addition, water losses as a result of surface blowdown, bottom blowdown, re-evaporation and leaks in the steam system must always be balanced out.

The quantities lost vary considerably depending on the specific system. They can be much more than half the quantity of steam produced and must also be replaced with make-up water. The maximum temperature of the make-up water after water treatment is normally 15°C which makes it highly suitable for pre-heating in the condensing heat exchanger.

The low water inlet temperature allows extensive flue gas condensation and therefore optimum use of condensing technology. With this application, the diversity factor between waste heat availability and heat energy demand is also available during routine operation which means this benefit always exists.

With high condensate flow rates however, the required make-up water flow rate is small which means that a condensing heat exchanger is not always cost-effective.

The condensing technology can however still be used providing a suitable low temperature water circuit is available. The condensation heat which is released can, for example, be used for process water heating, especially in the food industry, or as central heating backup.

In contrast to building heating systems which have clearly defined system and return temperatures, the industry is characterised by an extremely wide range of steam application systems and heating systems. A wide diversity of energy-saving and heat recovery systems therefore compete with one another.

A thorough analysis of all waste heat suppliers and heat consumers is required in order to find the most economical solution. To ensure the condensing technology is utilised to optimum effect, close collaboration between operators, planners and boiler manufacturers is particularly indispensable when determining which measures from the countless available options are the most efficient.

If a suitable heat consumer for the condensation heat in the flue gas is not available, air preheating is one measure which can be used to increase efficiency and is described in the following chapter.

2.1.3 Air preheater

Fig. 146 *Air preheater*

The air preheater can be used as an efficiency-enhancing measure in new systems to be installed together with economisers.

During this process, combustion air at ambient temperature is heated in a heat exchanger upstream of the burner to roughly 80°C. The feed water which is cooled down to 65°C now flows through a second economiser bundle and the flue gas temperature then falls to around 80°C.

Bosch offers air preheating for single or double flame-tube boilers with duoblock burners. As the burner is specially designed for this and the installation expenditure for the combustion air heat exchanger, additional economiser and pipework must be considered, air preheating is particularly attractive from an economic standpoint when the boiler is operated for many hours at full load, i.e. roughly 4,000h/year, or if the boiler output is roughly 5 tons steam/hour or more. Then the amortisation time for the additional costs involved in preheating are often only 1.5 – 2 years. It also generally makes sense however, to retrofit this equipment to existing systems with a high number of hours run annually, i.e. roughly 6,000h/year.

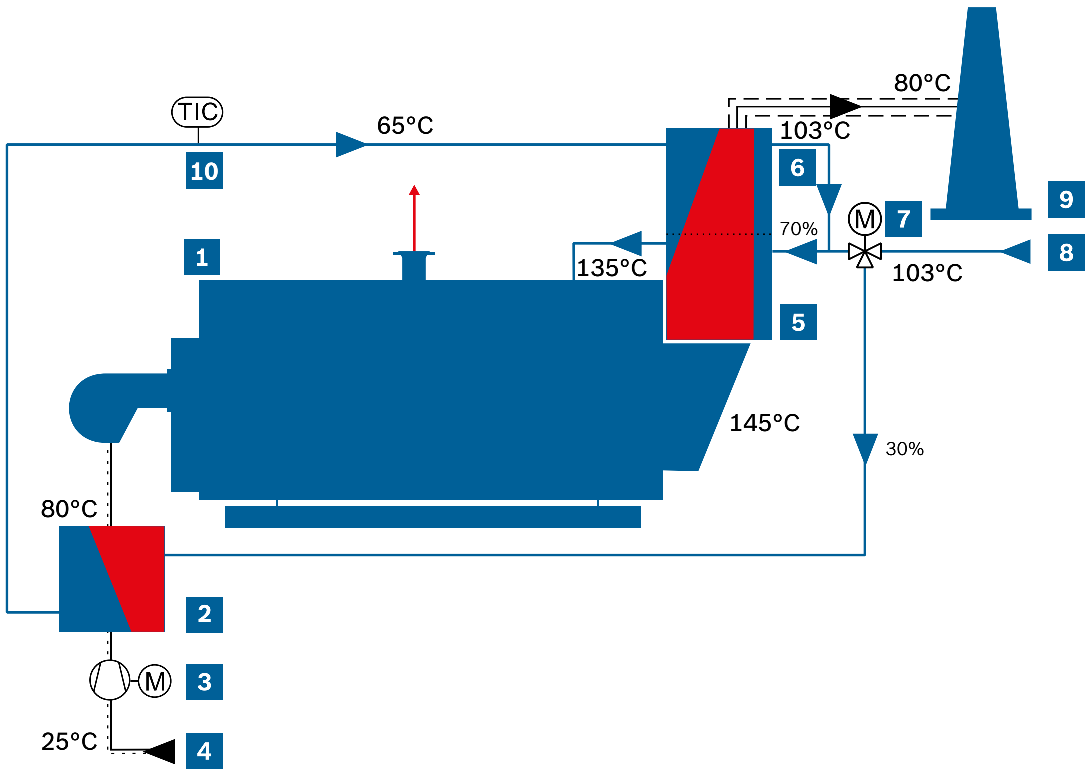

Fig. 147 *Combustion air preheating at steam boiler according to Bosch patent*

- **1** Steam boiler
- **2** Heat exchanger, combustion air
- **3** Fan
- **4** Combustion air
- **5** Flue gas heat exchanger stage 1
- **6** Flue gas heat exchanger stage 2
- **7** 3-way valve
- **8** Feed water
- **9** Chimney
- **10** Temperature controller **(TIC)**

2.1.4 Feed water cooler

Fig. 148 *Feed water cooling module*

The flue gas temperature is decisive for the combustion efficiency of steam boilers without flue gas condensation. The feed water used in the economiser to cool the flue gases in systems with thermal deaerating is however not colder than 103°C. This can only be used to reduce the flue gas temperature economically in the economiser to roughly 120°C.

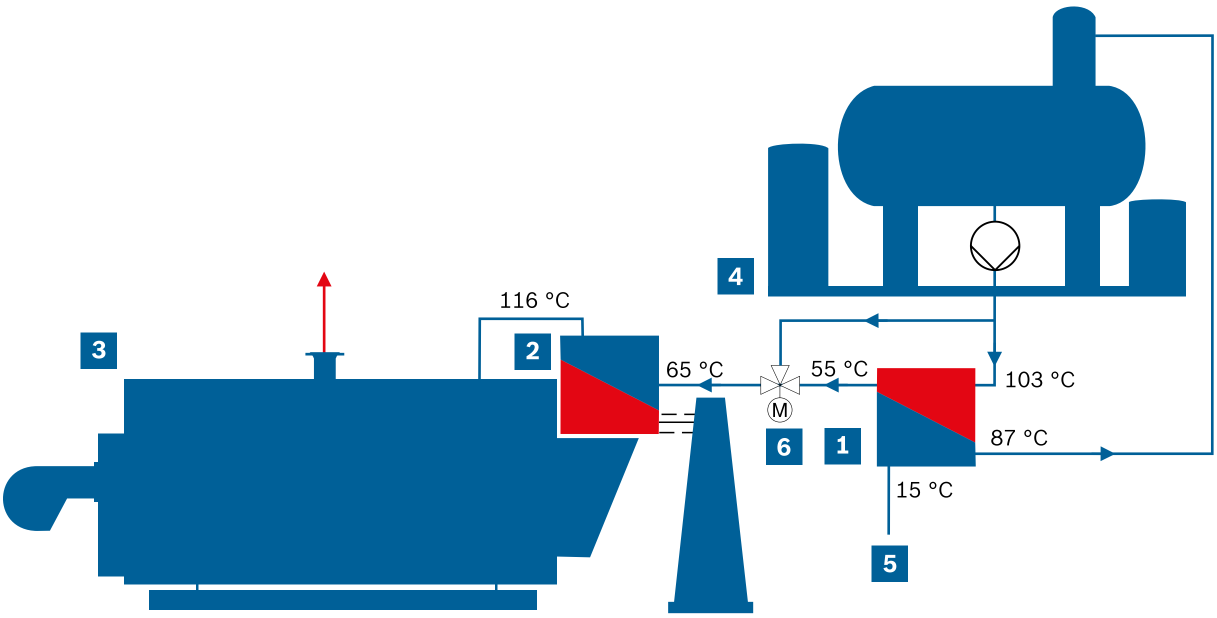

Fig. 149 *Feed water cooling module*

1 Feed water cooling module
2 Economiser
3 Steam boiler
4 Water service module
5 Make-up water
6 3-way valve

However, if heat consumers with a temperature level below 100°C are present in the overall system, e.g. heating of the make-up water of the steam boiler system, a building heating system or process water heating system, the feed water temperature can be reduced from 103°C down to 65°C using a simple inexpensive plate heat exchanger. Owing to the larger difference between the flue gas and feed water temperature, the flue gas can now also be further cooled to roughly 85°C without requiring further investment in the economiser. This increases the combustion efficiency and achieves up to 1.8% fuel savings.

This efficiency-enhancing measure can also be retrofitted to existing systems for a relatively small investment outlay.

2.1.5 Summary

Optimising the reduction of flue gas losses is a high-priority task in the planning and also operation of steam boiler systems. The following question often arises in relation to this:

What measure or combination of measures will achieve the best heat recovery?

The following diagram shows the measures for reducing flue gas losses described in previous sections using a steam boiler as an example.

Which technology is most suitable for optimum economic efficiency of a steam boiler system depends on the application in each case. The “size” and temperature level of a low temperature heat sink are particularly decisive when it comes to choosing the efficiency-enhancing measure.

Example:

Condensate accumulation rate	$c = \dot{m}_{Co} / \dot{m}_S$
Make-up water rate	$z = 1 - c$
UL-S	10,000 x 16
System steam output	10,000kg/h with p_{avg} = 13 bar
Blowdown rate	5%

Case	Component	Efficiency	
		Components	total
1	Boiler	88.9%	---
2	Boiler + economiser	88.9% + 6.5%	95.4%
3	Boiler + economiser + condensing heat exchanger (with z = 0.3 / α = 12%)	88.9% + 6.5% + 2.8%	98.2%
4	Boiler + economiser + condensing heat exchanger (with z = 0.5 / α = 20%)	88.9% + 6.5% + 3.8%	99.2%
5	Boiler + economiser + condensing heat exchanger (with z = 1 / α = 34%)	88.9% + 6.5% + 7.6%	100.9%
6	Boiler + economiser + air preheating (20°C to 65°C)	88.9% + 6.5% + 1.7%	97.1%
7	Boiler + economiser + feed water cooling (with z = 0.3)	88.9% + 6.5% + 0.6%	96.0%

Tab. 27 *Case studies for combinations of measures for the best heat recovery*

The sinks used for the condensing heat exchanger are generally make-up water for the production of steam, central heating backup or process water heating. The same applies for the feed water cooler which is an especially low cost alternative to the condensing heat exchanger if the water flow to be heated up is relatively small or, as in the case of heating, the heat cannot be used continuously the whole year round.

If no heat sink exists (or only one that is characterised by strong time-based fluctuations), use of air preheating is recommended.

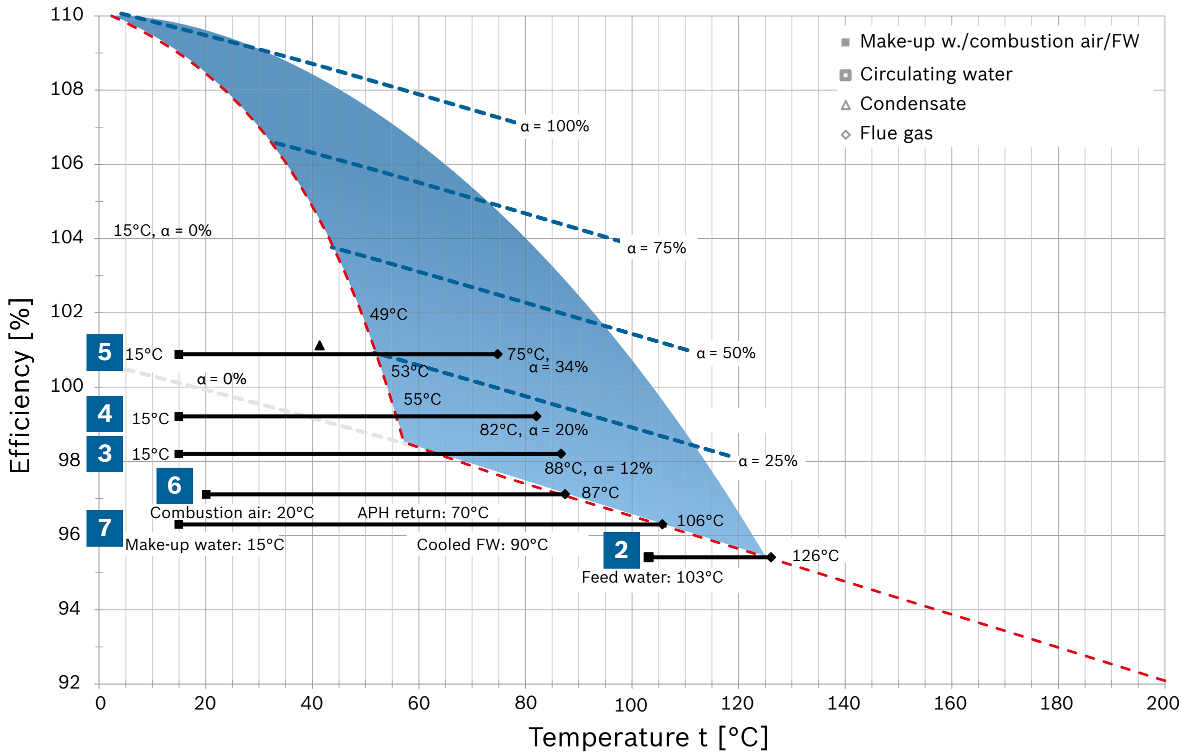

Fig. 150 *Temperature-efficiency diagram for steam boiler systems with measures for increasing efficiency*

1 Boiler (not shown)

2 Boiler + economiser

3 Boiler + economiser + condensing heat exchanger (with z = 0.3 / α = 12%)

4 Boiler + economiser + condensing heat exchanger (with z = 0.5 / α = 20%)

5 Boiler + economiser + condensing heat exchanger (with z = 1 / α = 34%)

6 Boiler + economiser + air preheating (20°C to 65°C)

7 Boiler + economiser + feed water cooling (with z = 0.3)

2.2 Increasing efficiency at the burner system

2.2.1 Combustion air fan

An optimum fuel/air mixture is required to achieve full combustion. However, industrial boiler systems are often run in partial load operation. In this mode of operation both the fuel and air supply are reduced.

The combustion air fan without speed control also runs in partial load ranges at nominal speed because in this case the air quantity supplied for combustion is restricted purely by closing air dampers. In this case the fan consumes a large amount of electrical power which disappears with no benefit due to the restriction. If the quantity of air is primarily modified through modulation of the fan speed, the power consumption in partial load ranges is reduced (roughly 40% can be potentially saved).

The noise generation behaviour is also along the same lines as the reduction in power consumption. All systems that are often operated in partial load ranges for extended periods should be equipped with speed-controlled fans.

Around 40% of the electrical energy can be saved by using a burner load profile with medium capacity utilisation. This normally achieves annual savings amounting to a four-figure Euro sum which means that a speed-controlled burner normally pays for itself within a year.

Example:

Boiler output	10t/h
Burner fan	22kW
Electricity savings	around 48,000kWh/a (42%)
Cost savings	around 6,720 €/a (with electricity price 0.14 €/kWh)

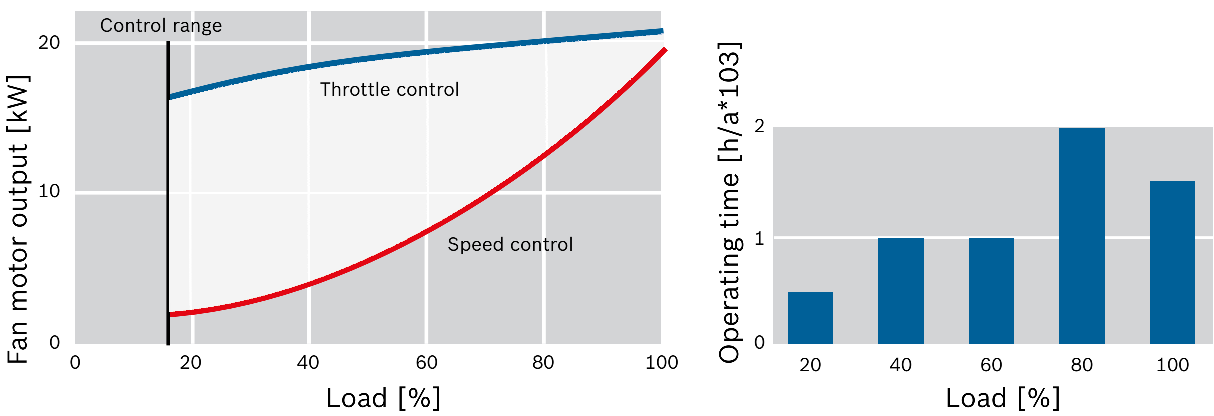

Fig. 151 *Energy savings with speed-controlled burner fan*

2.2.2 Excess air

In combustion technology, the ideal situation is stoichiometric combustion. This happens if all fuel molecules react completely with the oxygen without leaving any unburned fuel or oxygen behind.

If insufficient atmospheric oxygen is supplied during the combustion process, an incomplete combustion reaction may occur. A negative consequence of this would be the formation of carbon monoxide, a highly poisonous gas. If the quantity of air is increased too rapidly, all fuel molecules have already reacted with the oxygen molecules. The remaining oxygen molecules form a surplus which is not required. As the cold ambient air is normally used as combustion air, this cold air is ultimately heated with an unnecessarily high volume of excess air, which is released into the atmosphere together with the flue gases.

An optimum combustion air setting is therefore important for efficient operation and safe, clean combustion. This is attributable to air pressure, air temperature and air humidity fluctuations on the one hand and fluctuations in the fuel quality, which will increase. On the other hand, a certain amount of excess air compared to the theoretical ideal must be specified to provide a margin of safety. Ultimately, carbon monoxide, a poisonous and explosive gas, must not be allowed to form under any circumstances. These settings are normally carried out and checked when commissioning the boiler system and when carrying out quarterly or six-monthly maintenance.

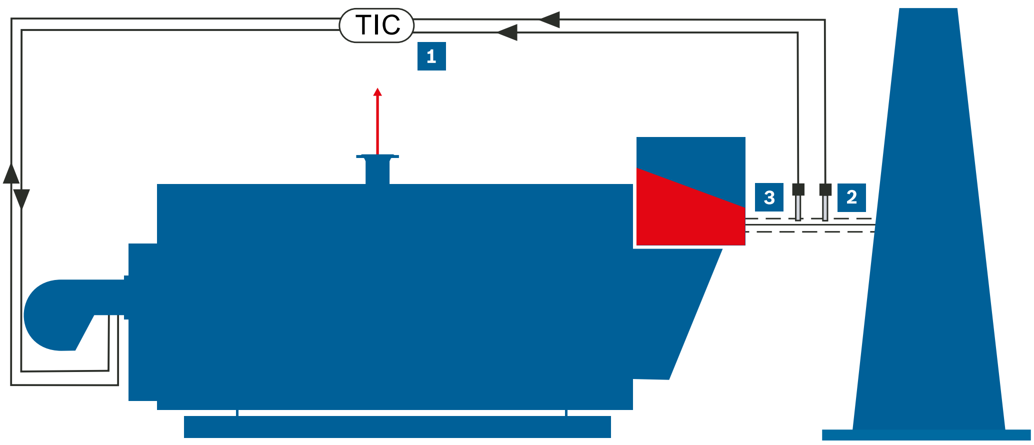

Fig. 152 *O_2 and CO control at steam boiler (simplified representation)*

1 Control
2 O_2 test probe
3 CO test probe

Steam
Flue gas

In order also to be able to operate the systems closer to the optimum operating point under varying conditions, continuous measurement and control units are required. An O_2 control essentially consists of an oxygen measurement probe which is installed in the flue gas flow and a control unit. This continuously records the residual oxygen content in the flue gas and forwards the signal to the burner control which adjusts the air quantity as required.

Combined electrodes (O_2 and CO) have been available for a number of years. In combination with CO measurement, the excess air λ can be set more precisely at the CO limit. When using an O_2 and CO control, the setting normally used for excess air at full load of 3 – 4% by vol. of oxygen in the flue gas can be reduced to 0.5 – 1.0% by vol. of oxygen. This equates to a flue gas loss reduction of roughly 1 percentage point at the same flue gas temperature. CO control cannot be used when using oil as the fuel.

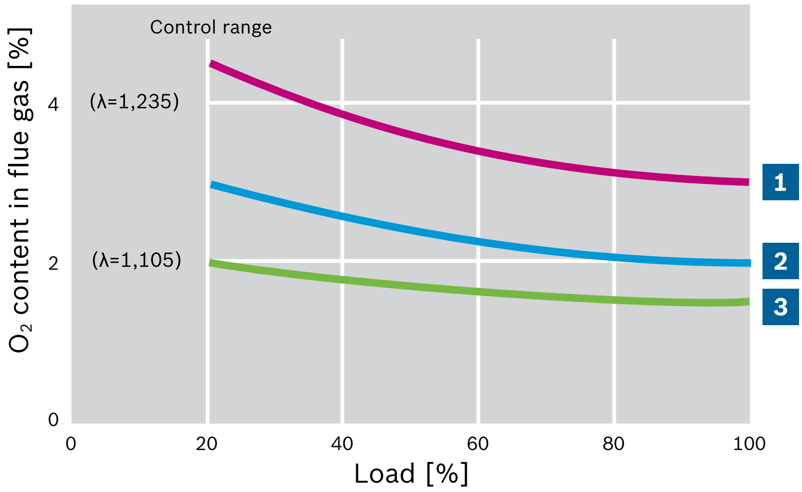

Fig. 153 *Residual oxygen content and excess air using O_2 and CO control via the burner load*

1 Without control
2 With O_2 control
3 With CO control

2.2.3 Output adjustment

In existing systems, and also occasionally new systems, the available boiler output is far greater than the actual steam output required.

The causes of this are frequently:

- **Reduction of demand in existing systems**, e.g. because consumers no longer exist or the existing potentials for heat recovery have subsequently been tapped
- **Oversizing during the planning of new systems**, e.g. due to incorrect diversity factors of consumers, taking power reserves that are far too high into account or expansion of the consumers that has already been considered but not yet implemented

As a consequence, the rate of steam extraction is too low in relation to the boiler output, which leads to a high number of burner switch-on and switch-off operations. This causes pre-ventilation losses and also stresses due to temperature fluctuations that can be extreme, especially with long pre-ventilation times.

→ Efficiency – Chapter 2.2.4: Pre-ventilation, page 273

The following measures can be taken to compensate for an overly high boiler output:

- Installation of low load controls that postpone immediate up-regulation following the burner start
- Use of power controllers that allow the burner to adhere to the low-load stage for an unlimited period
- Use of burners with high control range
- Matching of burner output to the actual requirements. This requires modification of the burner or addition of a burner with a smaller output range

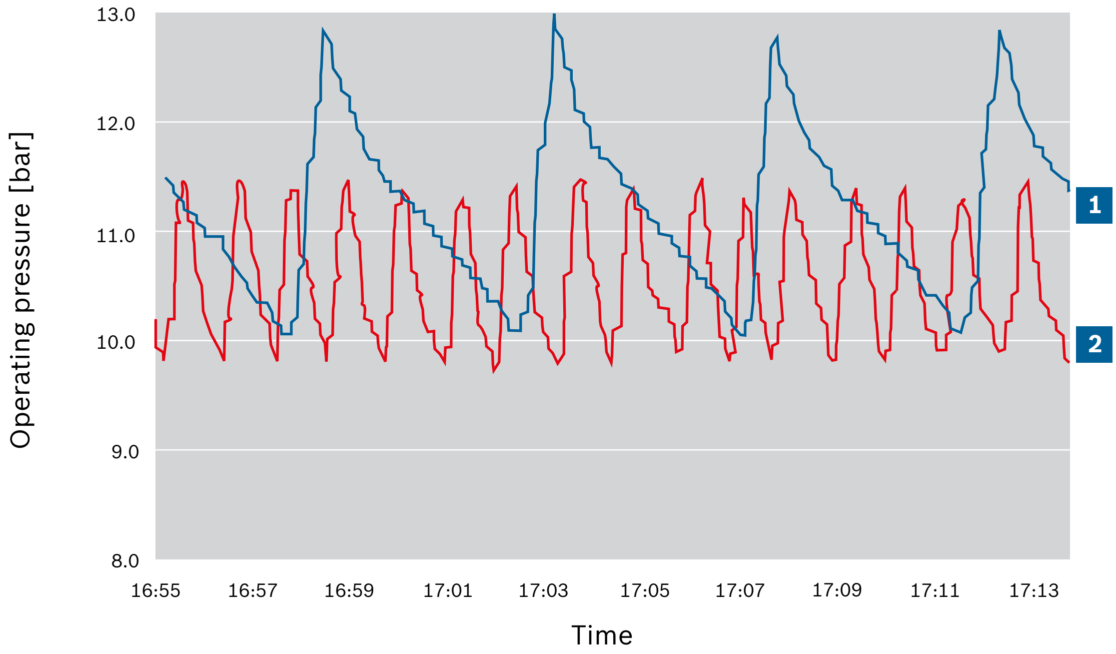

Fig. 154 *Pressure curve before and after adjustment of the burner output*

1 Pressure curve before adjustment of the burner output
2 Pressure curve after adjustment of the burner output

2.2.4 Pre-ventilation

Before every burner start it must be ensured that there are no ignitable mixtures in the flue gas paths. This is achieved in practise by pre-ventilation. Before the burner ignites the flame, the combustion air fan starts and pushes ambient air through the hot flue gas paths which are still at boiling temperature. This heats the cold air and draws heat from the boiler. A sufficient air change-over is prescribed which can lead to a significant energy loss, especially with frequent burner starts.

As a rule, the pre-ventilation time must be sized so as to achieve a 2 – 3-fold air change, with reference to the entire flue gas system. The design must be agreed with the technical supervisory authority. Frequent burner starts are not only uneconomical, they also have a detrimental effect on the service life. An ideal situation to aim for would be 1 – 2 burner switch-on cycles per hour. If there are more than 4 burner switch-on cycles per hour, measures should be taken to reduce the number of burner switch-on cycles, e.g. by adjusting the output of the burner.

→ Efficiency – Chapter 2.2.3: Output adjustment, page 272

$$Q_{l,pre\text{-}ventilation} = 1.26 \cdot \dot{Q}_{bu} \cdot \Delta T \cdot t \cdot 10^{-7}$$

F34. *Equation for approximate calculation of pre-ventilation losses*

$Q_{l,pre\text{-}ventilation}$	Pre-ventilation loss of system [kWh]
$\dot{Q}_{bu}$	Combustion capacity of system [kW]
ΔT	Temperature differential between the medium in the boiler and ambient air drawn in [K]
t	Sum of the actuator opening and closing times and pre-ventilation time

$$\dot{Q}_{bu} \approx \dot{m}_S \cdot \frac{0.65}{\eta}$$

F35. *Equation for approximate calculation of combustion output of the system*

$\dot{Q}_{bu}$	Combustion capacity of system [kW]
$\dot{m}_S$	Steam output [kg/h]
η	Efficiency of boiler incl. economiser [%]

$$\Delta T = T_{boi} - T_A = T_s\,(p_{avg}{=}13\text{ bar}) - T_L$$

F36. *Equation for calculation of temperature differential between the medium in the boiler and ambient air drawn in*

ΔT	Temperature differential between the medium in the boiler and ambient air drawn in [K]
T_{boi}	Temperatures of the medium in the boiler [K]
T_A	Temperatures of ambient air drawn in [K]
T_s	Boiling point of the medium in the boiler at a specific pressure p_{avg} [K]

$$t = t_1 + t_2 + t_V$$

F37. *Equation for calculating the sum of the actuator opening and closing times and pre-ventilation time*

t	Sum of the actuator opening and closing times and pre-ventilation time [s]
t_1	Opening time of the actuator (roughly 30 – 60s) [s]
t_2	Closing time of the actuator (roughly 30 – 60s) [s]
t_V	Pre-ventilation time (≤ 120s) [s]

t = 30 [s] + 30 [s] + 70 [s] = 130 [s]

B14. *Example calculation for determining the sum of the actuator opening and closing times and pre-ventilation time*

$$\Delta T = 195\ [°C] - 25\ [°C] = 170\ [K]$$

B15. *Example calculation for determining the temperature differential between the medium in the boiler and ambient air drawn in*

$$Q_{bu} \approx 10{,}000 \left[\frac{kg}{h}\right] \cdot \frac{0.65}{97\ \%} \approx 6{,}700\ [kW]$$

B16. *Example calculation for determining the approximate combustion output of the system*

$$Q_{l,pre\text{-}ventilation} = 1.26 \cdot 6{,}700\ [kW] \cdot 170\ [K] \cdot 130\ [s] \cdot 10^{-7} = 18.7\ [kWh]$$

B17. *Example calculation for determining the approximate pre-ventilation losses*

With an average of 4 burner starts per hour and average boiler load of 20% the heat loss is 6% of the boiler output.

When extrapolated over an elapsed time of 4,000h/a, this results in a total heat loss of roughly 300MWh/a; in financial terms a loss of €13,500 per year.

$$18.7\ [kWh] \cdot 4{,}000 \left[\frac{h}{a}\right] \cdot 4.0 \left[\frac{1}{h}\right] = 299 \left[\frac{MWh}{a}\right]$$

B18. *Example calculation for determining the approximate annual pre-ventilation loss [MWh]*

$$299 \left[\frac{MWh}{a}\right] \cdot 45.0 \left[\frac{€}{MWh}\right] = 13{,}455 \left[\frac{€}{a}\right]$$

B19. *Example calculation for determining the approximate annual pre-ventilation loss [€]*


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3 Increasing efficiency on the water and condensate side

3.1 Surface blowdown and bottom blowdown

Depending on the type of water treatment, the feed water of the steam boiler contains substances that accumulate as a result of evaporation inside the boiler and are still harmful to or disrupt the operation of the boiler.

→ Fig. 89, page 178

Some of the feed water must therefore be removed via the surface blowdown valve and bottom blowdown valve. The blowdown rate a is normally between 3 – 5% with reference to the feed water quantity.

So the quality of boiler water is always acceptable for the boiler and the system and to avoid unnecessarily high surface blowdown quantities, the surface blowdown valve and bottom blowdown valve should be designed so they can be controlled.

As the water removed from the boiler is at boiling point (e.g. at a temperature of 195°C at 13 bar), a considerable amount of energy is lost if no heat recovery systems are installed.

By using an expansion and heat recovery module, up to 90% of this energy can be returned to the boiler system and large quantities of cooling water can be saved.

With an average operating pressure of 13 bar and a blowdown rate of 5%, the energy loss without heat recovery is around 1.4% of the boiler output. In this case the heat recovery can save around 400,000kWh/a (based on a 10 t/h boiler operating at full load for 4,200 hours).

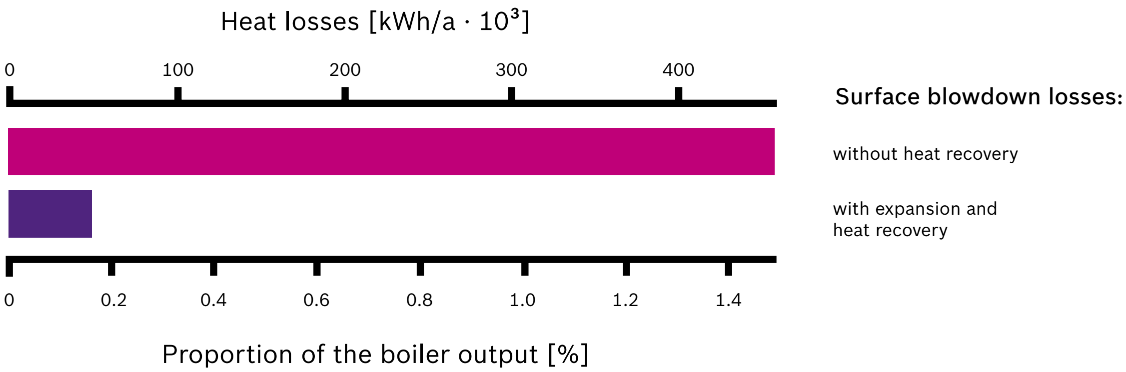


Fig. 155 *Potential savings of expansion and heat recovery (EHM or EHB)*

Following surface blowdown, the waste water is expanded in the heat recovery module (EHM or EHB) to the pressure of the feed water vessel and returned to the EHM or EHB, which can save heat-up steam. A plate heat exchanger installed downstream of the expansion vessel cools the remaining brine down further. The heat acquired is used to preheat the make-up water, which also saves heat-up steam for deaerating.

→ Products – Chapter 4.6: Expansion and heat recovery module EHM, page 348

→ Products – Chapter 4.7: Expansion, heat recovery and blowdown module EHB, page 349

Only the bottom blowdown water cannot be used here because the solids it contains can cause problems in the pressure reducer and heat exchanger.

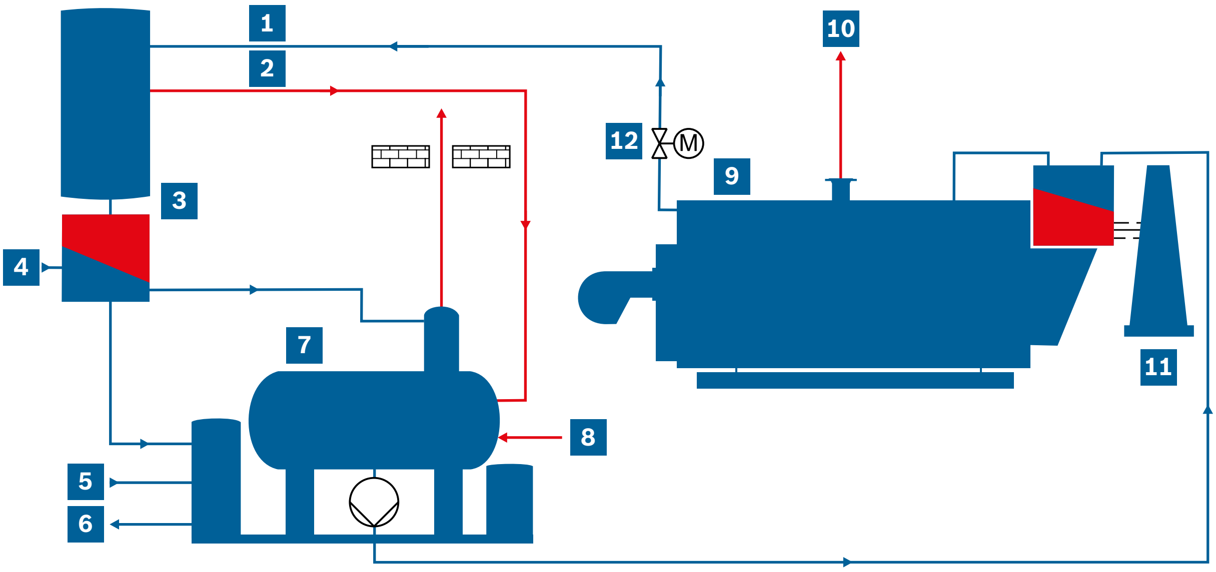


Fig. 156 *Schematic representation of expansion and heat recovery*

Water

Steam

1 Boiler water brine
2 Expansion steam
3 Expansion and heat recovery module
4 Make-up water
5 Cooling water
6 To sewer
7 Feed water vessel
8 Heat-up steam
9 Steam boiler
10 Steam
11 Chimney
12 Desalting valve

Fig. 157 *Expansion and heat recovery module EHB*

The corresponding module is available for new systems with integrated bottom blowdown vessel and also as a retrofit solution for an existing bottom blowdown vessel.

3.2 Exhaust vapour

In thermal full deaeration systems in principle, exhaust vapours, also referred to as waste steam, accumulate. The exhaust vapours are necessary for removing harmful gases such as oxygen (O_2) and carbon dioxide (CO_2) from the feed water vessel. In many boiler rooms this is evident from the steam plumes that normally exit via the roof.

As the feed water vessel is normally pressurised all year round to prevent oxygen permeation and corrosion problems associated with this, exhaust vapours are continuously produced. Exhaust vapour is also produced at the times when the boiler is in standby mode.

Two possible options are available for reducing the exhaust vapour losses:

- **Controlled exhaust vapour discharge valve**
  The controlled exhaust vapour discharge valve prevents the outward flow of exhaust vapour during phases in which deaeration is not necessary.
  This can save huge quantities of energy, especially in systems with a large percentage of downtime, e.g. with two-shift operation. The opening duration of the exhaust vapour discharge valve can be matched to the actual demand by analysing the water continuously, which also includes measurement of the oxygen concentration in the feed water vessel. This also reduces the losses.
- **Vapour cooler**
  The water in the exhaust vapour condenses in the vapour cooler. The thermal energy produced when condensing and cooling the exhaust vapour to $\leq$35°C is used to heat up the make-up water and thus reduces the quantity of required heat-up steam at the feed water vessel. As the condensate that accumulates in the vapour cooler is rich in oxygen and carbon dioxide and has a very low pH value, it is discharged via the bottom blowdown vessel into the sewer. In addition to heating up the make-up water, it can also be used for process water heating or central heating backup.
  As the deaeration system operates more or less continuously, the amortisation time is almost invariably less than a year. A vapour cooler can also be easily integrated into existing systems.

→ Products – Chapter 4.8: Vapour cooler VC, page 350

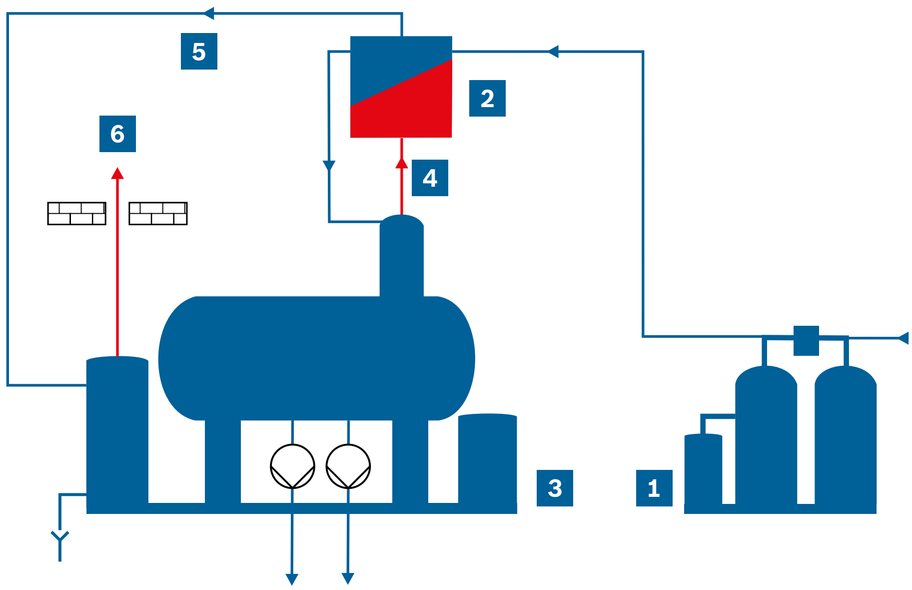


Fig. 158 *Schematic representation of the vapour cooler used for thermal full deaeration (highly simplified representation)*

1. Water treatment module WTM
2. Vapour cooler VC
3. Water service module WSM-V
4. Exhaust vapours (103°C)
5. Exhaust vapour condensate (roughly 35°C)
6. Via roof to the atmosphere

Fig. 159 *Vapour cooler*

3.3 Demineralisation

A freshwater demineralisation system can be installed downstream of the water softener which is required in all steam boilers.

→ Technology – Chapter 4.1.3: Demineralisation, page 181

This reduces the surface blowdown rate in particular, which in turn reduces the loss of heat and water from the boiler. It reduces the conductivity of the boiler water which also improves the quality of the steam. A method commonly used is reverse osmosis by means of a membrane module.

→ Technology – Chapter 4.1.3: Demineralisation – Reverse osmosis, page 183

3.4 Condensate management

Condensate forms anywhere where heat is released from the steam system. The saturated steam releases the heat during the transition from the gaseous to liquid phase, i.e. by condensing.

→ Technology – Chapter 4.4: Condensate management, page 199

The condensate produced is at boiling point (e.g with steam pipe drainage) or is supercooled (e.g. with heat exchangers).

Although when using heat exchangers the supercooling depends on which type of heat exchanger control is used, it is frequently in the range of 10 – 30K.

In nearly all cases it makes sense, also economically, to collect the condensate produced by the heat consumers and return it to the steam boiler circuit or use it for another purpose.

Costs are reduced due to the enthalpy which is still present in the condensate, and because less freshwater is required which also means fewer surface blowdown and bottom blowdown losses.

The maximum condensate quantities of the steam consumers must be taken into consideration when sizing the condensate tank and the corresponding condensate pumps. The time delay that exists when the condensate flows to the condensate sump must also be taken into consideration. The condensate tank should always be sized so it can provisionally hold at least the amount of condensate that accumulates in roughly half an hour between the lowest and highest water level. The flow rate of the condensate pumps should be at least 3 times the hourly condensate accumulation rates during normal operation. Particular attention should also be paid to the start-up operation of the heat consumers as this is when the condensate accumulation rate is at its highest due to the heat-up operation.

Depending on the pressure and temperature level, the enthalpy of the condensate is still considerable at the normal temperatures of 80 – 140°C when compared to the make-up water which is normally cold with a temperature of around 15°C. Less freshwater and therefore fewer energy for heating up is needed as condensate is returned to the feed water vessel. In addition, condensate does not have to be chemically treated and can instead be fed directly to the feed water vessel.

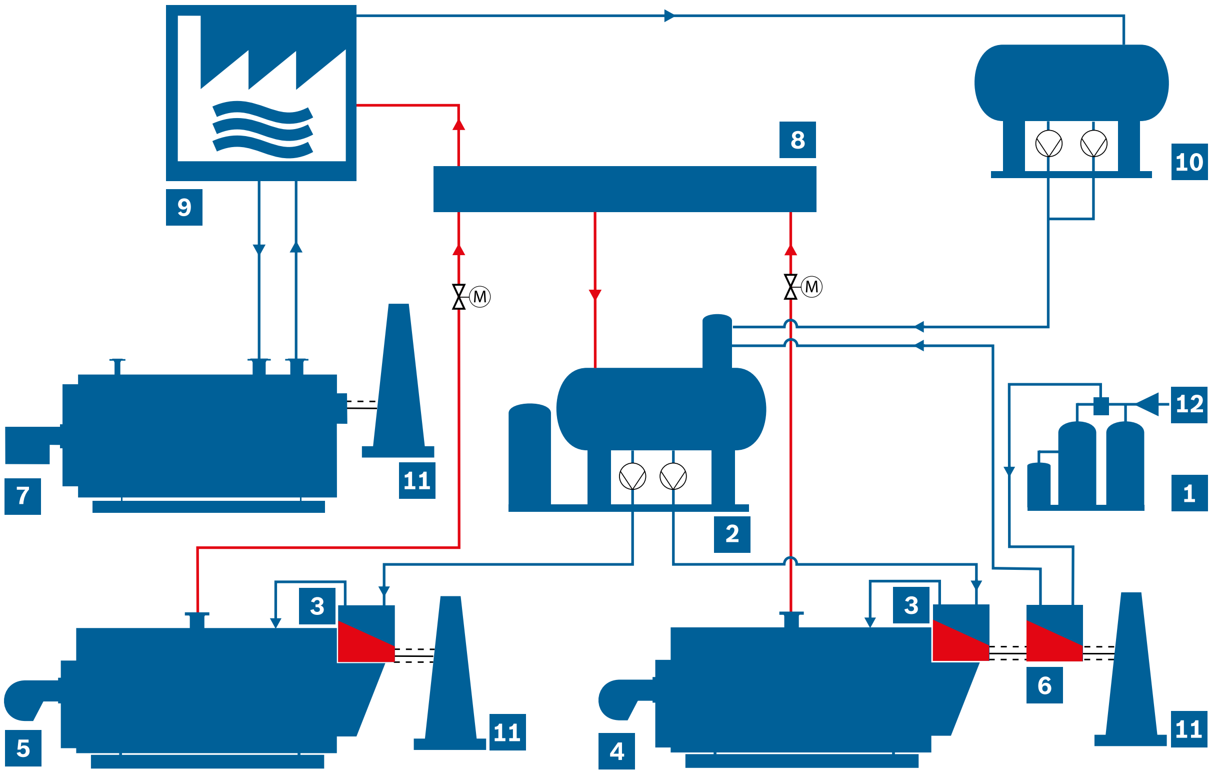


Fig. 160 *Schematic representation of an open condensate system*

1 Water treatment module
2 Water service module WSM-V
3 Economiser ECO
4 Steam boiler UL-S
5 Steam boiler UL-S
6 Condensing heat exchanger
7 Heating boiler UT-L
8 Steam distributor
9 Consumer
10 Condensate service module CSM
11 Chimney
12 Freshwater

3.4.1 Expansion steam

If the condensate is collected in an unpressurised tank, this is referred to as an open condensate system. The temperature level of the condensate is then always <100°C and the condensate may absorb oxygen. In the event of a corresponding water demand which depends on the level, a condensate pump pumps the condensate back to the feed water deaeration system.

As the condensate is normally collected from several steam consumers operating at different temperature and pressure levels, the temperature of the condensate arriving in the condensate tank may also be >100°C. Expansion steam is then produced and subsequently released to the atmosphere via the exhaust vapour line and therefore represents a heat loss. These exhaust vapours can be recovered via a module, similar to the exhaust vapour module, which is installed at the feed water vessel then made available to a low temperature consumer, e.g. a heating or hot water system.

3.4.2 High-pressure condensate tank

If several steam consumers equipped with heating surfaces are designed for a steam pressure which remains more or less the same in the high-pressure range (> 1.5 barg), the condensate of all heat consumers can be introduced into a shared high-pressure condensate system.

→ Technology – Chapter 4.4: Condensate management, page 199

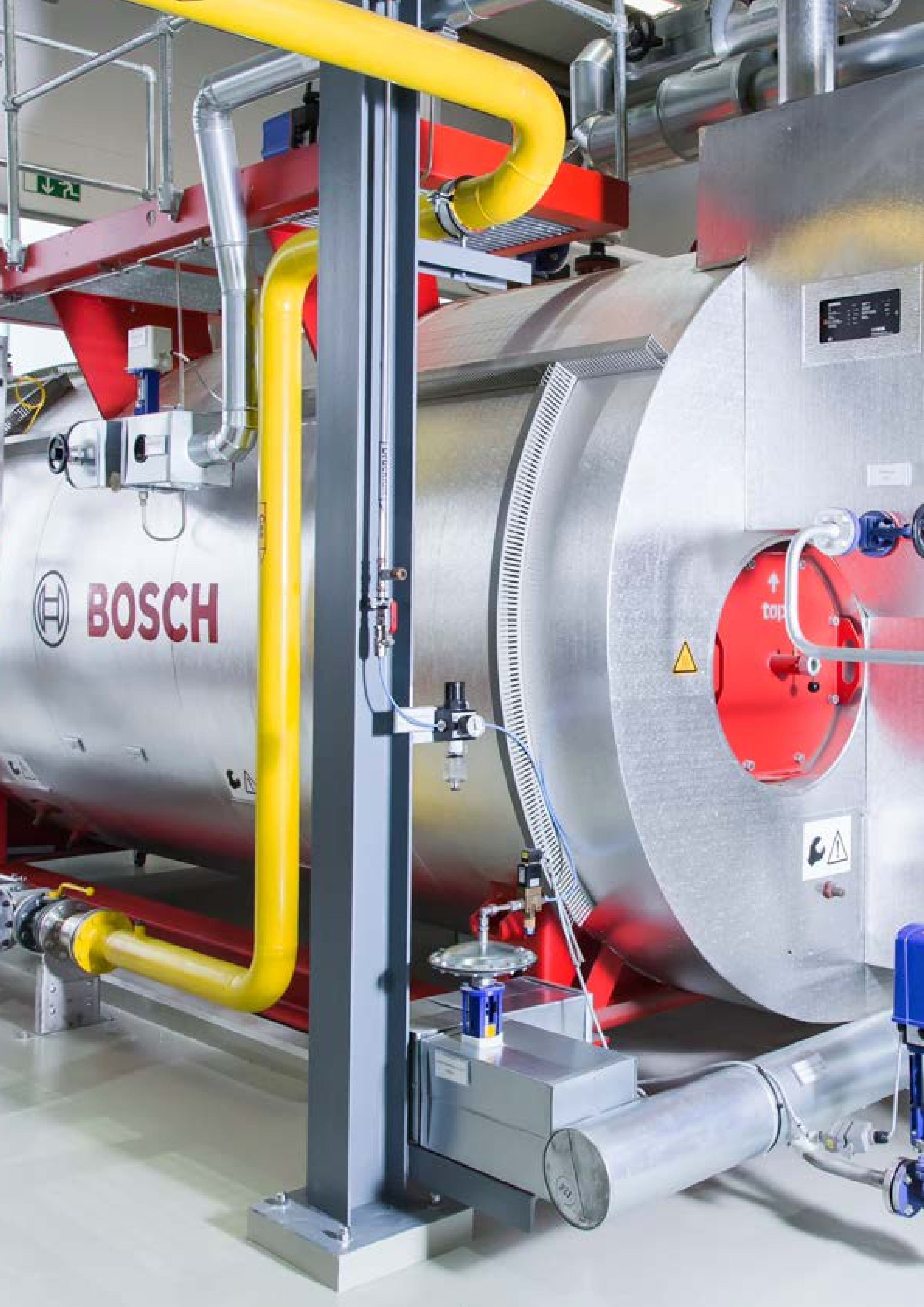
Expansion steam losses therefore do not occur as a closed system is being used. As in this case oxygen does not enter the condensate during normal mode, the condensate is fed back directly into the boiler or the economiser. This means that freshwater quantities and chemical dosing are low. Outstanding savings can be achieved when using this type of system as opposed to open condensate systems with the same consumption structure.

Fuel savings of up to 12% can be achieved with a closed high-pressure condensate system. Only very little freshwater needs to be replenished and the heat energy demand for heating and deaerating is less. In addition, the surface blowdown and bottom blowdown rates are also less due to the very low salt content in the high-pressure condensate. A further benefit of closed high-pressure condensate systems is the reduced corrosion rate in the condensate network.

High-pressure condensate systems should always be used if large expansion steam losses would occur as a result of introducing condensate at a high temperature into the condensate sump or feed water vessel. Typical areas of application are breweries and paper/cardboard factories, to name but a few.

However, it is also necessary to consider that, due to the high condensate temperatures, the flue gas temperatures can increase.

Fig. 161 *High-pressure condensate tank, including equipment and control*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4 Increasing efficiency at the boiler and system

4.1 Insulation

The losses due to conductivity and radiation occur due to the temperature differential between the medium in steam boilers, lines and valves and the surroundings.

The extent of the heat losses essentially depends on the surface area, the medium, the ambient temperature and design of the insulation.

As these losses are not output-dependent, they occur continuously, also in downtime phases, and are therefore also present 365 days a year in systems or parts of systems that have not been taken out of service. They adversely affect the annual degree of utilisation of the boiler system, especially if the system is frequently operated in partial load.

→ Efficiency – Chapter 1.7: Annual degree of utilisation, page 253

In addition to a more time-consuming investigation using a thermal imaging camera, “hotspots”, or areas where the greatest heat losses occur, can be detected and eliminated by feeling out the hot areas, visual inspection of the insulation or by using a surface or radiation thermometer.

However, the surface temperature only reflects the degree of heat loss to a certain extent. Especially when comparing different surface materials, a low surface temperature is occasionally an indication of higher heat losses.

The reason for this lies in the radiation coefficient of the insulating surface. If the coefficient is higher, the heat losses increase but at the same time the surface temperature decreases. It is therefore advantageous to use a material with a low emission coefficient ε.

Example:

Feed water vessel L = 3,600mm, Ø = 1,700mm
Insulation T = 100mm
Medium temperature 103°C

Surface material[1)]	Emission coefficient ε	Heat losses via container cladding	Surface temperature
Aluminium, plain-rolled	0.05	627.5W	30.0°C
Aluminium, oxidised	0.13	635.5W	29.0°C
Galvanised sheet metal, bare	0.26	645.5W	27.6°C
Galvanised sheet metal, dusty	0.44	655.5W	26.3°C
Austenitic stainless steel	0.15	637.2W	28.7°C
Alu-zinc sheet metal, slightly oxidised	0.18	639.7W	28.4°C
Nonmetallic surface	0.94	671.2W	24.2°C

Tab. 28 *List of emission coefficients, heat losses and surface temperatures of different surfaces*

1) According to VDI 2055 Sheet 1 Appendix A8

The biggest heat losses in existing systems normally occur as a result of uninsulated valves, areas that have not been re-insulated following inspection or repair or thermal bridges formed when moving the protective insulation layer.

Most of the conduction and radiation heat losses in existing systems can be avoided by eliminating these “hotspots” without having to completely re-insulate the system. Insulation of uninsulated areas in the overall system (e.g. boiler, steam and condensate pipes, valves, tanks) is one of the most efficient saving measures in existing systems.

The heat loss at the boiler itself can also be easily determined in the idle state. The pressure drop can be determined once the boiler has been shut down (e.g. at the weekend) with the steam, surface blowdown and bottom blowdown valves closed. Starting with a steam pressure in the boiler of 10 bar, the pressure drop should be no more than 0.2 bar/h. It must be observed that not only the radiation and conduction losses must be considered, but also the ventilation losses due to the flue resistance (if applicable). The result may also be influenced by valves that do not close tightly.

However, the heat loss measured indirectly via the pressure drop is present independent of the cause, and should be avoided.

The efficiency of the insulation can be improved by observing the following points.

4.1.1 Insulation thickness and surface area

The surface temperature and heat loss can be reduced by increasing the insulation thickness. In this case however the aim is to choose an optimisation measure that is sensible and economical as the surface losses cannot by any means be halved simply by doubling the thickness of the insulation.

In addition to the insulation thickness, the size of the surface also plays a decisive role. Compact boiler types, e.g. with asymmetrical design, as well as an integrated economiser and resulting smaller insulation surface are advantageous in this respect.

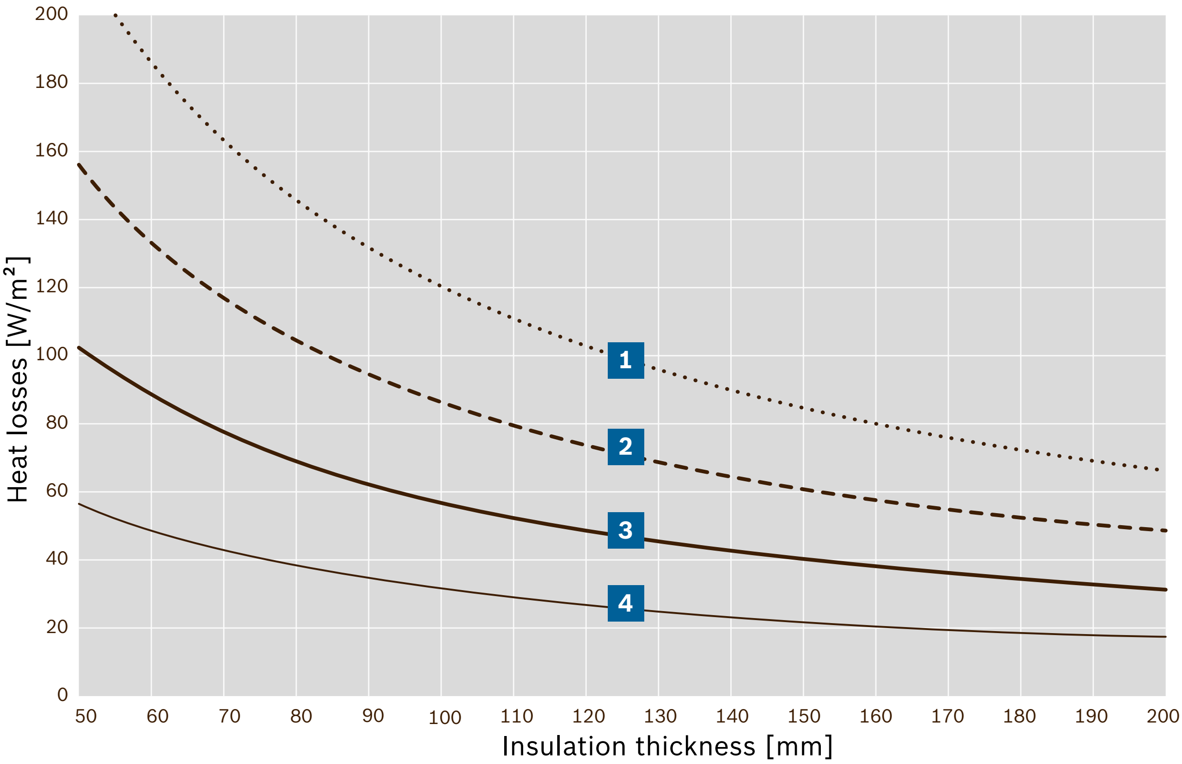


Fig. 162 *Heat losses via the insulated area of the container or boiler surface*

1 Medium temperature: 250°C (······)
2 Medium temperature: 200°C (- - - -)
3 Medium temperature: 150°C (——)
4 Medium temperature: 100°C (——)

The figure (Fig. 162) shows that with an insulation thickness of 100mm and a medium temperature of 150°C the heat loss is roughly 57W/m².

This falls by 30% to around 40W/m² when the insulation thickness is increased to 150mm. The heat loss can be reduced by 44% to 32W/m² by increasing the insulation thickness from 100mm to 200mm.

This applies only for insulated areas without thermal bridges in each case. As the losses via these bridges can quickly exceed the losses in the well insulated cylindrical area, they must always be considered and, whenever possible, minimised.

4.1.2 Insulation of pipework

To save energy and to comply with occupational health and safety requirements, it is now mandatory for pipework carrying hot media in all parts of the system to be continuously insulated. The regulations and additionally the economic aspects indicate what specific insulation thickness to use.

Both the absolute heat loss per running meter of uninsulated pipework (left ordinate) and also the savings factor of an insulated section of pipework (right ordinate) can be determined with reference to the medium temperature, the pipework diameter and insulation thickness from the following diagram.

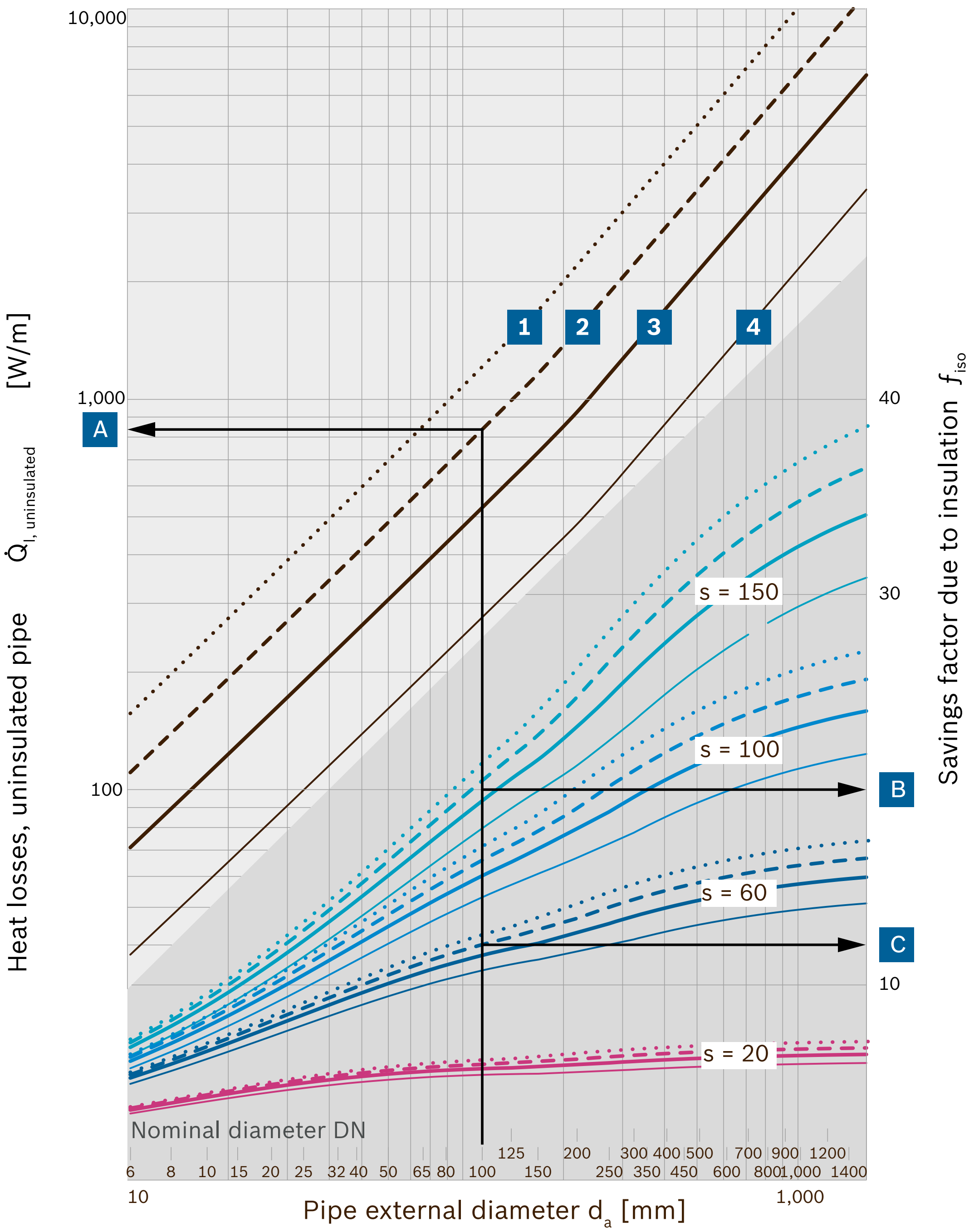


Fig. 163 *Savings factor due to insulation and heat losses in pipework*

1 Medium temperature: 250°C (······)	Insulation thickness s = 150mm
2 Medium temperature: 200°C (- - - -)	Insulation thickness s = 100mm
3 Medium temperature: 150°C (——)	Insulation thickness s = 60mm
4 Medium temperature: 100°C (——)	Insulation thickness s = 20mm

The calculations for the diagram Fig. 163 are based on VDI 2055 sheet 1: uninsulated painted steel pipe, mineral wool insulation, aluminium sheet metal insulation jacket, horizontal pipework, ambient temperature 20°C.

Example (derived from the diagram Fig. 163):

Diameter of steam line DN 100

Steam temperature 200°C

A **Heat loss in uninsulated condition** (left ordinate)

$$\dot{Q}_{l,\,uninsulated} = 837 \left[\frac{W}{m}\right]$$

B **Savings due to insulation** (right ordinate)
(insulation thickness s = 60mm; f_{iso} = 12.6)

$$\dot{Q}_{l,\,insulated} = \frac{837 \left[\frac{W}{m}\right]}{12.6} = 66.4 \left[\frac{W}{m}\right]$$

C **Savings due to insulation** (right ordinate)
(insulation thickness s = 150mm; f_{iso} = 20.5)

$$\dot{Q}_{l,\,insulated} = \frac{837 \left[\frac{W}{m}\right]}{20.5} = 40.8 \left[\frac{W}{m}\right]$$

Increasing the thickness of the insulation on a 100m pipe from 60mm to 150mm saves around €920 annually (based on 8,000 operating hours and energy costs of 4.5ct/kWh).

In this case every metre of uninsulated pipework costs more than €300 a year.

Example	Thickness of insulation [mm]	Heat loss in pipework [W/m]	Total heat loss[1] [kWh]	Absolute savings[2] [kWh]	Percentage savings[2] [%]	Costs saved[2] [€]
A	uninsulated	837.0	669,600	---	---	
B	s = 60	66.4	53,120	---	---	
C	s = 150	40.8	32,640	20,480	38.6	921.60

Tab. 29 *Example of potential savings as a result of increasing the insulation thickness, based on a steam pipe*

[1] Based on 100m pipe length and 8,000 operating hours/year

[2] With reference to the thickness of the insulation s = 60mm

Minimising thermal bridges

Thermal bridges invariably occur when metallic connections with a very high thermal conductivity break through the insulation. This is the case, for example, with connectors, boiler supports or platform brackets.

It must be ensured in the area of the protective insulation jacket in particular that the penetrations required for functional reasons do not come into direct contact with the insulation jacket, as otherwise thermal bridges would be created at these points and energy would be lost. A reliable way to prevent this is by simply wrapping connectors in insulating fabric. Elements whose purpose is to improve structural stability and rigidity, should be within the insulation so they could not conduct heat outwards to the protective insulation jacket.

Similarly, spacers should not be used with cylindrical casings as these also act as thermal bridges. Heat conduction from the hot boiler drum to the protective insulation jacket is prevented and the thermal insulation performance of the insulating mat is completely effective.

Fig. 164 *Avoiding thermal bridges by insulating cylindrical boiler and container shells without spacers*

4.1.3 Insulated inspection apertures

Steam boilers are subject to periodic internal inspections by the relevant monitoring organisations. Openings are required in the insulation jacket for inspection apertures, such as hand holes or head holes, or manholes. These openings are insulated and sealed with removable insulating covers.

The cleaning and inspection apertures at the flue gas collection chambers and economiser housings are sealed using the same insulation technology so that excess radiant heat is not lost via the inspection apertures. Labels are attached to indicate the inspection apertures below.

It must be ensured, especially following inspections or if the insulating covers have been removed for any other reason, that the insulation is reinstalled on the inspection apertures.

If an inspection aperture with an area of roughly 0.5m² is not resealed, this means that at an operating pressure of 10 bar and a temperature of 185°C the energy loss per day is roughly 15kWh.

Fig. 165 *Removable insulation at inspection apertures (UL-S with integrated economiser)*

4.1.4 Insulated valves

Valves are located at many points in steam boiler systems and are required for operation and maintenance. For installation or cost reasons, or owing to various supply limits, the insulation of valves or adaptor flanges in new systems is still frequently omitted. Likewise, uninsulated valves can also often be found in existing systems.

A great deal of energy is however lost via these uninsulated areas. The following table can be used to estimate the energy lost via an uninsulated valve.

Pipe nominal diameter		DN 50	DN 65	DN 80	DN 100	DN 125	DN 150	DN 200	DN 250
Length according to EN 558 series 1	[mm]	230	290	310	350	400	480	600	730
Heat loss, uninsulated	[W]	224	343	419	586	795	1,119	1,800	2,728
Heat loss, insulated	[W]	21	27	29	33	43	58	88	127
Savings	[W]	202	316	390	553	752	1,061	1,712	2,601
Heat loss at 8,000 Bh/a	[kWh/a]	1,619	2,527	3,117	4,425	6,018	8,489	13,693	20,810
Savings with 4.5ct/kWh	[€/a]	73	114	140	199	270	382	616	936

Tab. 30 *Heat losses and operating costs of uninsulated valves (medium temperature 200°C)*

Information on table:

- Medium temperature 200°C
- Calculation of pipework heat losses based on VDI 2055 sheet 1
- Conversion of heat losses in pipework to heat losses at valves with linear factor 1.6 for insulated valves and linear factor 2 for uninsulated valves. (This results in far more conservative heat losses for uninsulated valves and fewer savings than when using the calculation method according to VDI 2055 sheet 1.)
- Valve length according to EN 558 series 1

With a medium temperature of 200°C and valve nominal diameter of DN 100, a heat loss reduction of roughly 550W is achieved by insulating the valves. This is roughly 1,060W with an nominal diameter of DN 150. The cost of €100 – 200 for insulating a valve pays off within a year.

As an entire steam system requires valves at many points, the total potential based on insulation of the valves of the steam and condensate system is on average roughly 1 – 5% of the fuel consumption.

4.2 Control

Optimising and adjusting the control of boiler systems to the actual operation also represents a huge potential for savings. This optimisation always makes sense as the design conditions of boiler systems are different to the actual operating conditions. This may become necessary if additional consumers are subsequently installed in new systems, for example, or if current operations change as a result of converting and extending production with existing systems.

4.2.1 Reduction of operating pressure

An average operating pressure based on the required temperature level and pressure losses to the consumers are defined at the concept and design stages of a steam boiler system. However, this design is frequently based on a very conservative estimate, when in fact a slightly lower operating pressure would be sufficient during operation in practise.

For the purpose of energetic optimisation during operation, it therefore makes sense to determine the necessary average operating pressure and set this at the boiler control. Due to the reduction in operating pressure, the temperature in the boiler and steam pipes falls which reduces radiation and conduction losses.

With each change of the operating pressure, the conditions at the system must be taken into account.

→ Planning – Chapter 2.1: Average operating pressure, page 27

A reduction in the average operating pressure of 8 bar (≙ 175°C saturated steam temperature) to 6 bar (≙ 165°C saturated steam temperature) immediately reduces the conduction and radiation heat losses by 7% which means that fuel savings of around 0.2% can be achieved.

In addition to the heat losses, the flue gas temperature also falls slightly which additionally increases the annual degree of utilisation.

Additionally, the full operating pressure is not always required outside the main operating times of a steam boiler system (e.g. at the weekend). It often makes sense to set a lower operating pressure at these times.

4.2.2 Boiler sequence control

If several steam boilers are installed at a plant, the operation of each single boiler can be optimised by using a boiler sequence control.

The task of a boiler sequence control is to match the number of boilers actually activated to the current power demand. This adjustment can be achieved by automatically switching the lag boilers on or off according to the criteria of the sequence control. This ensures an energy-saving mode of operation of the boiler system. Adjusting the boiler sequence to the actual power demand reduces pre-ventilation losses, automatically carries over boilers into heat maintenance mode and achieves efficiency-optimised operation of boilers. This adjustment and associated reduction in heat losses improves the annual degree of utilisation.

4.3 Automatic monitoring

Faults can be found more quickly and potential for optimisation more easily identified by monitoring and visualising important operating parameters of a steam boiler system.

The following values can be monitored and evaluated, for example:

- Flue gas temperature
- Average operating pressure
- Level, pump starts, pump run time
- Burner load, burner starts and pre-ventilation, O_2 value in flue gas
- Conductivity and blowdown rate
- Water values

4.3.1 Continuous water analysis

The following savings in the area of water treatment can be made through continuous water analysis.

- Energy (minimisation of exhaust vapour losses)
- Use of chemicals (requirements-based dosing)

→ Technology – Chapter 4.5.5: Continuous water analysis, page 204

4.3.2 Condition Monitoring

Optimum annual degree of utilisation of the steam boiler system during continuous operation should be captured through appropriate status monitoring and maintenance. To do so it is important to observe and compare the various parameters of a boiler system over a longer period in order to be able to respond appropriately to any deterioration in operating conditions or changes to the mode of operation of the boiler for operational reasons.

In many firms, monitoring and analysis of the energy generated and consumed is a requirement as part of their overall energy management strategy because the potential for fuel or electricity savings is not insignificant and can often be achieved with no additional investment costs simply by adapting the operating data to the actual situation.

→ Technology – Chapter 3.10: Boiler control, page 167

This task can partially be undertaken by automated Condition Monitoring. The following operating data is recorded and evaluated:

- Display of operating hours, start frequency, number of cold starts over time
- Detection of unfavourable start-up conditions
- Detection of soiling on the water and flue gas side or unwanted condensation
- Generation of service reports according to requirements
- Display of energy losses as a result of bottom blowdown and surface blowdown
- Display of fuel and water consumption over time
- Display of steam removal rate over time
- Display of boiler load profile over time

The software analyses and evaluates the system data, then displays the results to operating personnel according to a traffic light system: green means everything OK. Orange and red indicate that the boiler is increasingly not running as it should be or is not running economically. As a result, modes of operation that lead to inefficiency, increased wear or unplanned downtimes are identified on time and avoided.

The high data transparency also makes it easier to energetically optimise boiler operation. Any scope for improvement is identified by acquiring and displaying meaningful system data, such as the boiler load profile, number of burning switching operations or heat losses resulting from surface blowdown and bottom blowdown.

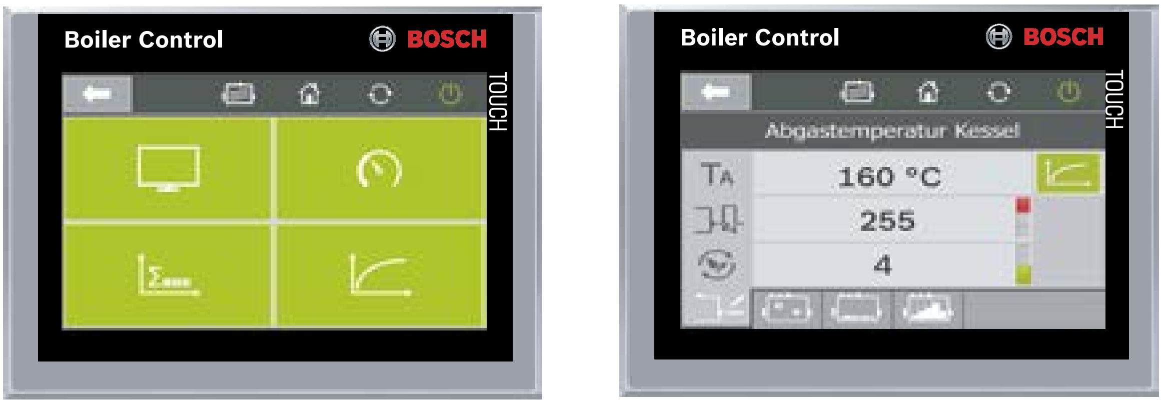


Fig. 166 *Condition Monitoring of the boiler control BCO*

4.3.3 MEC Optimize

MEC Optimize, the digital efficiency assistant, is a further development of Condition Monitoring. It is integrated into the boiler control and records all data of the steam boiler, water treatment, heat recovery equipment and other connected system components.

The operating data is stored locally over the years and evaluated using trend analyses. If the fuel consumption increases for example due to excessive blowdown rates or contamination in the boiler, the efficiency assistant detects this and provides information on the possible causes. In defined cases, messages can also be sent directly via the MEC Remote remote maintenance system to the mobile phone of the operator.

→ Products – Chapter 6.4: MEC Optimize, page 371

4.4 Service

Fig. 167 *Industrial Service*

The obligation of the operator to carry out regular maintenance and repairs on the steam boiler system arises from the statutory regulations for operation of a steam boiler system and the manufacturer's specifications.

Unfortunately the inspection of the system for monitoring purposes which is scheduled every day or every 72h is often simply regarded as a chore. Maintenance and service should not be neglected purely for safety reasons, it goes much further than this and should be regarded as an important system optimisation task.

Many operational improvements can only be made as a result of careful observation during actual operation. Even small changes to the sequence of operations, weekly utilisation of the system and the necessary pressure or temperature level can mean that the system is no longer running under ideal operation conditions. Several of the adjustments that must then be made to optimise the system can be implemented with very little investment expenditure.

An energy inspection of existing systems is recommended at regular intervals. Even the simplest of measures, e.g. modification of control parameters, can be hugely effective.

It is recommended that system maintenance and re-adjustment be carried out every three months, or every six months at the latest. The operator benefits from the following improved characteristics of his system:

- Consistently high energy efficiency
- Long service life
- High degree of failure safety

4.4.1 Maintenance

Steam boiler systems must be analysed and checked within 24h or 72h by the operating personnel. In addition to regular maintenance by the boiler attendant, a steam boiler must undergo one comprehensive inspection and one smaller-scale inspection annually.

Within the scope of a maintenance service agreement, our customer service engineers carry out inspection and maintenance of the boiler, combustion, control and water treatment system through to the complete boiler house 2 or 4 times a year. This increases the operational reliability and availability of the system, fuel consumption is optimised and production downtimes avoided. If required, Bosch Industrial Service can also carry out all necessary monitoring work during the prescribed 72h inspections. This can be carried out individually depending on the requirements in each case, either on a one-off basis or continuously as part of a maintenance service agreement.

4.4.2 Modernisation

Fig. 168 *Modernisation of an existing system to reflect the latest standards*

Providing they are well maintained, steam boiler systems can operate reliably for ≥ 30 years. Owing to the following further developments more or less every steam boiler system that is 15 years old or more requires modernisation:

- System and boiler components (e.g. frequency control, O_2 and CO control, feed water cooling, condensing technology)
- Control technology (e.g. sensors, programmable logic controllers, control and monitoring logics, automation system and telecontrol technology)

Additional modernisation is necessary due to increasing requirements in the following areas:

- Environmental protection
- System efficiency
- Regulations and laws (e.g. emissions from combustion systems, obligation to carry out energy management or audits)

In addition, operating companies and their steam consumers have also developed considerably over time to the extent that boiler systems are now normally operated in a manner which is vastly different to the original design intentions. An investigation carried out by the Federal Association of the German Heating Industry (BDH)[V)] has revealed that a considerable modernisation backlog exists in the area of heat and steam generation plants. More than 80% of existing systems in Germany are run inefficiently. Energy efficiency can be increased by 20 – 30% by taking appropriate measures.

Retrofitting to existing systems can also be simply and efficiently carried out using our modular system components. In many cases the modernisation measures amortise within 1 – 2 years. As a rule, all the efficiency-enhancing measures described can also be retrofitted.

The following table provides information on which measures are particularly suitable for retrofitting as they can be easily integrated with minimum disruption to operations. The table also provides information on which savings can be achieved with the respective measures. With appropriate planning, combining individual measures can lead to additional synergic effects.

- **Very easy**: low planning expenditure with no changes to the existing control system and can normally be implemented during operation with no or very short interruptions
- **Easy**: more planning required, can be retrofitted in the control cabinet and involves short interruptions to operations
- **Complex**: more extensive conversion work involving interruptions to operations

V) Federal Association of the German Heating Industry

Especially suitable for retrofitting	Potential savings	Implementation expenditure
Replacement of defective or missing insulation (e.g. valves, inspection apertures)	3 – 8% fuel	Very easy
Vapour cooler	≤0.5% fuel	Easy
Feed water cooling	≤1.8% fuel	Easy
Expansion and heat recovery module	≤1.0% fuel Freshwater savings Waste water reduction	Easy
Complete demineralisation	1 – 5% fuel	Easy
Controlled exhaust vapour valve	0.5 – 1% fuel	Easy
Burner replacement to adjust output	≤8% fuel	Easy
Combustion control, O_2 and CO control	≤1.0% fuel	Easy
Speed control, fan	≤75% electricity costs	Easy
Automatic status monitoring and control optimisation	1 – 3% fuel	Easy
Expansion steam in the condensate	1 – 3% fuel	Easy
Flue gas heat exchanger	5 – 7% fuel	Easy
Condensing heat exchanger	5 – 7% fuel	Easy
Air preheating	1 – 3% fuel	Complex
Conversion from oil to gas operation, use of multi-fuel combustion systems	≤25% costs, ≤30% CO_2 emissions	Complex
High-pressure condensate system	5 – 12% fuel	Complex

Tab. 31 *Retrofitting measures with corresponding potential savings*

5 Process combination

5.1 Combined heat and power

Using a combined heat and power system for commercial or industrial applications can provide a feasible alternative to pure process heat generation or thermal heat generation.

A gas turbine or combined heat and power unit generate mechanical energy (power) which is converted to current via a generator. The hot flue gases which are normally at a temperature of 300 – 600°C are subsequently fed to a waste heat or 4-pass boiler to generate steam or hot water (heat).

A 4-pass boiler is a conventionally-fired 3-pass boiler with an integrated additional fourth smoke-tube pass and can be designed as a steam boiler or hot water boiler.

→ Products – Chapter 3.2: 4-pass boiler with burner, page 336

Thanks to the integrated combustion, peak load boilers that are usually required when using heat recovery boilers only can normally be omitted. This greatly reduces investment costs, space requirements and equipment expenditure. The thermal output obtained through introduction of the waste heat accounts for up to 15% of the total rated output of the boiler. This is usually absolutely sufficient to cover the base-load output in relation to the heat energy demand.

→ Products – Chapter 3.1: UNIVERSAL heat recovery steam boiler HRSB, page 333

However, if the base-load output is significantly higher, using a peak load boiler in combination with a pure waste heat boiler may prove to be a more suitable alternative.

Whatever the case, it is recommended that the power rating of the unit producing the waste heat (gas turbine/CHP module) is selected so that the thermal energy acquired from the flue gases does not exceed the base-load output of the heat consumers. This ensures that power can be generated continuously at the most economical operating point without having to divert unused waste gas heat from time to time to the atmosphere.

Fig. 169 *Bosch heat recovery boiler HRSB*

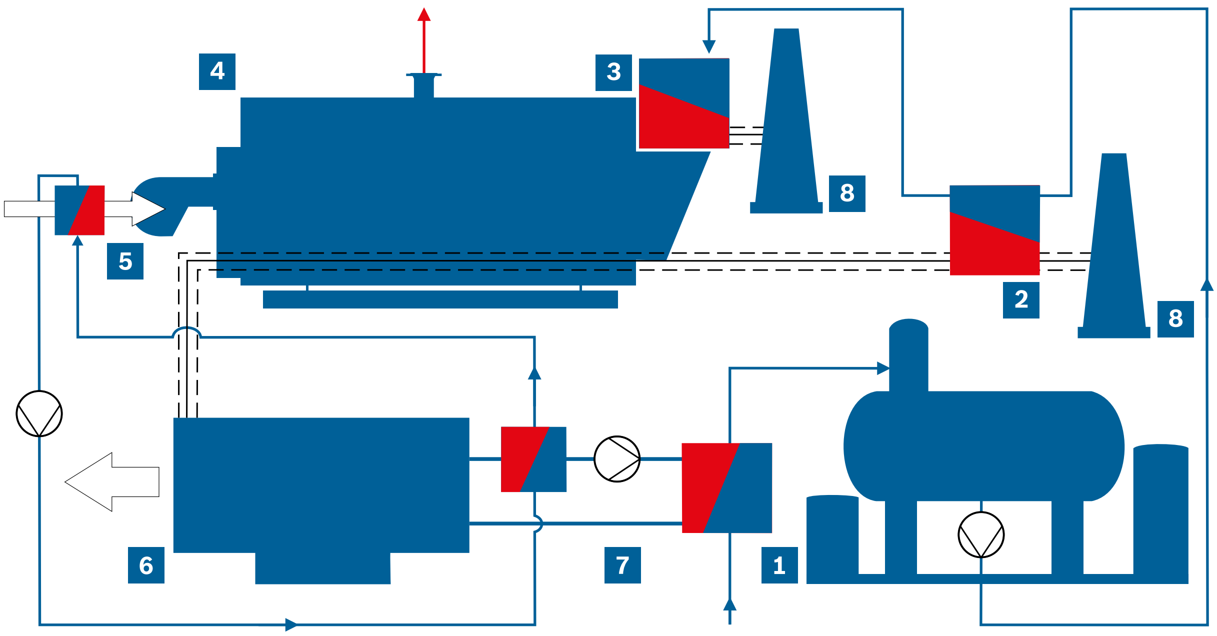


Fig. 170 *Example of the connection of a CHP unit to the process steam generation via an internally-fired shell steam boiler*

1 Water service module WSM-V	**5** Combustion air pre-heater
2 Flue gas heat exchanger	**6** CHP
3 Economiser	**7** Engine cooling water
4 4-pass steam boiler	**8** Chimney

5.2 Solar heat backup

If the make-up water demand of a steam boiler system is very high, it makes sense to use combinations with solar heat. Treated make up water can be preheated using solar energy. Additional energy is then fed to the steam generator to produce high-pressure saturated steam.

Given the right framework conditions, an economical and environmentally-clean supply of energy can be ensured with this type of system combination.

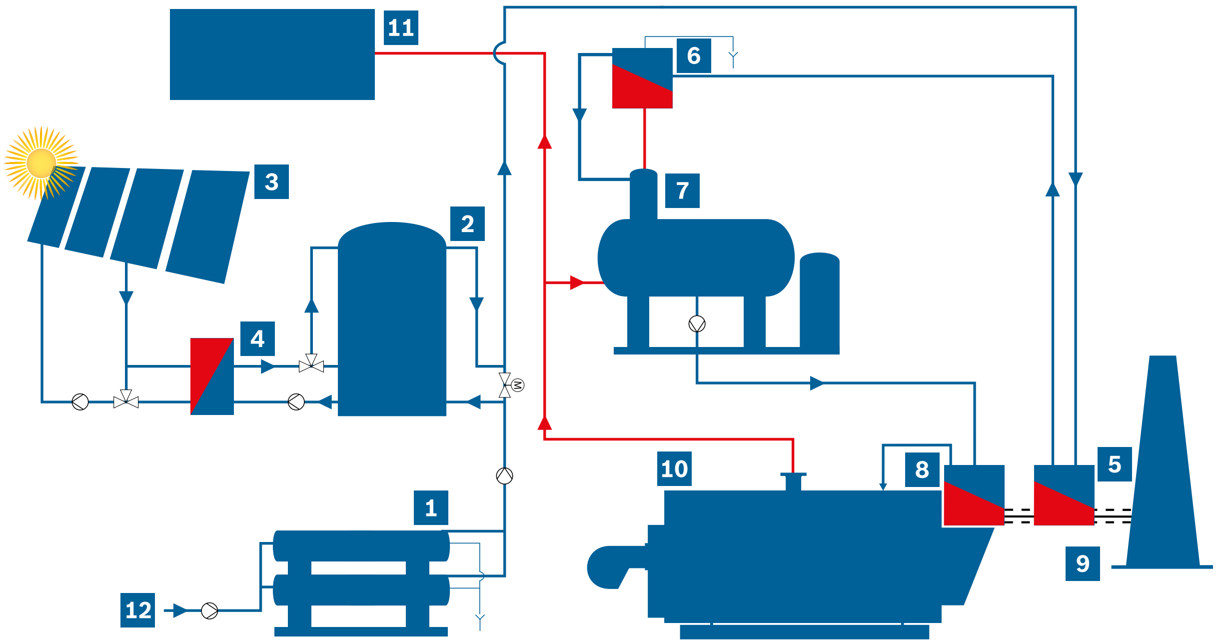


Fig. 171 *Example of the connection of a solar heat system to the process steam generation (highly simplified representation)*

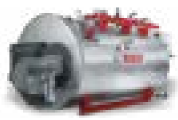
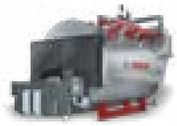
1 Osmosis system
2 Heat storage tank
3 Solar heat system
4 Heat exchanger
5 Condensing heat exchanger ECO
6 Vapour cooler VC
7 Water service module WSM-V
8 Economiser ECO
9 Chimney
10 Steam boiler UL-S
11 Consumer
12 Freshwater

Products


BOSCH
Bosch Industriekessel GmbH
Ein Unternehmen der
Bosch Thermotechnik GmbH
BOSCH

1 Overview of steam boiler products

Steam boilers

	CSB[1]	CSB[2]	U-MB	UL-S(X)	ZFR(X)
					
Output t/h	0.3–4.8	0.3–5.2	0.2–2	1.2–28	18–55
Max. temperature °C	110	204	204	300	300
Max. pressure in bar	0.5	16	16	30	30

Tab. 32 *Steam boilers*

1) Low-pressure variant
2) High-pressure variant

Heat recovery

Heat recovery boiler HRSB	4-pass boiler with burner	3-pass boiler without burner	Recovery and use
			
Heat recovery steam boiler	Heat recovery boiler, steam/hot water		Waste heat

Tab. 33 *Heat recovery*

Components

Boiler/ system control	Water	Steam/condensate	Fuel supply
			
Controls	Modules	Modules	Combustion system

Tab. 34 *Components*


BOSCH

2 Steam boilers

2.1 UNIVERSAL steam boiler CSB

Ultra-compact steam boiler for the smaller output range. Enables future-proof low emissions and a high efficiency level. The ideal solution for food and beverage industries, manufacturing industries, hospitals, laundries and hotels.

Fig. 172 *Steam boiler CSB*

Technical data CSB		
Heat transfer medium	Low pressure saturated steam	High-pressure saturated steam
Design	Shell boiler	Shell boiler
Output in kg/h	300 to 4,800	300 to 5,200
Safety pressure in bar	Up to 0.5	Up to 16
Max. temperature in °C	110	204
Fuel	Oil, gas, multifuel firing	Oil, gas, multifuel firing

High level of efficiency for reduced operating costs

The integrated economiser uses flue gas heat to reduce fuel consumption and lower the flue gas temperature. Together with the innovative insulation concept and Bosch compound insulating materials, this allows for a particularly high level of boiler efficiency.

- High efficiency rating of up to 95.3% with integrated economiser (optional)
- Reduced power consumption of the burner fan thanks to low resistance on the flue gas side
- Fit for the future: Thanks to the low-NO_x burner and generously dimensioned flame tube, the boiler already reliably falls below the strict EU emissions limits of the MCPD for 2025 and/or local emissions regulations

User-friendly operating concept

- Compact control CSC with touchscreen mounted on the boiler
- Alternatively available with boiler control BCO which offers additional functions: Remote access via MEC Remote, connection to automation systems and efficiency assistant MEC Optimize

Reliable performance and customised equipment

The steam-drying unit and the generously dimensioned steam chamber in the Universal CSB design guarantee a high level of steam quality that suits your processes.

- Available in high-pressure and low-pressure versions
- Flexible boiler equipment including firing unit, flue gas heat exchanger, water treatment and control system
- Universal, can be used with e.g. natural gas, biogas, fuel oil or multi-fuel firing
- Certified in accordance with the European Pressure Equipment Directive (high-pressure steam boilers), internationally applicable with country-specific safety equipment

Quick installation and hassle-free maintenance

- Compact design optimised for ease of transport and simple installation
- Smooth commissioning thanks to pre-wired compact control and pre-assembled modules
- Easy cleaning, maintenance and service thanks to telescopic reversing chamber
- No inserts in the heat exchanger tubes allows good accessibility

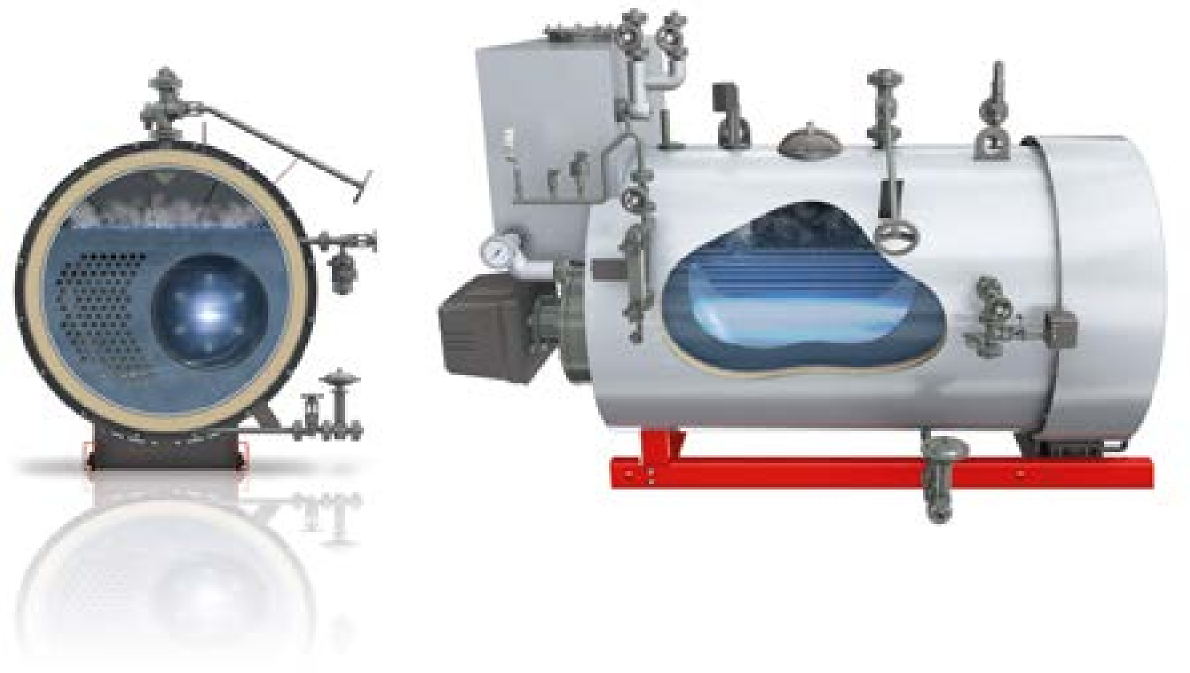


Fig. 173 *Sectional view CSB*

Construction

The steam-drying unit and the generously dimensioned steam chamber in the Universal CSB design guarantee a high level of steam quality that suits your processes. The high-quality production of the entire boiler body using the latest in welding robots allows for a particularly high level of robustness and durability.

Thanks to the special helical heat exchanger tubes, the heat exchange per m² of heating surface is improved significantly. The use of inserts in the exhaust system is not required, which makes cleaning significantly easier. Furthermore, the energy requirement for the burner fan is reduced thanks to the low flue-gas-side resistance.

The telescopic reversing chamber of the industrial steam boiler makes maintenance and inspection work easier. It can be opened safely by a sliding system without needing very much space. Likewise, the entire rear tube plate is fully accessible.

Associated boiler house components

- Flue gas heat exchanger ECO
- Feed water cooling module FWM
- Condensate service module CSM
- Water service module WSM
- Water treatment module WTM
- Pump module PM
- Water analyser WA
- Feed water regulation module RM
- Blow-down, expansion and cooling module BEM
- Expansion and heat recovery module EHM
- Vapour cooler VC
- Expansion, heat recovery and blow-down module EHB
- Gas regulation module GRM
- Oil supply module OSM
- Oil circulation module OCM
- Oil pressure regulation module ORM
- Oil preheater module OPM
- Steam distributor SD
- Steam accumulator module SAM
- Controls for optimising combustion
- Compact steam boiler control CSC
- Boiler control BCO
- System control SCO
- Remote access MEC Remote
- Efficiency assistant MEC Optimize
- Control for large-scale plants MEC System

Fig. 174 *Compact steam control CSC for the steam boiler CSB*

→ Products – Chapter 4: Modules for steam boilers, page 341

→ Products – Chapter 5: Boiler supply modules, page 361

Equipment

We offer the UNIVERSAL steam boiler CSB as a complete boiler system including equipment*. The basic equipment comprises the boiler pressure vessel, the control and safety components, the burner unit, an integrated economiser, a pump module, a terminal box and the compact control CSC mounted on the boiler. Alternatively, you can select the boiler control BCO that allows connection to automation systems. The sensors, actuators and country-specific safety equipment are already wired and combined in the terminal box. Pre-assembled, plug-in and coded cable bundles simplify the connection between the boiler control cabinet and the terminal box.

*The equipment level is variable and can be freely configured to customer requirements.

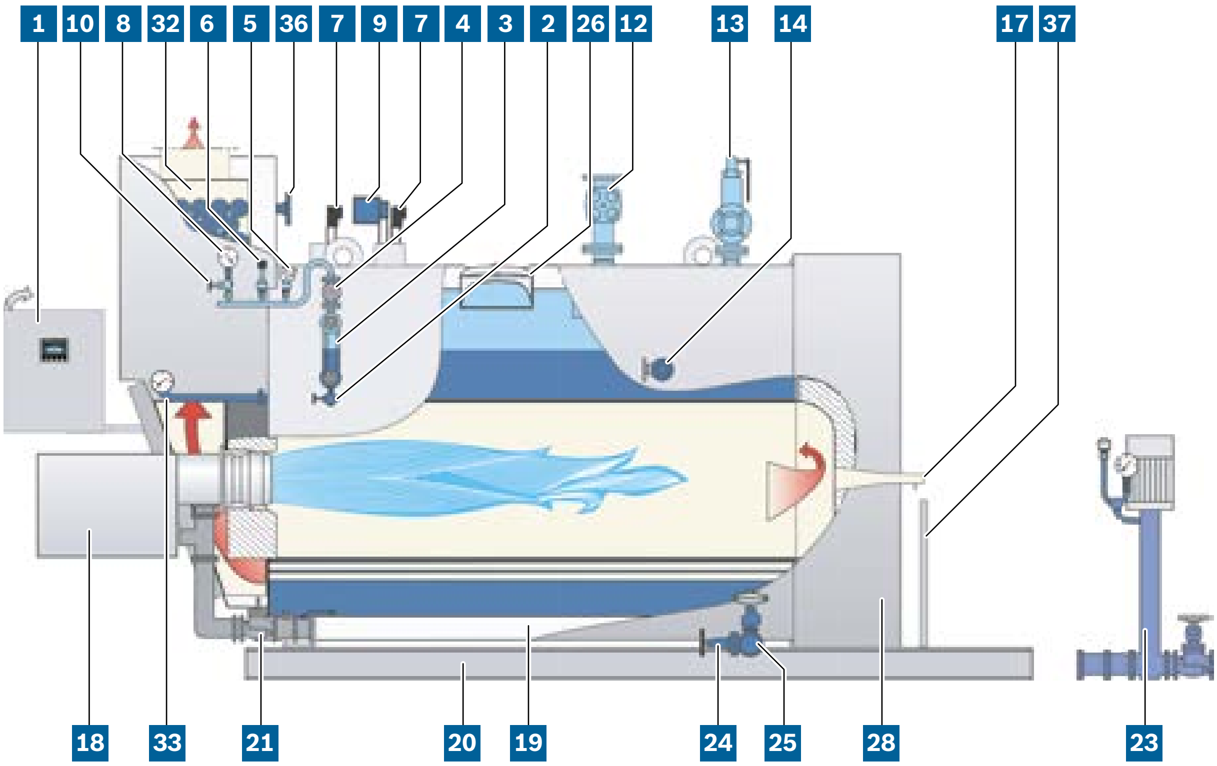


Fig. 175 *Illustration of CSB*

- **1** Control switchgear cabinet with compact steam control CSC, swivel-mounted (alternative: boiler control BCO)
- **2** Blow-off tap
- **3** Reflective water level indicator
- **4** Manostat tube shut-off valve, maintenance-free
- **5** Pressure limiter
- **6** Pressure transmitter (4 – 20mA)
- **7** Low-level limiter electrode
- **8** Pressure gauge
- **9** Level transducer (4 – 20mA)
- **10** Pressure gauge shut-off valve with testing function
- **12** Steam removal valve
- **13** Full-lift safety valve
- **14** Desalting and fully automatic conductivity measurement (here not drawn)
- **17** Sight hole
- **18** Burner
- **19** Insulation with protective shell
- **20** Base frame
- **21** Gas regulation module
- **23** Pump module
- **24** Drain shut-off valve, maintenance-free
- **25** Quick shut-off blow-down valve
- **26** Inspection opening, steam side
- **28** Telescopic rear reversing chamber for easy inspection
- **32** Flue gas heat exchanger ECO
- **33** Connection piping ECO/boiler
- **36** Water inlet connection ECO
- **37** Bow-type handle for reversing chamber

2.2 UNIVERSAL steam boiler U-MB

The product description U-MB stands for “UNIVERSAL Modular Boiler” (3-pass steam boiler with modular design). The U-MB type consists of several modules, which perfectly fulfil individual requirements. Typical application areas are the food and beverage industry, laundry and cleaning businesses, as well as smaller industrial companies.

Fig. 176 *Image of U-MB system*

Technical data	U-M type
Heat transfer medium	High-pressure saturated steam
Design	3-pass flame-tube/smoke-tube technology
Output in kg/h	200 to 2,000
Safety pressure in bar	Up to 16
Max. temperature in °C	204
Fuel	Oil, gas, multifuel firing

High efficiency for reduced operating costs

The boiler components are configured with a focus on low emissions, high steam quality and optimum energy efficiency.

- High level of efficiency due to the integrated economiser
- Maximisation of efficiency thanks to modular heat recovery modules

User-friendly operating concept

- Intuitive PLC-based boiler control
- Automatic start-up, standby and shutdown control SUC
- Ready to connect to automation systems
- Digital efficiency assistant MEC Optimize
- Protected remote access MEC Remote

Reliable performance and customised equipment

The 3-pass steam boiler can be used universally for all applications. Naturally it can be combined with all the other available system components from our modular range for fuel and water supply, water disposal, water analysis and heat recovery.

- Comprehensive, series-wide standard equipment
- Shell boiler and 3-pass technology
- Small space requirement due to compact footprint
- The modular design, which is based on the systematic use of design features and parts that are also used in other type series, ensures a particularly attractive price-performance ratio

Fast installation and effective maintenance

- Reduced installation effort thanks to supply as a single unit – the equipment, the combustion system and the economiser have already been fitted in the factory
- Compact design for bringing the boiler into site easily if space is limited
- Smooth commissioning due to pre-parameterised boiler control
- Simplified on-site wiring due to plug-in connections

→ Products – Tab. 4: Steam boiler with facilitated installation conditions (example Germany), page 51

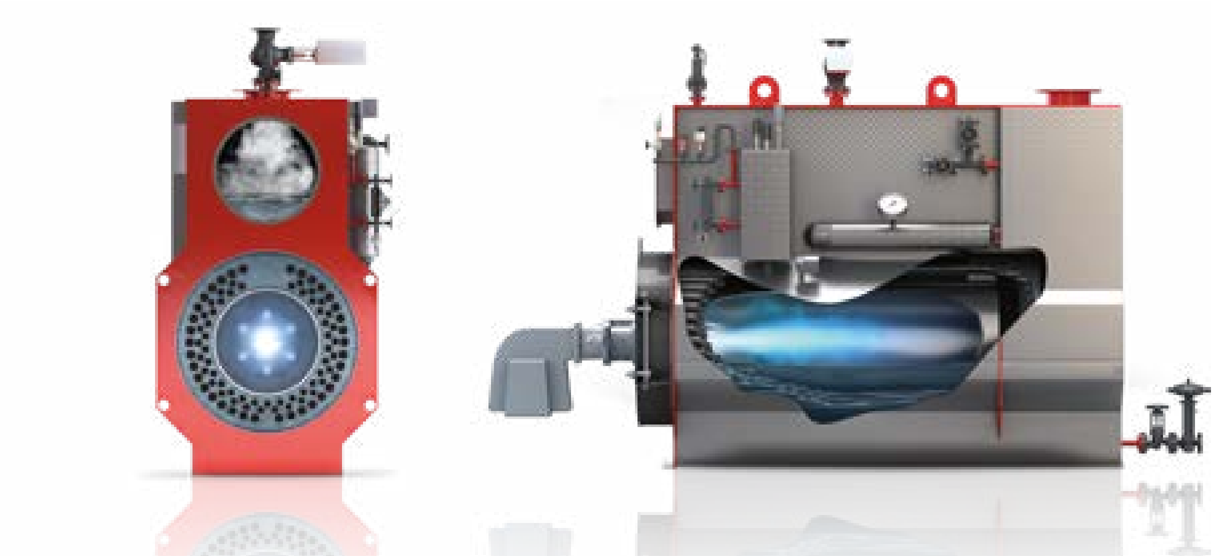


Fig. 177 *Sectional view U-MB*

Construction

The steam boiler U-MB is designed as a 3-pass flame tube/smoke-tube boiler. It consists of several modules, namely the heat generating section in 3-pass design, the steam chamber on top of this, and an integrated economiser. Thanks to its 3-pass design, there is no requirement for flow components in the smoke tubes.

The heat generating section of the U-MB is based on the UNIMAT boiler design – proven for decades and many thousands of times in practice. The generously sized flame tube geometry enables an efficient combustion process.

The choice of the steam section has a critical influence on the steam quality. A generous sizing has a very positive impact on the residual steam moisture.

The integrated economiser has a direct influence on the energy efficiency. The heat contained in the flue gases is used for preheating the boiler feed water, which means that most of it is recovered. This reduces fuel consumption and emissions.

The steam generator is tested for type examination and is manufactured to the strict guidelines of the Module D Quality Assurance System of the Pressure Equipment Directive.

Associated boiler house components

- Flue gas heat exchanger ECO and flue gas heat exchanger ECO for condensing use
- Feed water cooling module FWM
- Condensate service module CSM
- Water service module WSM
- Water treatment module WTM
- Pump module PM
- Water analyser WA
- Feed water regulation module RM
- Expansion and heat recovery module EHM
- Vapour cooler VC
- Gas regulation module GRM
- Oil supply module OSM
- Oil circulation module OCM
- Oil pressure regulation module ORM
- Oil preheater module OPM
- Steam distributor SD
- Steam accumulator module SAM
- Controls for optimising combustion
- Blow-down, expansion and cooling module BEM
- Expansion, heat recovery and blow-down module EHB
- Boiler control BCO
- System control SCO
- Remote access MEC Remote
- Efficiency assistant MEC Optimize
- Control for large-scale plants MEC System

Fig. 178 *Water service module WSM*

→ Products – Chapter 4: Modules for steam boilers, page 341

→ Products – Chapter 5: Boiler supply modules, page 361

Equipment

We offer the UNIVERSAL steam boiler U-MB as a complete boiler system including equipment*. The basic equipment comprises the boiler pressure vessel, the control and safety components, the burner unit, an integrated economiser, a pump module, a terminal box and the control switchgear cabinet including the easy-to-operate boiler control BCO. The sensors, actuators and country-specific safety devices are already wired and combined in the terminal box.

Pre-assembled, plug-in and coded cable bundles simplify the connection between the boiler control cabinet and terminal box during installation. The freestanding or wall-mounted switchgear cabinet can be adapted and set up to best suit the requirements on site.

*The equipment level is variable and can be freely configured to customer requirements.

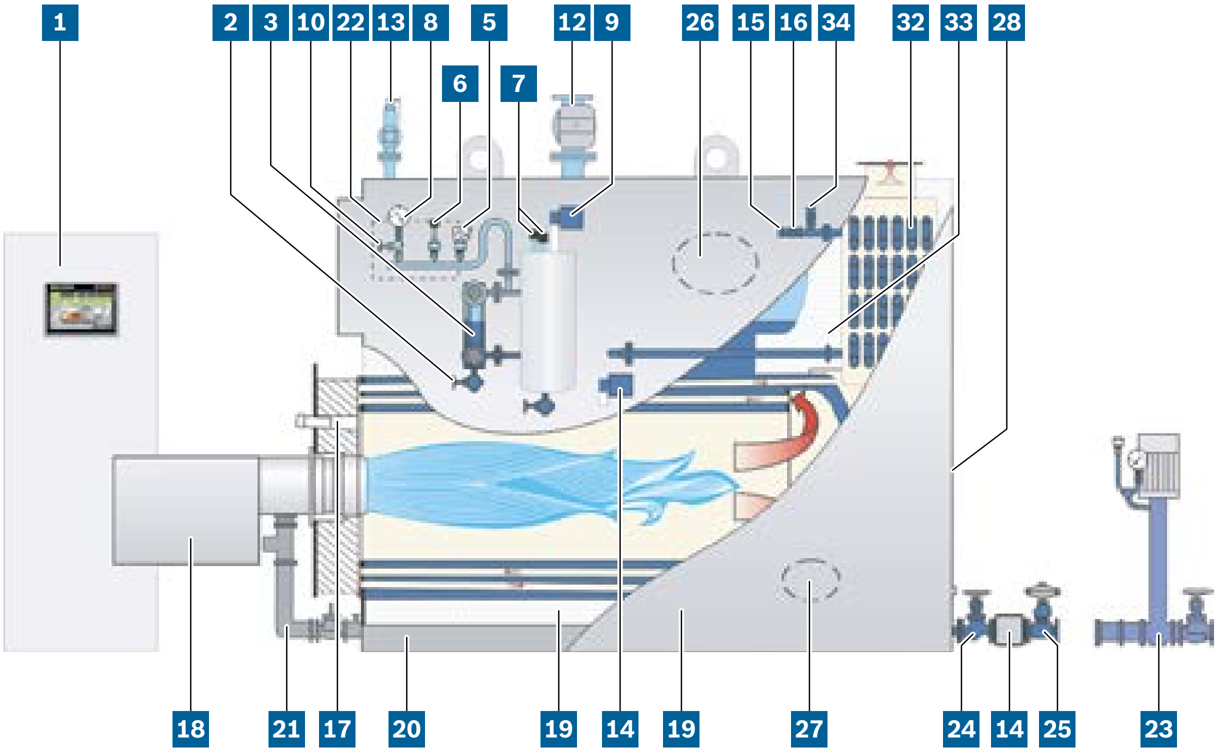


Fig. 179 *Illustration of U-MB*

1	Control switchgear cabinet with boiler control BCO	18	Burner
2	Blow-off tap	19	Insulation with protective shell
3	Reflective water level indicator	20	Base frame
5	Pressure limiter	21	Gas regulation module
6	Pressure transmitter (4 – 20mA)	22	Terminal box
7	Low-level limiter electrode	23	Pump module
8	Pressure gauge	24	Drain shut-off valve, maintenance-free
9	Level transmitter (4 – 20mA)	25	Bottom blowdown quick-release valve
10	Pressure gauge shut-off valve with testing function	26	Inspection aperture, steam side
12	Steam removal valve	27	Inspection aperture, water side
13	Full-lift safety valve	28	Inspection aperture, flue gas side
14	Fully automatic conductivity measurement and surface blowdown	32	Flue gas heat exchanger ECO
15	Feed water non-return valve	33	Connection piping ECO/boiler
16	Feed water shut-off valve, maintenance-free	34	Vent shut-off valve ECO
17	Flame inspection hole		

2.3 UNIVERSAL steam boiler UL-S/UL-SX

The UNIVERSAL UL-S boiler type is a 3-pass shell boiler, which fulfils all the requirements in the medium and high output ranges. Typical application areas are in processing industries, the commercial sector and public buildings.

Fig. 180 *Image of U-LS/UL-SX system*

Technical data	UL-S type	UL-SX type
Heat transfer medium	High-pressure saturated steam	High-pressure superheated steam
Design	3-pass flame-tube/smoke-tube technology	3-pass flame-tube/smoke-tube technology
Output in kg/h	1,250 to 28,000	2,600 to 28,000
Safety pressure in bar	Up to 30	Up to 30
Max. temperature in °C	235	300
Fuel	Oil, gas, multifuel firing	Oil, gas, multifuel firing

High efficiency for reduced operating costs

You can save up to 7% with the integrated economiser for waste heat recovery. Other optional modules, such as continuous feed water control for a constant water level in the boiler, speed-controlled burner fans for electricity reduction and O_2/CO controls for optimum combustion quality, achieve an even higher efficiency and reduce the environmental impact.

- High level of efficiency due to 3-pass technology, an integrated economiser and effective heat insulation concept
- Flue gas temperatures below 50°C are possible with condensing use
- The boiler can be equipped with a separate 4th pass for waste heat utilisation (e.g. from combined heat and power units)
- Low-emission combustion down to below 50mg NO_x thanks to the use of highly developed firing systems and careful matching of the best boiler/burner combination

User-friendly operating concept

- Intuitive PLC-based boiler control
- Automatic start-up, standby and shutdown control SUC
- Ready to connect to automation systems
- Digital efficiency assistant MEC Optimize
- Protected remote access MEC Remote

Reliable performance and customised equipment

We manufacture the proven UL-S steam boiler in different output sizes with up to 28 tons of steam. This boiler series can also be efficiently operated as an intelligent controlled boiler cascade.

- High level of pressure consistency and steam quality, even with widely fluctuating steam demand, thanks to a high steam chamber and three-component control
- Large steam formation surface thanks to asymmetric design
- Suitable for almost all burner systems
- The boiler pressure vessel can also be used as a pure heat recovery boiler (without burner) downstream from combined heat and power units or gas turbines
- Engineering design which has already proven itself thousands of times in practice – durable and reliable

Fast installation and effective maintenance

- Smooth commissioning due to pre-assembled modules and a pre-parameterised boiler control
- Easy subsequent expansion and modernisation
- Simplified on-site wiring due to plug-in connections
- Easy to maintain – simple to inspect on both the flue gas side as well as the water side

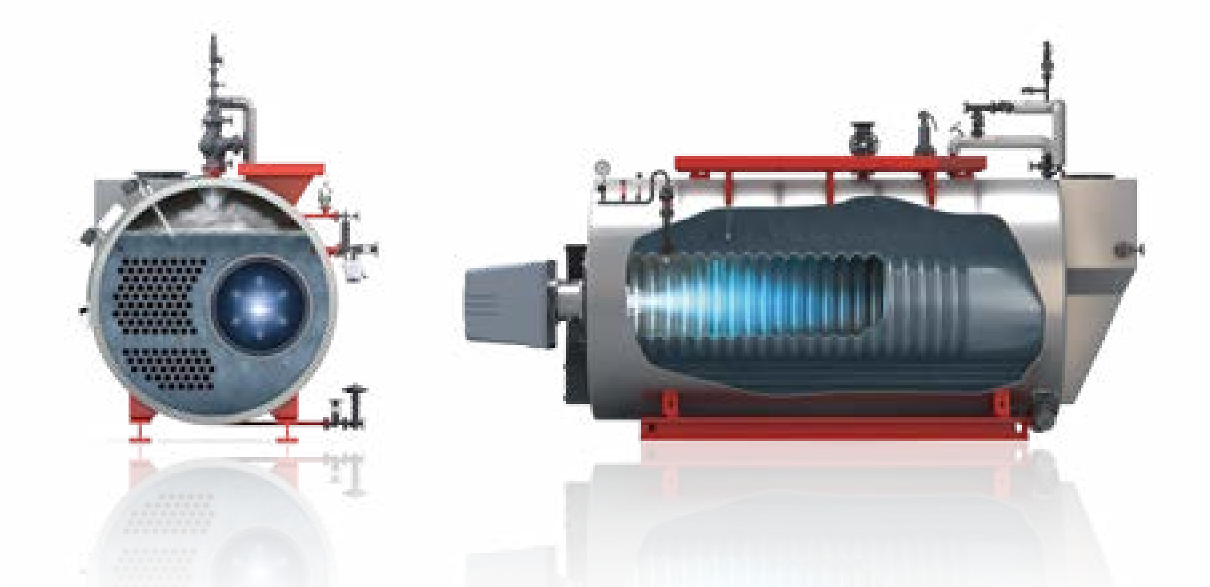


Fig. 181 *Sectional view UL-S/UL-SX*

Construction

Our 3-pass patent dating from 1952 forms the basis for the outstanding and ongoing success of this product line. The lateral flame tube (1st pass) and the adjacent smoke tube bundles (2nd and 3rd pass) are ideally integrated into the pressure vessel together with the fully wetback reversing chamber. This arrangement results in a large heating surface with exceptionally small overall dimensions. Additionally, the UL-S boiler has thus a maximised steam chamber which is particularly advantageous for dynamic steam demand. The flame tube is fixed at both ends of the boiler body and connected to the casing through ingenious use of diagonal stays (corner anchors) which evenly distribute the load. Compared to outdated stud bolt constructions, the Bosch design increases robustness and durability of the boilers – also when exposed to dynamic loads.

Associated boiler house components

- Flue gas heat exchanger ECO and flue gas heat exchanger ECO for condensing use
- Feed water cooling module FWM
- Condensate service module CSM
- Water service module WSM
- Water treatment module WTM
- Pump module PM and Water analyser WA
- Feed water regulation module RM
- Air preheating system APH
- Gas regulation module GRM
- Oil supply module OSM
- Oil circulation module OCM
- Oil pressure regulation module ORM
- Oil preheater module OPM
- Steam distributor SD
- Steam accumulator module SAM
- Remote access MEC Remote
- Efficiency assistant MEC Optimize
- Control for large-scale plants MEC System
- Controls for optimising combustion
- Compact steam boiler control CSC
- Blow-down, expansion and cooling module BEM
- Expansion and heat recovery module EHM
- Expansion, heat recovery and blow-down module EHB
- Vapour cooler VC
- Super heater module
- Boiler control BCO
- System control SCO

Fig. 182 *Steam distributor SD*

→ Products – Chapter 4: Modules for steam boilers, page 341

→ Products – Chapter 5: Boiler supply modules, page 361

Equipment

We offer the UNIVERSAL steam boiler UL-S/UL-SX as a complete boiler system including equipment*. The basic equipment comprises the boiler pressure vessel, the control and safety components, the burner unit, an integrated economiser, a pump module, a terminal box and the control switchgear cabinet including the easy-to-operate boiler control BCO. For UL-S boilers with an output up to 4,000kg/h, the affordable CSC control version can be used as an alternative. The sensors, actuators and country-specific safety devices of the boiler are already wired and combined in the terminal box. Pre-assembled, plug-in and coded cable bundles simplify the connection between the boiler control cabinet and terminal box during installation. The freestanding or wall-mounted switchgear cabinet can be adapted and set up to best suit the requirements on site.

*The equipment level is variable and can be freely configured to customer requirements

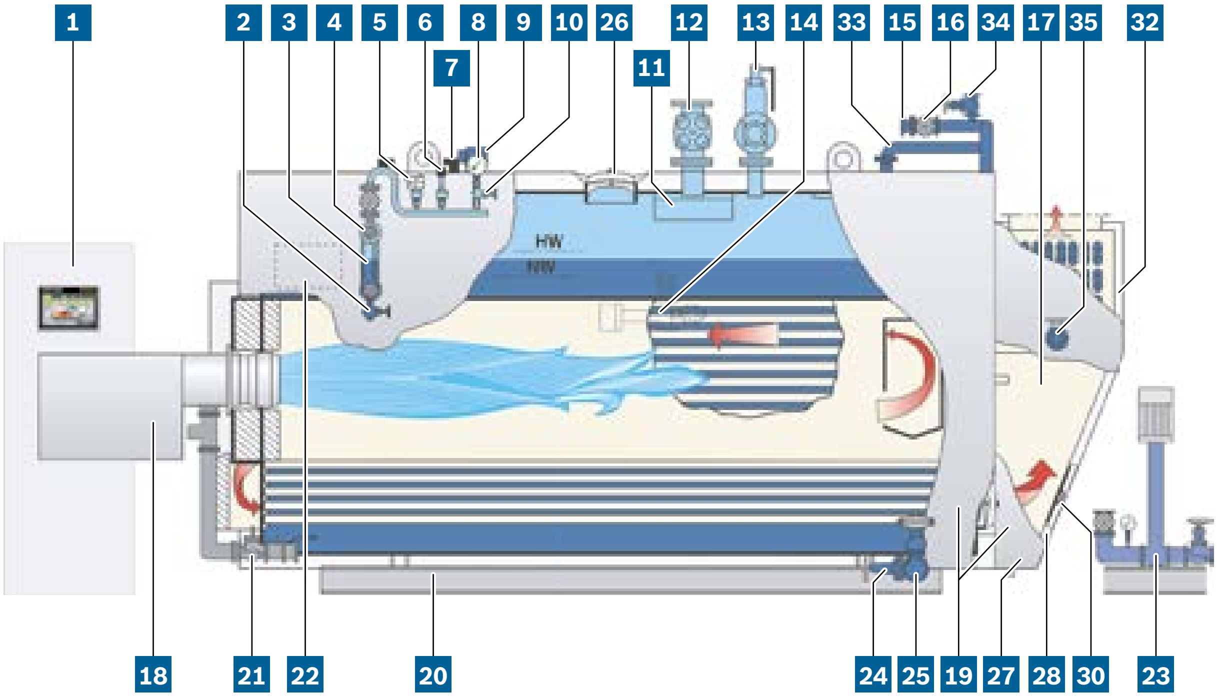


Fig. 183 *Illustration of UL-S/UL-SX*

- **1** Control switchgear cabinet with boiler control BCO (CSC control version can be used as alternative for boilers with outputs up to 4,000kg/h)
- **2** Blow-off tap
- **3** Reflective water level indicator
- **4** Manostat tube shut-off valve, maintenance-free
- **5** Pressure limiter
- **6** Pressure transmitter (4 – 20mA)
- **7** Low-level limiter electrode
- **8** Pressure gauge
- **9** Level transducer (4 – 20mA)
- **10** Pressure gauge shut-off valve with testing function
- **11** Steam dryer
- **12** Steam removal valve
- **13** Full-lift safety valve
- **14** Fully automatic conductivity measurement and surface blowdown
- **15** Feed water non-return valve
- **16** Feed water shut-off valve, maintenance-free
- **17** Flame inspection hole
- **18** Burner
- **19** Insulation with protective shell
- **20** Base frame
- **21** Gas regulation module
- **22** Terminal box
- **23** Pump module
- **24** Drain shut-off valve, maintenance-free
- **25** Bottom blowdown quick-release valve
- **26** Inspection aperture, steam side
- **27** Inspection aperture, water side
- **28** Inspection aperture, flue gas side
- **30** Flue gas collection chamber
- **32** Flue gas heat exchanger ECO
- **33** Connection piping ECO/boiler
- **34** Vent shut-off valve ECO
- **35** Drain shut-off valve ECO (draining)

2.4 UNIVERSAL steam boiler ZFR/ZFR-X

The UNIVERSAL ZFR steam boiler is a shell boiler in 3-pass technology with two flame tubes and completely separate smoke gas paths. It covers more or less every demand for steam and heat energy in the high output range. Typical application areas are energy suppliers, public buildings, processing industries and commercial businesses in all sectors of the economy.

Fig. 184 *ZFR/ZFR-X steam boiler system*

Technical data	ZFR type	ZFR-X type
Heat transfer medium	High-pressure saturated steam	High-pressure superheated steam
Design	3-pass double flame-tube/ smoke-tube technology	3-pass double flame-tube/ smoke-tube technology
Output in kg/h	18,000 to 55,000	18,000 to 55,000
Safety pressure in bar	Up to 30	Up to 30
Max. temperature in °C	235	300
Fuel	Oil, gas, multifuel firing	Oil, gas, multifuel firing

High efficiency for reduced operating costs

In the case of the UNIVERSAL steam boiler ZFR, the modulating output regulator for "unrestricted" single flame-tube or double flame-tube operation and the continuous feed water control are mandatory. In order to use additional potential savings, we can offer you optional modules for increased efficiency, e.g. speed-controlled burner fans or combustion controls through maintaining O_2 and/or CO levels.

- High level of efficiency due to 3-pass technology and integrated economiser
- Effective thermal insulation concept
- Low-emission combustion thanks to the use of highly developed combustion systems and careful matching of the best boiler/burner combination and flame tube geometry

User-friendly operating concept

- Intuitive PLC-based boiler control
- Automatic start-up, standby and shutdown control SUC
- Ready to connect to automation systems
- Digital efficiency assistant MEC Optimize
- Protected remote access MEC Remote

Reliable performance and customised equipment

The double-flame tube/smoke tube boiler with separate smoke gas passages is also suitable for operation with just one burner. This results in a very high load flexibility. Boiler components such as economiser and super heater can easily be added thanks to their modular design.

- High level of pressure consistency and steam quality even with widely fluctuating steam demand
- Suitable for almost all burner systems
- Extremely wide control range can be achieved thanks to single flame-tube operation
- Acceptance in accordance with the European Pressure Equipment Directive, and can therefore be used worldwide
- Engineering design which has already proven itself thousands of times in practice – durable and reliable

Fast installation and effective maintenance

- Smooth commissioning due to preassembled modules and pre-parameterised boiler control
- Easy subsequent expansion and modernisation
- Simplified on-site wiring due to plug-in connections
- Maintenance-friendly – easy to inspect both on flue gas side and water side

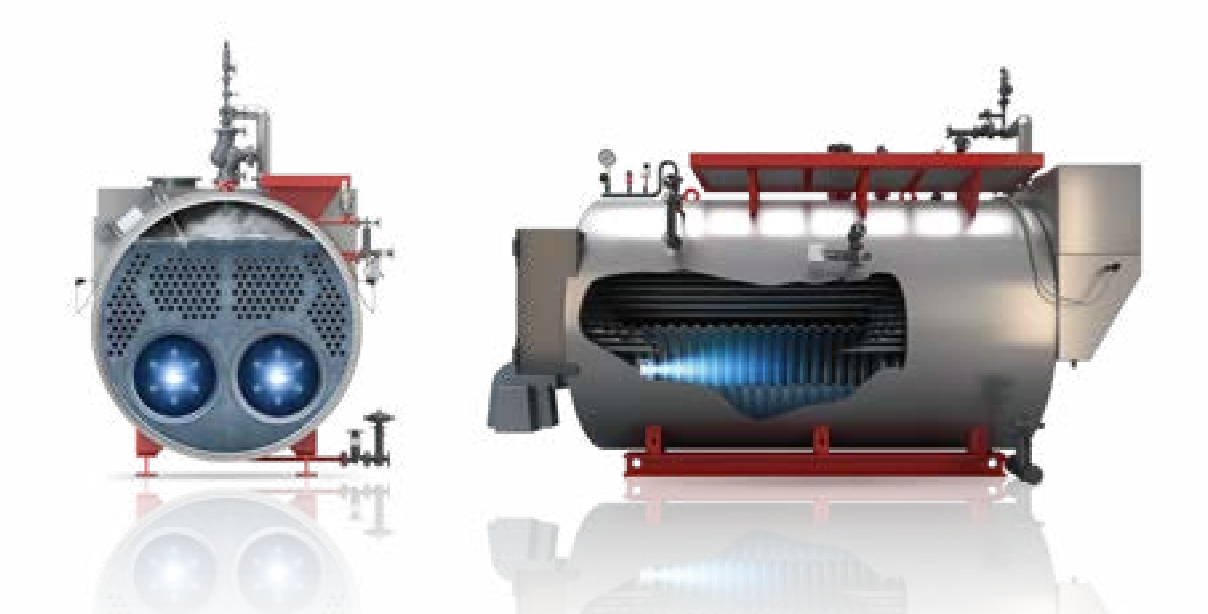


Fig. 185 *Sectional view ZFR/ZFR-X*

Construction

Its suitability for the unrestricted parallel or single operation of its combustion systems is not only due to the stable separation on the flue gas side. The special design measures for neutralising the tension forces in single flame-tube operation are crucial for permanent stability. The flame tubes are pushed through in the front and rear floors and welded tightly all around. In contrast to boiler designs with stud bolts, inadmissible bending stresses are avoided. The integrated rear flue gas reversing chamber thus offers the advantages of the fully wetback cooling while significantly reducing its mechanical stress. Water circulation and heat transport efficiency are significantly increased by means of guide profiles on the boiler base.

Additionally, flow paths between the flame tubes and the adjacent smoke-tube areas further accelerate the circulation.

A fully automatic operation with one or both burners is possible without restriction due to the approved single flame-tube operation. Even different fuels in both combustion systems do not pose any problems. The control range is doubled and each low load phase is run with one burner and with consequent gain in efficiency level.

→ Technical report FB003: Double flame-tube boilers

Associated boiler house components

- Flue gas heat exchanger ECO and flue gas heat exchanger ECO for condensing use
- Blow-down, expansion and cooling module BEM
- Expansion, heat recovery and blow-down module EHB
- Expansion and heat recovery module EHM
- Feed water cooling module FWM
- Condensate service module CSM
- Water service module WSM
- Water treatment module WTM
- Pump module PM
- Water analyser WA
- Feed water regulation module RM
- Vapour cooler VC
- Air preheating system APH
- Gas regulation module GRM
- Oil supply module OSM
- Oil circulation module OCM
- Oil pressure regulation module ORM
- Oil preheater module OPM
- Steam distributor SD
- Steam accumulator module SAM
- Super heater module
- Controls for optimising combustion
- Remote access MEC Remote
- Efficiency assistant MEC Optimize
- Control for large-scale plants MEC System
- Boiler control BCO
- System control SCO

Fig. 186 *Flue gas heat exchanger ECO 6 for condensing use*

→ Products – Chapter 4: Modules for steam boilers, page 341

→ Products – Chapter 5: Boiler supply modules, page 361

Equipment

We offer the UNIVERSAL steam boiler ZFR/ZFR-X as a complete boiler system including equipment*. The basic equipment comprises the boiler pressure vessel, the control and safety components, the burner unit, an integrated economiser, a pump module, a terminal box and the control switchgear cabinet including the easy-to-operate boiler control BCO. The sensors, actuators and country-specific safety devices are already wired and combined in the terminal box. Pre-assembled, plug-in and coded cable bundles simplify the connection between the boiler control cabinet and terminal box during installation. The freestanding or wall-mounted switchgear cabinet can be adapted and set up to best suit the requirements on site.

*The equipment level is variable and can be freely configured to customer requirements.

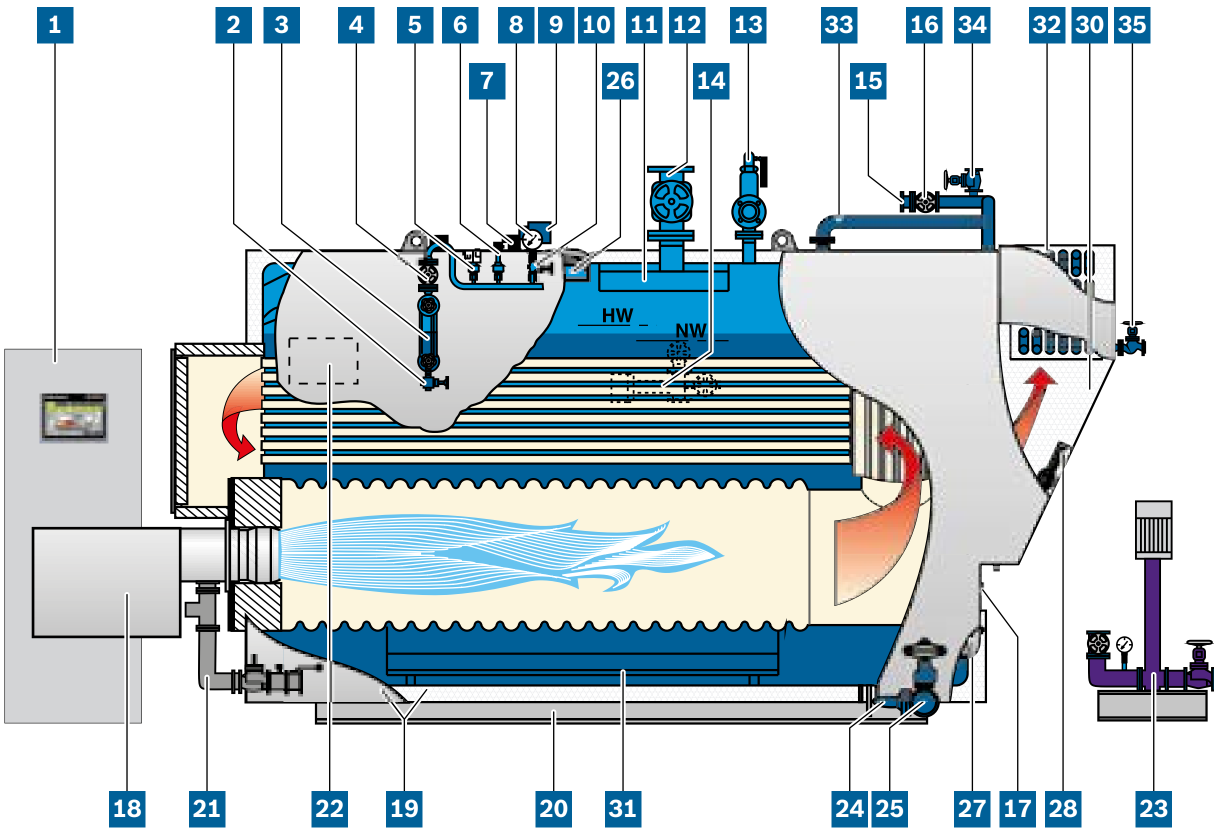


Fig. 187 *Illustration of ZFR/ZFR-X*

1	Control switchgear cabinet with boiler control BCO
2	Blow-off tap
3	Reflective water level indicator
4	Manostat tube shut-off valve, maintenance-free
5	Pressure limiter
6	Pressure transmitter (4 – 20mA)
7	Low-level limiter electrode
8	Pressure gauge
9	Level transmitter (4 – 20mA)
10	Pressure gauge shut-off valve with testing function
11	Steam dryer
12	Steam removal valve
13	Full-lift safety valve
14	Fully automatic conductivity measurement and surface blowdown
15	Feed water non-return valve
16	Feed water shut-off valve, maintenance-free
17	Flame inspection hole
18	Burner
19	Insulation with protective shell
20	Base frame
21	Gas regulation module
22	Terminal box
23	Pump module
24	Drain shut-off valve, maintenance-free
25	Bottom blowdown quick-release valve
26	Inspection aperture, steam side
27	Inspection aperture, water side
28	Inspection aperture, flue gas side
30	Flue gas collection chamber
31	Water circulation guide profiles
32	Flue gas heat exchanger ECO
33	Connection piping ECO/boiler
34	Vent shut-off valve ECO
35	Drain shut-off valve ECO (draining)

2.5 Super heater module

Single and double flame-tube/smoke-tube boilers with super heaters for superheated steam generation.

If superheated steam is required instead of saturated steam, a super heater module can be placed on the front reversing chamber. A bypass flap constantly controls the temperature of the superheated steam over a wide load range. The smoke tube areas remain easily accessible thanks to the hinged door of the reversing chamber.

- Modular system, controlled on the flue gas side – no injection water required for temperature control of the superheated steam
- Easy maintenance and installation – simple cleaning possibility of the 2nd and 3rd boiler pass
- Long service life thanks to low thermal loading of the heat exchanger bundle of the super heater

→ Technical report FB020: Steam boilers with superheater module

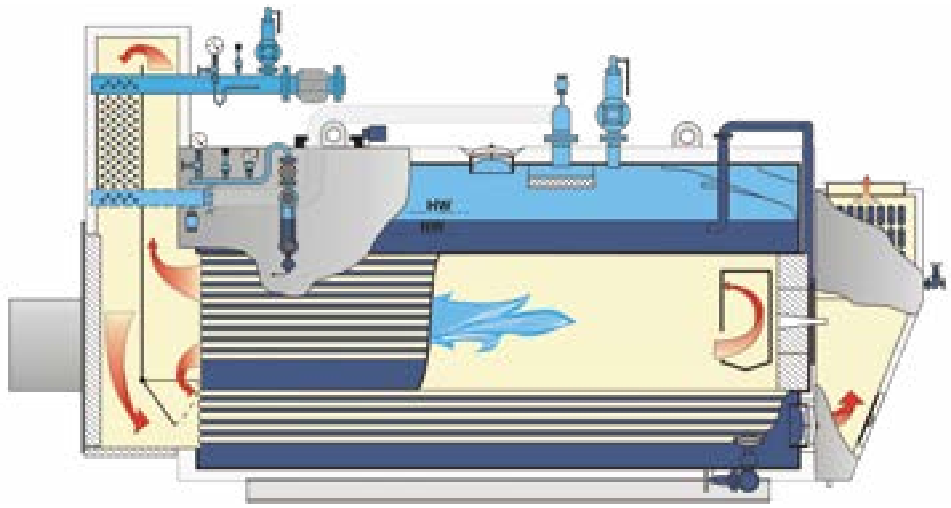


Fig. 188 *Sectional view UL-SX*

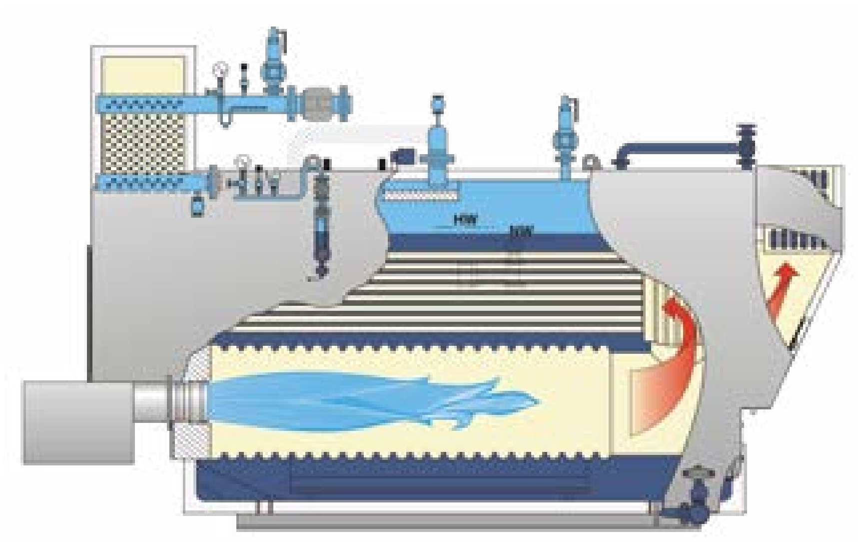


Fig. 189 *Sectional view ZFR-X*

Fig. 190 *Double flame-tube boiler with super heater module*

3 Heat recovery boilers and waste heat recovery

3.1 UNIVERSAL heat recovery steam boiler HRSB

The heat recovery boiler utilises flue gas heat for process steam generation.

Fig. 191 *UNIVERSAL heat recovery steam boiler HRSB system*

Technical data	HRSB type
Heat transfer medium	High-pressure saturated steam
Design	Heat recovery shell boiler
Output in kg/h	400 to 4,100
Safety pressure in bar	10 to 16
Max. flue gas temperature of the waste heat source in °C	550
Min. flue gas volumes of the waste heat source in kg/h	500
Max. flue gas volumes of the waste heat source in kg/h	23,500
Fuel of the waste heat source	Natural gas (other flue gas types on request)
Output range of combinable combined heat and power units in MWel	Approx. 0.5 to 4

Used in combination with a combined heat and power unit, the heat recovery steam boiler HRSB can play a significant part in utilising primary energy efficiently. The hot flue gases from the upstream combustion processes are passed to the heat recovery boiler and used for steam generation. Thanks to its modular design and compact dimensions, it is the ideal choice for both new plants and modernisation projects alike.

Construction

The heat recovery steam boiler, which is certified in accordance with the PED (Pressure Equipment Directive), is available in eight standardised versions. It consists of a highly efficient tubular heat exchanger the efficiency of which can be further increased by using an optional integrated economiser. In addition, we offer a flue gas bypass. If no steam is extracted, the boiler will use it for diversion on the flue gas side. This means that the combined heat and power unit or other waste heat sources can continue operating without interruption.

Equipment

The heat recovery steam boiler is insulated and features state-of-the-art safety equipment. The flue gas bypass is supplied separately to facilitate transportation and is fitted and insulated on site. The boiler control BCO, based on PLC, can be controlled via touchscreen and is housed in a separate floor standing or wall-mounted control switchgear cabinet.

Benefits at a glance

- Increase in efficiency and environmental responsibility through use of waste heat sources
- High supply reliability thanks to own firing
- High efficiency through efficient tubular heat exchanger and good thermal insulation
- Additional efficiency gain thanks to optional integrated economiser
- Matched, modular system for easy planning and fast installation
- Complete system including combined heat and power unit on request
- Intuitive PLC-based boiler control with outstanding operating data transparency
- Smooth commissioning due to pre-parameterised boiler control
- Simplified on-site wiring due to plug-in connections
- Robust, reliable and durable
- Reduced component diversity with regard to spare parts inventory
- Service from a single source
- System control by SCO with BCOs of heat recovery boilers and conventionally-fired boilers is possible

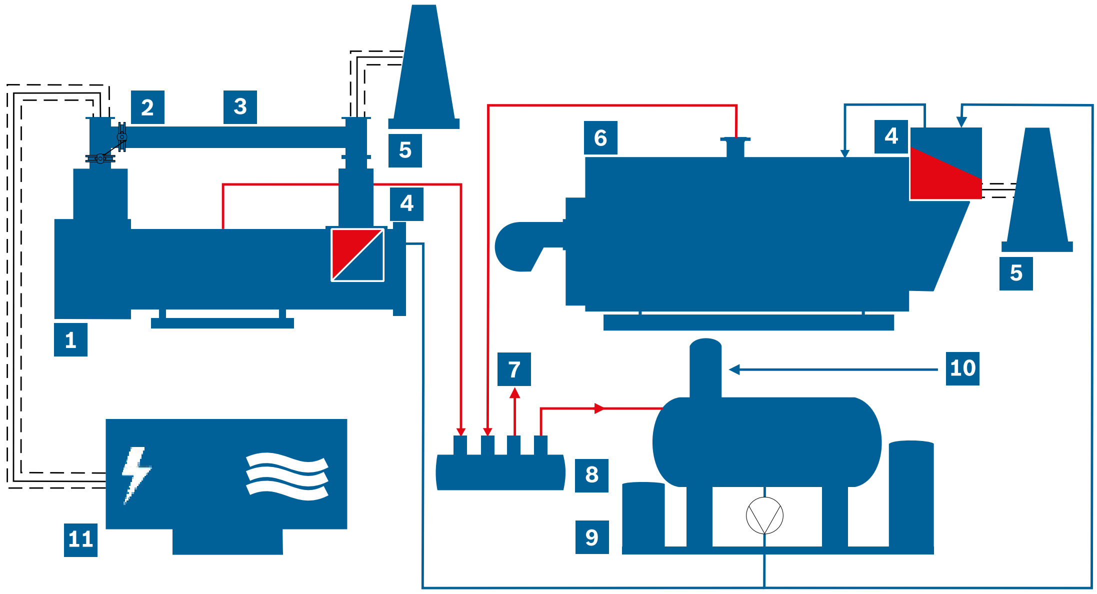


Fig. 192 *Function diagram of UNIVERSAL heat recovery steam boiler HRSB (highly simplified representation)*

1 Heat recovery boiler
2 Bypass dampers
3 Flue gas bypass
4 Economiser
5 Chimney
6 Peak load steam boiler
7 Consumer
8 Distributor
9 Water service module WSM-V
10 Make-up water
11 Combined heat and power unit

UL-S series as 3-pass heat recovery boiler

- The UL-S series can also be used as pure heat recovery boiler
- For use with high flue gas temperatures
- For use in combination with combined heat and power units or gas turbines
- Utilisation of waste heat for generating steam

Fig. 193 *Front view of 3-pass heat recovery boiler without burner*

3.2 4-pass boiler with burner

The conventional fired boiler generates process heat while simultaneously utilising the heat potential from waste heat sources.

Fig. 194 *4-pass boiler with burner*

Technical data	4-pass boiler, UL-S type
Heat transfer medium	High-pressure saturated steam
Design	3-pass flame-tube/smoke-tube boiler with integrated 4th smoke-tube pass
Output in kg/h	700 to 28,000
Safety pressure in bar	Up to 30
Max. flue gas temperature of the waste heat source in °C	550
Min. flue gas volumes of the waste heat source in kg/h	500
Max. flue gas volumes of the waste heat source in kg/h	23,500
Fuel of the waste heat source	Natural gas (other flue gas types on request)
Output range of combinable combined heat and power units in MWel	Approx. 0.2 to 4
Fuel for firing of the boiler	Gas, oil, multifuel firing

This industrial steam boiler variant is a conventional fired 3-pass boiler with additional integrated smoke tube pass for the utilisation of waste heat. It is predominantly used in combination with CHP plants or gas turbines. In the fourth pass of the boiler, the hot flue gases from the upstream combustion processes are used to help generate process heat.

The use of waste heat boilers without firing normally requires an additional peak-load boiler. On the design variant with own firing, the fourth pass supplies the base-load output and the firing system switches on if demand increases. This eliminates the need for set-up time and costs, space requirements and investment costs for an additional pressure vessel with complete safety equipment and feed pumps. Furthermore, the use of heat exchangers in the flue gas system of the CHP plant is reduced.

Construction

The design of our heat recovery boilers with burner corresponds to the basic design of the UL-S series. The boilers are fitted with an additional integrated smoke-tube pass (4th pass) for waste heat utilisation.

Equipment

The equipment options are identical to that available for the UNIVERSAL steam boiler UL-S series.

Benefits at a glance

- Increase in efficiency and environmental responsibility through use of waste heat sources
- High supply reliability thanks to own firing
- Matched, modular system for easy planning and fast installation
- Complete system including combined heat and power unit and integrated system control on request
- Intuitive PLC-based boiler control with outstanding operating data transparency
- Smooth commissioning due to pre-parameterised boiler control
- Simplified on-site wiring due to plug-in connections
- Robust, reliable and durable
- Reduced component diversity with regard to spare parts inventory
- Service from a single source

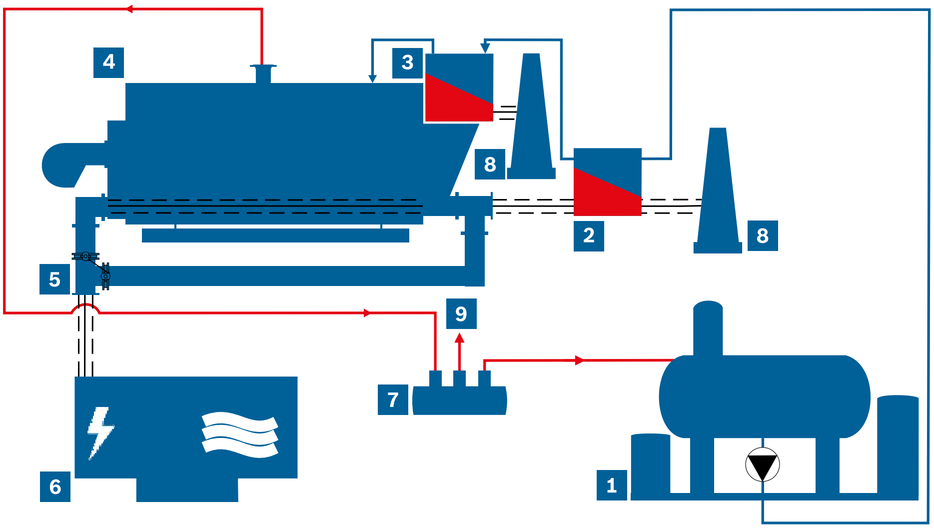


Fig. 195 *Function diagram of 4-pass boiler with burner (highly simplified representation)*

1 Water service module WSM-V
2 Flue gas heat exchanger
3 Economiser
4 4-pass steam boiler
5 Flue gas bypass
6 Combined heat and power unit
7 Distributor
8 Chimney
9 Consumer

3.3 Energy-saving system technology

High-efficiency boiler systems with optimally-matched boiler house components ensure low energy consumption and low emissions.

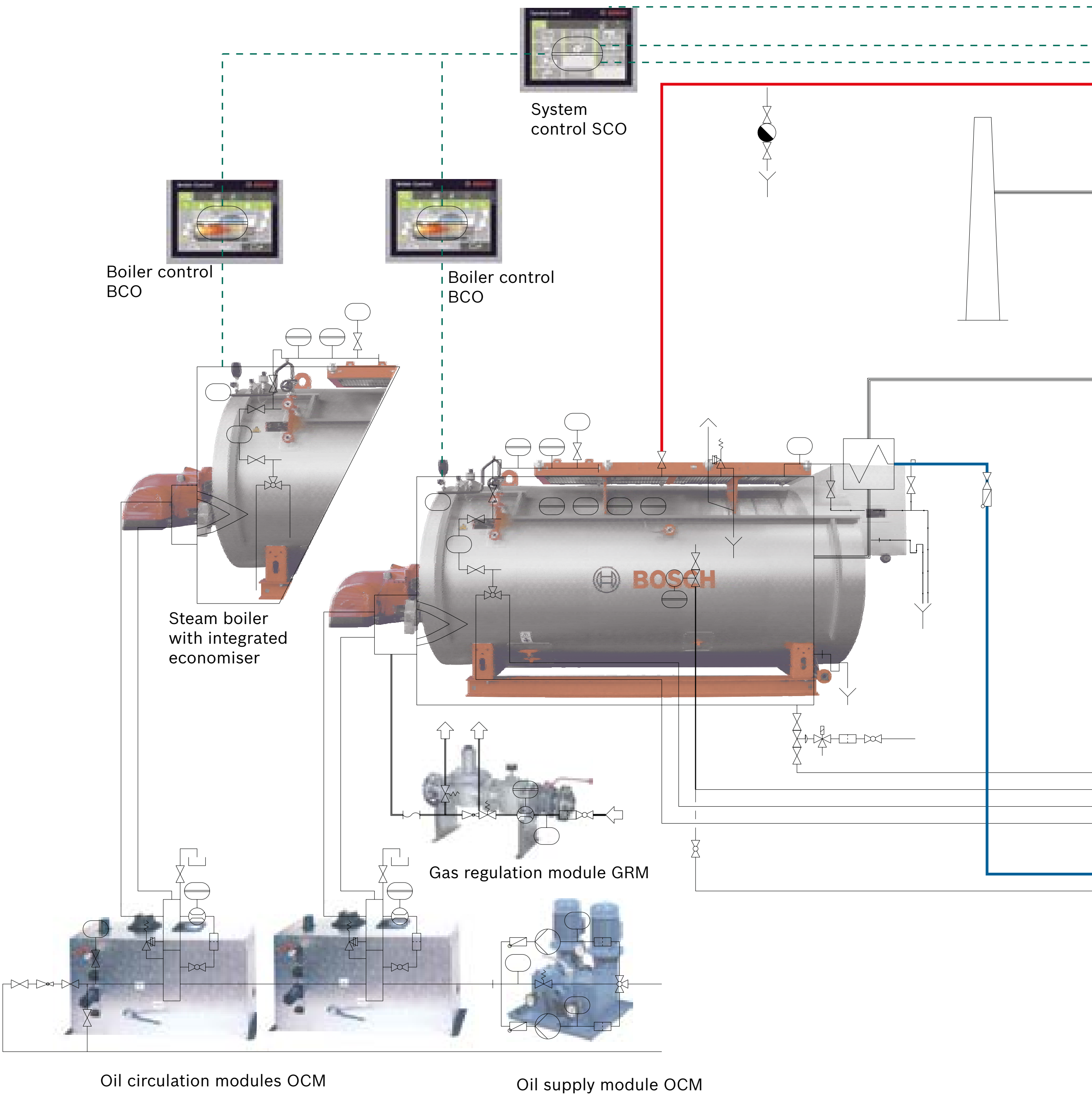
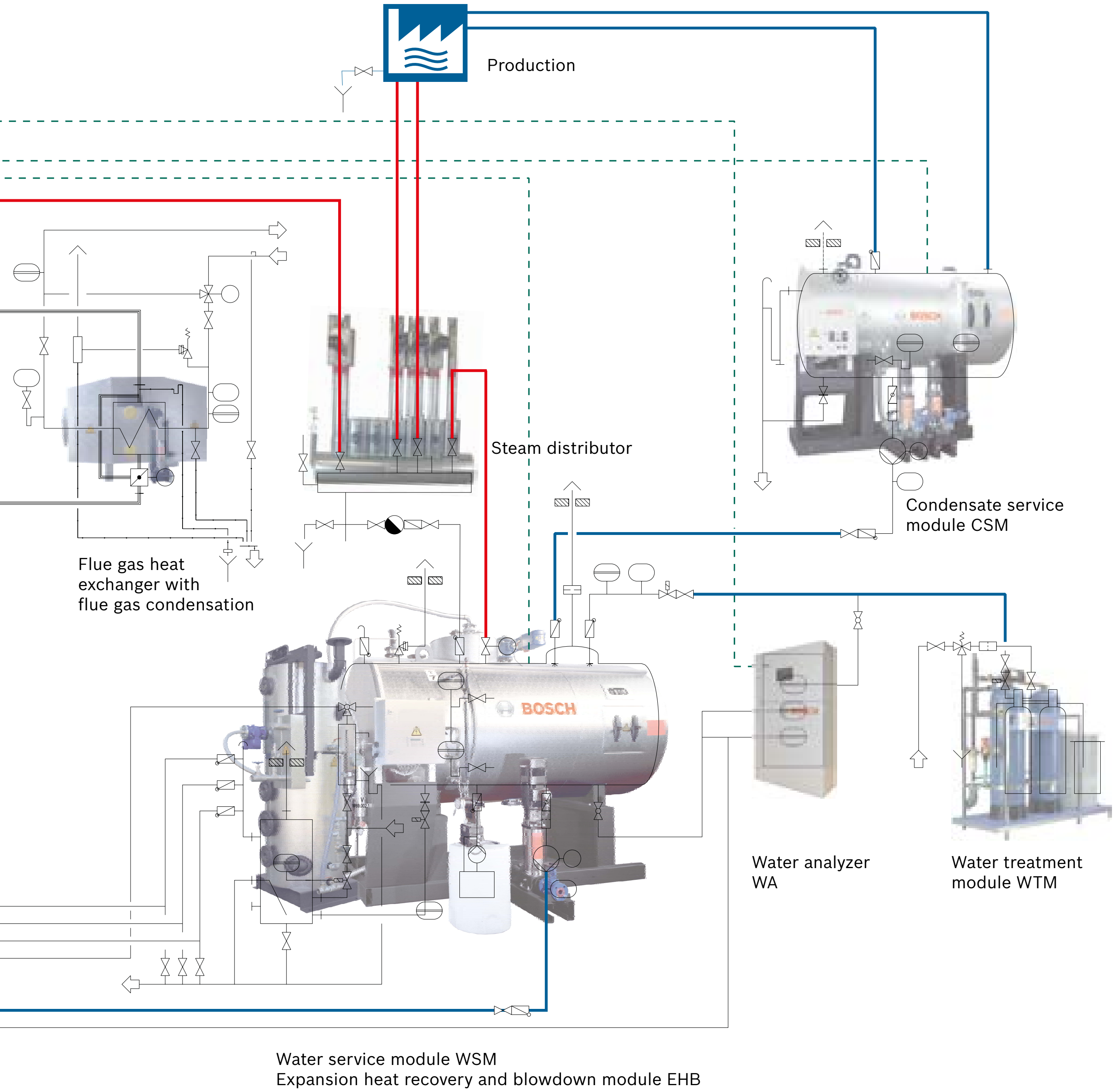


Fig. 196 *Function diagram of boiler house components*


Production
Steam distributor
Condensate service module CSM
Flue gas heat exchanger with flue gas condensation
BOSCH
Water analyzer WA
Water treatment module WTM
Water service module WSM
Expansion heat recovery and blowdown module EHB

4 Modules for steam boilers

Bosch modules for steam boilers allow you to equip your system according to your requirements. They ensure maximum operational safety, a long service life and a high degree of efficiency under the specific operating conditions.

4.1 Water service module WSM

The water service module supplies steam boilers with degassed and chemically conditioned feed water and disposes of the surface blowdown and bottom blowdown water.

- Feed in and storage of condensate and make-up water
- Thermal partial deaeration of the feed water with WSM-T
- Thermal full deaeration of the feed water with WSM-V
- Chemical conditioning of the feed water
- Expansion and cooling of the surface blowdown and bottom blowdown water
- Cooling of the water samples
- PLC control and visualisation of
  - Water level in the tank
  - Feed water temperature for the WSM-T
  - Tank pressure for the WSM-V
  - Blowdown temperature
- Control for chemical dosing
- Dry running protection feed pump module
- Overflow protection

Fig. 197 *Water service module WSM-V for full deaeration for all steam boilers with outputs ranging from 2,000 to approx. 100,000kg/h*

Construction

All components are piped, thermally insulated and electrically wired into a multi-functional assembly unit. Complex scaffold constructions are not necessary: the compact module is mounted on a stable support device and designed for installing at ground level. All functions are computer-aided and automatically controlled with a programmable logic controller with touch panel.

Equipment

The module consists of the steam heated feed water tank, the chemical dosing device, the blowdown expansion vessel, a water sample cooler and the associated fittings as well as the control cabinet. Additional optional components such as a heat recovery facility for surface blowdown water, a second chemical dosing device or feed pump modules are available. A spray or trickle deaerator is mounted on the feed water tank of the WSM-V.

Benefits at a glance

- Fast and easy planning, installation and acceptance
- No need for positive suction head, ground level installation
- Ready for operation with just a few connections
- Easy commissioning, maintenance and operation
- Complete warranty unit
- Easy transportation and relocation
- High degassing efficiency with WSM-T
- Outstanding degassing efficiency with WSM-V
- Reduced consumption of chemicals with WSM-V

Fig. 198 *Water service module WSM-T for partial deaeration for all steam boilers with outputs up to 8,000kg/h*

4.2 Steam distributor SD

In the distributor, the generated steam mass flow is distributed to the consumers and residual moisture is separated and drained.

Construction

A collecting pipe with an order-related number of pipe outlets is fully assembled with flange connections and all necessary fittings into a module unit.

Equipment

The distributors are fitted with pressure indicators, shut-off, non-return and condensate drain valves and will be delivered thermally insulated.

Benefits at a glance

- Reduction of network losses by centralised distribution for systems with complex consumer structures
- Savings thanks to centralised operation and maintenance

Fig. 199 *Steam distributor SD in existing system*

4.3 Steam accumulator module SAM

The module is used for storing a defined energy content that is available as expansion steam during pressure reduction. The application area is the covering of peak loads, e.g. if the capacity of a steam generator is exceeded briefly. The greater the water content of the accumulator, the greater the re-evaporation heat is. The steam accumulator is filled 50% with water and is heated up with steam to the charging pressure. The accumulator is discharged by opening the shut-off devices on the consumer side. Always the exact same steam quantity that was removed previously is fed into the accumulator. This means that it is generally not necessary to supply additional feed water to the steam accumulator during operation. A float condensate trap is provided to prevent an increasing water level.

Construction

The steam accumulator consists of a horizontal cylindrical tank with a built-in steam nozzle pipe.

Equipment

The module is thermally insulated and delivered with assembled equipment ready for operation. The module is fitted with venting, drain shut-off, filling shut-off, steam inlet and outlet valves, overflow and overpressure protection, a direct temperature display as well as a water level indicator.

Benefits at a glance

- Balance of brief peak loads
- Reduction of water entrainment and its negative effects
- Reduction of switching frequency of the steam generators
- Reduction of energy consumption and wear

Fig. 200 *Steam accumulator module SAM*

4.4 Condensate service module CSM, condensate high-pressure plant CHP

Condensate from steam consumers is channeled, collected and temporarily stored in the condensate service module. A condensate pump moves condensate back into the feed water deaeration plant if the corresponding need for water arises. Unpressurised condensate service modules are usually installed near the consumer.

The condensate high-pressure plant maintains the condensate at the necessary pressure and temperature so that expansion steam losses are prevented or significantly reduced. The condensate is fed directly to the steam boiler via the condensate pump when required. Further deaeration of the high-pressure condensate is not necessary. Condensate high-pressure plants should always be used if the discharge into the feed water tank or into unpressurised condensate service modules would be accompanied by high expansion steam losses due to the condensate parameters.

Construction

All components are piped, thermally insulated and electrically wired into a multi-functional assembly unit. The unpressurised condensate service module is mounted on a stable support device and designed for installing at ground level. The condensate high-pressure plant is prepared for open installation and needs a positive suction head of at least 1.5 metres. All functions are computer-aided and automatically controlled with a programmable logic controller.

Equipment

The system consists of the components condensate tank, condensate pump module, control cabinet and equipment accessories. The piping and thermal insulation of the system is pre-installed ex works.

Benefits at a glance

- Decrease in energy and water consumption by reducing make-up water quantities
- Minimisation of expansion steam losses, surface and bottom blowdown quantities, less chemical consumption and reduced corrosion potential in the steam condensate system when using condensate high-pressure plants
- Fuel and fresh water savings of up to 12% are possible with the condensate high-pressure plant CHP

Fig. 201 *The unpressurised condensate service module collects the condensate streams and channels them back into the water/steam circuit via the deaeration system*

Fig. 202 *The amount of fuel, make-up water requirement and use of chemical dosing agents for the water treatment can be reduced drastically by a condensate high-pressure plant*

4.5 Blowdown, expansion and cooling module BEM

The purpose of the blowdown, expansion and cooling module is the intake of all hot waste water of a steam boiler system. This waste water is collected, expanded and cooled down to the permitted, set discharge temperature in the module. The module is designed for multi-boiler systems with a maximum of three steam boilers.

Construction

A closed, upright container mounted on a supporting structure, with various feed and drain connections. The lower half of the module is filled with water during operation, the upper half is expansion space. The prevailing media temperature is recorded and converted to an electrical signal with the temperature measuring transducer in the lower part of the module. Mixed cooling is achieved by the supply of cold, softened make-up water and the waste water is safely drained off when the permitted discharge temperature is reached. The discharge temperature can be controlled by the control system of the water service module.

Equipment

The module comprises a vertical cylinder sealed with plates at both ends and all-round protection against contact. It is thermally insulated and fully assembled ex works with all necessary fittings.

Benefits at a glance

- Quick and easy assembly, ready for immediate operation with few connections
- Exact compliance with official guidelines thanks to automatic operating mode

Fig. 203 *Blowdown, expansion and cooling module BEM*

4.6 Expansion and heat recovery module EHM

The module recovers a substantial amount of the heat quantity contained within the hot water (surface blowdown water/condensate) of a boiler system. The pressurised water is expanded in the expansion tank. The expansion steam produced thereby supports the heating of the feed water tank. The make-up water of the boiler system is preheated in the downstream heat exchanger and the surface blowdown water/condensate is cooled to a temperature of approx. 35°C.

Construction

The module comprises an expansion tank, an integrated heat exchanger for heat recovery, the supporting structure and the necessary equipment.

Equipment

The module is offered thermally insulated and fully assembled ex works with all necessary fittings.

Benefits at a glance

- Quick and easy assembly, ready for immediate operation with few connections
- Increase in efficiency of the system
- Reduction of the fuel, cooling water and waste water costs of up to 2%

Fig. 204 *Expansion and heat recovery module EHM*

4.7 Expansion, heat recovery and blowdown module EHB

The module comprises the combination of the expansion, heat recovery and blowdown module EHM with the blowdown, expansion and cooling module BEM. Its purpose is therefore the recovery of the thermal energy contained within the hot water (surface blowdown water/condensate) and the discharge of waste water taking into account the permitted discharge temperature.

Construction

The module consists of an expansion tank as well as a waste water and cooling tank. A heat exchanger with associated fittings is integrated for heat recovery.

Equipment

Two cylinders one above the other sealed with plates at both ends, a collecting station, all necessary fittings, the internal piping and thermal insulation are included in the scope of delivery and are offered ex works fully assembled.

Benefits at a glance

- Quick and easy assembly, ready for immediate operation with few connections
- Exact compliance with official guidelines thanks to automatic operating mode
- Increase in efficiency of the system
- Reduced fuel, cooling water and waste water costs of up to 2%

Fig. 205 *Expansion, heat recovery and blowdown module EHB*

4.8 Vapour cooler VC

Owing to their principle of operation, thermal full deaeration systems produce exhaust vapours. Without a vapour cooler, exhaust vapour would be released into the open air without being used. In the vapour cooler, however, the exhaust vapour condenses by means of a heat exchanger. The accumulated thermal energy generated during the cooling of the exhaust vapour is used to heat up the make-up water.

Construction

Plate-type heat exchanger with threaded connections, wetted parts are made of stainless steel.

Equipment

The module comprises a heat exchanger with associated fittings.

Benefits at a glance

- Heat recovery and thus efficiency improvement
- Useable energy for additional heating or for transfer to separate water circuit

Fig. 206 *Vapour cooler VC*

4.9 Pump module PM

The module is used for pumping the feed water from the feed water tank into the shell boiler or for pumping the condensate from the condensate tank into the deaeration plant. As an option, the pump module can be equipped with a motor with a frequency converter for continuous, demand-related water quantity control.

Construction

The supplied pumps are vertical multi-stage high-pressure centrifugal pumps with a fully enclosed, fan-cooled motor. They are specially designed for use in shell boilers.

Equipment

The pump module is delivered fully assembled ex works on a console with pressure indicator, shut-off, filter and non-return valves.

Benefits at a glance

- Pre-assembled for quick installation
- Speed-controlled version for increasing the efficiency of the flue gas heat exchanger
- Reduction in power consumption and increase in operating convenience

Fig. 207 *Pump module PM*

4.10 Feed water regulation module RM

If no speed-controlled feed pump is available, continuous regulation with the feed water regulation module is recommended as an alternative for all boilers fitted with modulating burners and flue gas heat exchangers. The module ensures longer flow-through times of the flue gas heat exchanger and thus optimum heat recovery from the boiler flue gases. At the same time, this also secures the minimum quantity required for the feed pump cooling via the feed water control module.

The preassembled module is used in a suitable location in the feed water pressure line. It is switched as supply flow control.

Fig. 208 *Feed water regulation module RM*

Equipment

The feed water regulation module for continuous control consists of a feed water control valve, discharge device, dirt trap device and two shut-off valves as well as a bypass device.

Benefits at a glance

- Increased efficiency of flue gas heat exchanger
- Reduced number of pump switching operations
- Constant boiler water level
- Secure minimum flow rate for cooling of feed pump

4.11 Flue gas heat exchanger ECO stand-alone

The flue gas heat exchanger is designed to save energy through lowering the flue gas temperature by heating the mains return flow water.

Flue gases contain significant heat potential at high temperature. Economiser modules with their highly efficient heat recovery surfaces utilise this heat potential and thus increase the boiler efficiency of new or existing steam boiler systems significantly. The flue gas heat exchanger is installed downstream of the boiler and is used for “dry” operation for heating up feed water. To use the condensing heat, the flue gas condensation can take place in an additional downstream flue gas heat exchanger module and make-up water can be heated up. The subsequent installation in existing single flame-tube steam boiler systems can be carried out very easily by these modules.

Construction

In the lower part, the flue gases are collected and flow through the integrated heat exchanger in the upper part for heat recovery.

Equipment

The module is mounted on a stable base frame and has rails at the back for transportation. Actuator, piping of the connections, flue gas control and drain shut-off valves are fully assembled and included complete with thermal insulation in the scope of delivery ex works.

Benefits at a glance

- Increased boiler efficiency
- Reduced fuel consumption by up to 7%
- Easily retrofitted to existing systems

Fig. 209 *Flue gas heat exchanger ECO stand-alone*

4.12 Stand-alone flue gas heat exchanger with flue gas condensation

Using condensing technology, this flue gas heat exchanger recovers energy from the residual heat of the boiler flue gas.

The operating mode is the same as a normal economiser. The flue gas heat exchanger recovers heat from the hot boiler flue gas, while cool water flows through the heat exchanger tubes and reduces the flue gas temperature. The energy gained through flue gas condensation gives a higher level of boiler efficiency and therefore reduces fuel consumption and flue gas emissions.

Construction

Stainless steel heat exchanger in welded construction for installation downstream of the boiler, with connection pieces for water inlet, water outlet and drainage, and including inspection apertures on the flue gas side. For the model with bypass, the hot flue gases are controlled by means of control dampers.

Equipment

The module is fully fitted with lifting lugs and feet as well as a flue gas control valve and thermal insulation.

Benefits at a glance

- Improvement in utilisation rate
- Fuel savings of up to 7%
- Easy retrofitting to existing systems
- Can be used with both steam and hot water systems

Fig. 210 *Stand-alone flue gas heat exchanger with flue gas condensation*

4.13 Air preheating system APH

By means of this system the combustion air is preheated and the flue gas temperature is reduced. The efficiency is increased. When installing a new steam boiler system with economiser, air preheating is the ideal solution for increasing efficiency, particularly in cases where the integration of a flue gas condenser is impractical for process reasons. The Bosch air preheating system is available for single or double flame-tube boilers with duoblock burners. The system is economically viable from a boiler capacity of around five tonnes of steam per hour. The fan can be installed on the top of the boiler, this means that the compact system requires little space for installation. Return-on-investment (ROI) is generally achieved after 1.5 to 2 years but depending on the load profile it can be achieved earlier.

Construction

In the Bosch system, a part of the heated feed water flow is utilised for increasing the temperature of the combustion air. The feed water cooled in this manner increases efficiency by further reducing the flue gas temperature in the downstream, combined flue gas heat exchanger.

Equipment

The air preheating system consists of a three-way valve, a combined flue gas heat exchanger and an air-side heat exchanger. In comparison with conventional two-circuit systems, it is now possible to omit the circulation pump, the expansion vessel and various electronic safety and control systems. This reduces not only investment costs, but also the recurrent costs for maintenance and replacement parts.

Fig. 211 *Air preheating system APH at a boiler*

Benefits at a glance

- Increased system efficiency
- Reduced fuel consumption of up to 2.5%
- Reduced emissions
- Lower investment costs compared to conventional solutions
- Low maintenance and servicing costs
- Shorter amortisation time
- Superior quality standardised system from Bosch

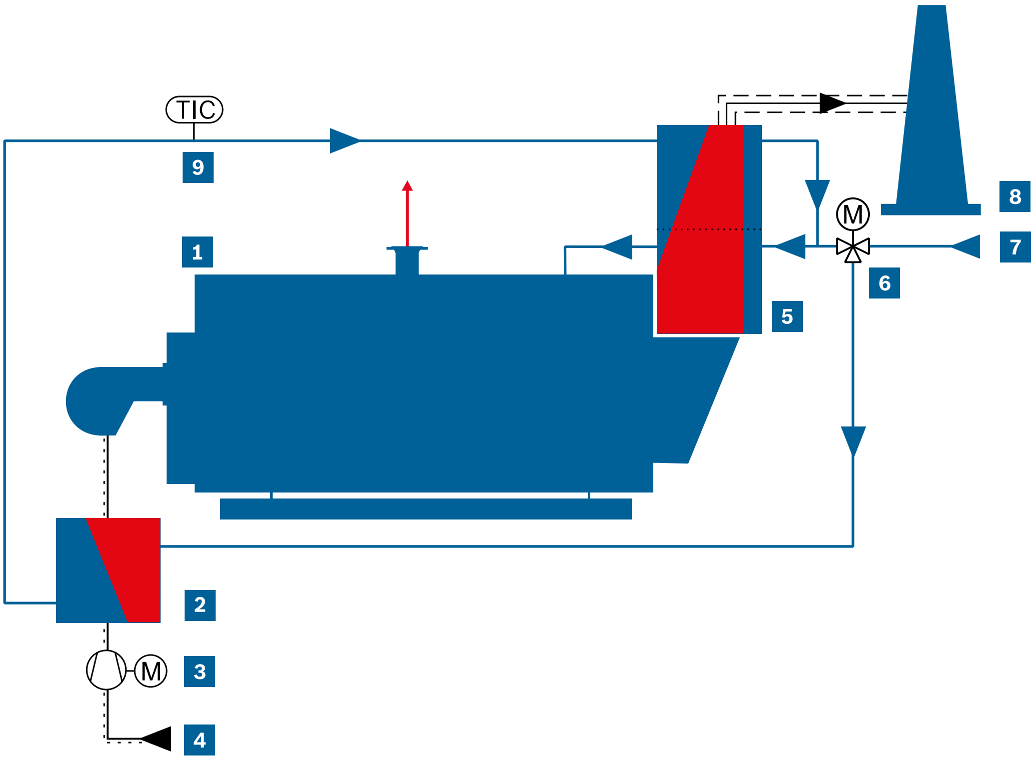


Fig. 212 *Illustration of an air preheating system at a steam boiler (highly simplified representation)*

1 Steam boiler
2 Heat exchanger, combustion air
3 Fan
4 Combustion air
5 Combined flue gas heat exchanger
6 Three-way valve
7 Feed water
8 Chimney
9 Temperature controller

4.14 Feed water cooling module FWM

The flue gas temperature is an important criterion for assessing the efficiency of a steam boiler system. Older and smaller systems have often relatively high flue gas temperatures. This is accompanied by unnecessarily high fuel costs. For systems with medium to high operating hours, using technical solutions for reducing the flue gas losses such as condensing heat exchangers or air preheating systems pay off quickly. However, the feed water cooling module is a particularly cost-effective easily retrofittable alternative for systems with lower weekly operating hours for:

- Boilers with low to medium condensate recirculation
- Systems without make-up water preheating modules
- In the case of continual hot water demand, e.g. for office buildings or industrial processes
- Boiler systems with economisers but without downstream condensing heat exchangers
- Boilers with low operating hours, e.g. production with single-shift operation
- Boilers with outputs < 10t/h

Construction

Cold make-up water is heated up in the feed water cooling module by using the warm feed water in a heat exchanger. As a result of the feed water cooling down, there is a larger temperature difference between the water and flue gas in the economiser. The improved heat transfer in the economiser reduces the flue gas discharge temperature. The firing efficiency is thus enhanced by up to 1.8%. The control of the module ensures that the temperatures and flow rates are always within the permitted range. This prevents:

- Thermal stresses caused by too cold feed water flowing into the boiler
- Corrosion caused by unwanted condensation of the flue gas when it is cooled down too much

The feed water cooling module is an effective reliable measure for reducing energy costs.

Equipment

The feed water cooling module consists of a plate heat exchanger including insulation, valves, pipework adapters and temperature sensors and is supplied on a base frame ready for connection. The module sizing and parameter settings of the control are made specifically to order and are matched to the mode of operation of the system.

Benefits at a glance

- Up to 1.8% fuel cost saving
- Easy retrofitting to older systems thanks to a small space requirement and simple piping
- Matched control for safe operation of the boiler and components
- Quick amortisation, even on systems with few operating hours
- Ready for operation with just a few connections
- Easy commissioning, maintenance and operation

Fig. 213 *Feed water cooling module FWM*

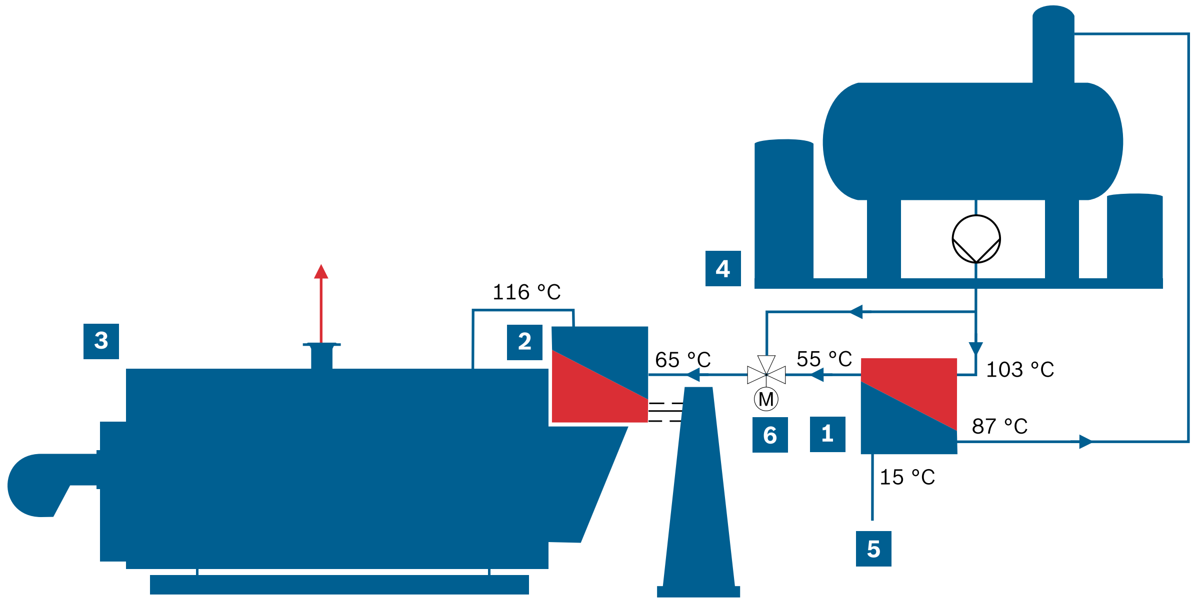


Fig. 214 *Illustration of a steam boiler system with feed water cooling module (highly simplified representation)*

- 1 Feed water cooling module
- 2 Economiser
- 3 Steam boiler
- 4 Water service module
- 5 Make-up water
- 6 Three-way valve

4.15 Water analyser WA

Smooth boiler operation is based on good water quality. The water analyser measures and monitors the following parameters continuously:

- pH value in the boiler water
- pH value, oxygen content and conductivity in the boiler feed water
- pH value and conductivity of the condensate or steam accumulator water content

All data is transferred to the system control SCO via the bus system. All relevant water parameters, together with the boiler water conductivity and conductivities of the individual condensate flows, are therefore available in the system control SCO. Demand-based control tasks can be carried out fully automatically. When defined limits are exceeded, all parameters are transferred to the fault memory of the system control SCO of the plant control. The data can also be recorded continuously. This can be transferred via the bus system to a higher-level control system for further processing.

Functions of the water analyser are:

- Stepless control of the dosing system for oxygen binder
- Stepless control of the dosing system for alkalisation
- Activation of exhaust vapour valve including display of saved exhaust vapour energy in kWh

Construction

The water analyser consists of an analysis component and an electronic component, both of which are housed in two wall-mounted casings which are interconnected at the factory.

Equipment

The analysis component contains the measuring modules:

- pH control for measuring the pH value of the boiler feed water and of the boiler water content for a maximum of three boilers
- O_2 control for measuring the O_2 content of the boiler feed water
- Conductivity sensor for measuring the conductivity value of the boiler feed water
- For sample preparation, flow coolers for
  - Boiler water and boiler feed water
  - Control valves for switching and distributing each individual medium
- Flow rate indicator for visual inspection

The electronic component consists of:

- Control unit including touch panel
- Power supply
- Electronics for the measuring modules
- Communication processors for data exchange between the water analyser WA and system control SCO

Benefits at a glance

- Increase in operational safety thanks to continuous monitoring of the water values
- Automated monitoring with constant measurement of the pH value, oxygen content and conductivity
- Savings on chemicals thanks to needs-based dosing of additives
- Increased system efficiency through reduced desalting losses and saving of exhaust vapour energy
- A water analyser can monitor up to three boilers
- All the measured values can be transmitted via Ethernet to the system control SCO or to the customer's automation system, where they can be fully visualised

Fig. 215 *Water analyser WA*


BOSCH

5 Boiler supply modules

You can configure the operation of steam boilers according to your needs with our ready-to-install boiler supply modules. At the same time, our technology enables you to optimise your system control and to protect the system from harmful operating influences.

5.1 Water treatment module WTM

To avoid boiler scale, it is only permissible to operate boiler systems with softened feed water. In the Bosch B002 guideline on water characteristics, the permitted total hardness for different types of boilers and operational modes is limited. For softening water, raw water is filtered and make-up water is generated by means of the ion exchange process. The hardening components calcium and magnesium ions are replaced by sodium ions.

Fully automatic versions simplify operation, prevent operating errors, enable continuous operation and ensure increased utilisation of capacity when using the same raw water hardness. The module can be controlled either based on quality or volume.

Construction

On a support structure, all elements of the water softening plant are clearly and functionally arranged fully assembled. The water treatment module is suitable for all boiler sizes.

Equipment

The water treatment module consists of the water softener unit and a salt-softening container.
A drainage water connection, sampling device, pressure indicator as well as control fittings, shut-off and filter valves complete the module.

Benefits at a glance

- Constant softened feed water for preventing calcification of the boiler heating surfaces
- Good heat transfer, high efficiency and long service life of the boiler
- High level of operational safety
- Quality-controlled version allows external hardness monitoring to be dispensed with – e.g. for improved utilisation of capacity and without the need for permanent supervision of operation even in the case of varying raw water hardness

Fig. 216 *Water treatment module WTM*

5.2 Gas regulation module GRM

The module regulates the constant gas pressure upstream of the burner – in the respective pressure and flow rate area. Ensures against inadmissible excess pressure, inadmissible gas flow rate and has a gas quick acting shut-off valve.

Construction

All elements included in the scope of delivery are arranged in the necessary order and delivered fully assembled on a support structure.

Equipment

The gas regulation module includes all fittings such as filter, ball valve, shut-off valve etc., which are necessary for the gas-side fuel supply of the burner.

Benefits at a glance

- Pre-assembled for quick installation
- Exact compliance with official guidelines
- Higher operational safety

Fig. 217 *Gas regulation module GRM*

5.3 Oil circulation module OCM

The oil circulation module prepares liquid fuels and measures the throughput. As a ready to connect extraction module per burner for easy installation in ring lines with an upstream pressure of at least 1.5 bar. The two-chamber oil collector vessel is designed for light and heavy fuel oil pressure atomising burners with a spill back atomiser system and leckage oil monitoring.

Construction

The oil circulation module is combined into a fully assembled compact unit on a carrier plate and is delivered with a protective cover.

Equipment

The module includes a two-chamber collector vessel, a filter valve, the oil quantity indicator, a shut-off valve, pressure safeguard valve, vent shut-off valve and two drain plugs. For heavy fuel oil operation there is also a heater cartridge for the filter and vessel.

Benefits at a glance

- Pre-assembled for quick installation
- Reliable recording of the oil throughput

Fig. 218 *Oil circulation module OCM*

5.4 Oil supply module OSM

The oil supply module is used for pumping and filtering liquid fuels in ring lines for supplying one or more burners.

Construction

It is pre-assembled in an oil collection tray as a single or double station with all fittings for easy installation in the ring line and leckage oil monitoring.

Equipment

Double stations enable filter cleaning without interruption of operations and offer 100% reserve. The heavy fuel oil pump module is fitted with electric or combination heating for steam or hot water.

Benefits at a glance

- Can be used for all Bosch boiler systems with oil firing and ring line supply
- Pre-assembled for quick installation

Fig. 219 *Oil supply module OSM*

5.5 Oil pressure regulation module ORM

Pressure controlling device for maintaining the pressure in the oil ring line.

Construction

The oil pressure regulation module consists of a controller, including connection parts such as manometer, manometer valve and a bypass valve.

Benefits at a glance

- Pre-assembled for quick installation
- Higher operational safety

Fig. 220 *Oil pressure regulation module ORM*

5.6 Oil preheater module OPM

The oil preheater module preheats the pumpable heavy fuel oil to the atomiser temperature of the respective burner.

Construction

A cylindrical heat exchanger is combined into a compact unit assembled with fittings and delivered on a stable support structure.

Equipment

The heat exchanger with an extendible tube bundle can optionally be fitted with steam or steam/electrical heating. The module, including the heating control, thermal insulation and all fittings, is pre-assembled ready to connect.

Fig. 221 *Oil preheater module OPM*

Benefits at a glance

- Can be used for all Bosch boiler systems with oil firing and ring line supply
- Higher operational safety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6 System controls

6.1 Boiler control BCO

The intuitive PLC-based boiler control offers outstanding operating data transparency for optimum boiler operation.

Fig. 222 *Home screen of boiler control BCO for steam boiler systems*

The boiler control BCO provides all necessary functions for optimum operation of steam and hot water boilers according to specialised requirements. Extensive information regarding operating states, operating data and measured values can be viewed on its touch screen display. Various system data are analysed, evaluated and transparently displayed via a traffic-light model using the integrated Condition Monitoring software. Operating characteristics that could lead to a drop in efficiency, increased wear or unplanned stoppages can be determined at an early stage and, in many cases, avoided. This ensures the boiler system operates at a consistently high level of efficiency and availability. The diagnostics function, which is included as standard, supports the boiler operating company or the service technician in quickly localising and rectifying irregularities in operation. This further increases transparency and operating safety.

The automatic start-up, standby and shutdown control SUC for high-pressure steam boilers is available as an optional function of the boiler control BCO. When SUC is used, start-up and shutdown processes are performed fully automatically, at the press of a button or in response to an external request signal. Integrated automatic functions protect the system against unnecessary stress during cold starts, in heat maintenance mode and in normal operation.

Standard equipment

- 9, 12, 15 or 19-inch touch screen display
- Output regulation
- Level control
- Low-load control
- Condition and efficiency monitoring

- Operating hours counter for boilers, pumps and burners
- Diagnostics function
- Register of the number of burner starts
- Plain text display of operating and fault messages
- Message history
- Display and intermediate storage of all measured values and states relevant to operation
- For steam boiler systems: surface blowdown control and automatic bottom blowdown

In addition to the output regulation, level, water quality, bottom blowdown and safety chain control functions that feature as standard in every modern steam boiler, the boiler control BCO can also be extended to include the following additional options and functions:

- Automatic starting from cold
- Measurement and control of flue gas temperature for boiler with economiser
- Measurement and control of superheated steam temperature for boilers with super heater
- Measurement of steam, feed water and fuel flow rates
- Automatic feed pump changeover via pressure, time or fault
- Time-controlled heat maintenance mode with pressure reduction
- Display of operating hours, start frequency, number of cold starts over time
- Detection of unfavourable start-up conditions
- Detection of soiling on the water and flue gas side or unwanted condensation
- Generation of service reports according to requirements
- Display of energy losses as a result of bottom blowdown and surface blowdown
- Display of fuel and water consumption over time
- Display of steam removal rate over time
- Display of boiler load profile over time
- Interfacing with higher-level control systems
- Remote maintenance via MEC Remote
- Interfacing with a central automation system

Benefits at a glance

- Intuitive operation through the use of graphic symbols on touchscreen displays
- Simple optimisation of all measurement and control functions
- Integrated monitoring and protective functions ensure outstanding supply and operational reliability
- Easy connection to higher-level visualisation and control systems
- Optional remote access using MEC Remote: visualisation of user interface
- Condition Monitoring for consistently high system efficiency and availability of boiler systems
- Fully automatic high-pressure steam boiler operation with the start-up, standby and shutdown control SUC

6.2 Compact steam boiler control CSC

Fig. 223 *CSC control for installation on boiler or as wall-mounted control switchgear cabinet*

The control for the smaller steam output range of up to 4,000kg/h is a convincing product due to the ease of handling and is supplied ex works with all the important functions for semi-automatic boiler operation.

Overview

The compact programmable control CSC is the ideal solution for steam boilers with steam outputs up to 4,000kg/h. It comes with all the important standard functions for convenient control and operation. While the boiler control BCO is tailored for more complex systems, the CSC is an affordable alternative for small capacity single steam boilers.

Construction

The programmable logic control is equipped with an intuitive touch display. It is integrated into a boiler control cabinet and permanently mounted on the boiler complete with wiring to the sensors, actuators and burner. Wall-mounted installation of the control cabinet is available as an option.

Equipment standard functions

- Low water and high water level indicator
- Pressure limiter for maximum excess pressure
- Water level control, 2-step or stepless
- Boil-dry protection device for feed pump
- Output regulation, 2-step or stepless
- Alarm and fault messages with message memory

In addition to the standard functions, the CSC can be extended to include additional functions, such as conductivity control or automatic bottom blowdown.

Benefits at a glance

- Attractive price-performance ratio for steam boilers with steam outputs of up to 4,000kg/h
- Colour touch display for easy operation and clear visualisation of operating conditions
- Flexible installation and minimal space requirement: installed on the boiler in the factory or supplied as wall-mounted switchgear cabinet
- Pre-wired and function-tested at the factory
- Power electronics for fuel supply, feed water pump, bottom blowdown and surface blowdown
- Ideal water conditions due to fully automatic conductivity-controlled surface blowdown and bottom blowdown

6.3 System control SCO

Fig. 224 *Home screen of system control SCO*

The SCO combines the controls of steam boilers and/or hot water boilers as well as individual module controls into a higher-level management system and opens up a wide range of new possibilities.
The individual boiler controls BCO, any additional controls and the SCO communicate via a high-performance bus system. This dispenses with the need for complex wiring work and isolation of signals.
The connection to higher-level visualisation and control systems can be established via various protocols, e.g. Modbus or BACnet.

Construction

High-performance programmable logic control with operator interface as TFT colour display with touch-screen.

Equipment

- Sequence control of multi-boiler systems
- Integration of water analyses
- Integration of deaeration and condensate systems

- Integration of the control of various components in one control cabinet
- Integration of foreign matter monitoring systems
- Integration of oil supply systems
- Extremely wide range of pressure and temperature controls
- Reserve pump control with automatic boiler sequence control (for steam)
- Integration of dosing pumps

Optional equipment

- Integrated air conditioning for tropical regions
- Stainless steel control cabinet
- External actuation using automation system

Benefits at a glance

- Easy connection to higher-level visualisation and control systems
- Integrated monitoring and safety functions to prevent maloperation
- Comprehensive storage of operating parameters and system status messages
- Optional remote access using MEC Remote: visualisation of user interface
- Intuitive operation through the use of graphic symbols on modern touchscreen displays

6.4 MEC Optimize

Fig. 225 *Efficiency and availability at a glance: MEC Optimize saves, evaluates and visualises the data of all connected system components*

MEC Optimize is an intelligent system supplied by Bosch for monitoring and optimising industrial boiler systems. MEC Optimize captures and analyses all data from the boiler system and linked system components and stores these over many years. The system clearly and precisely indicates any increase in energy consumption and evaluates the mode of operation of the system. Forecasts of component wear are also issued based on the individual operating mode, which enables improved maintenance planning and in turn increases system availability.

Handling the system documentation is made simple: all the important documents for the boiler system, such as operating instructions, are preloaded in digital form on the system.

Using the digital boiler logbook boiler attendants can enter the recorded measurement values at every test interval, and use the export function to print these for signing or separate archiving, as required.

The intelligent boiler logbook also checks all the entered data, then compares this with the manufacturer's specifications and gives action recommendations, in case there are any discrepancies.

The MEC Optimize user interface can be visualised using any standard desktop PC or tablet, also worldwide using any Internet-ready terminal device in combination with MEC Remote. This means that the persons in charge can keep tabs on energy consumption and system availability at all times.

As an option, MEC Optimize can also transfer the current system status to MEC Remote, the Bosch remote maintenance tool, as well as reporting important information via SMS or e-mail to the operator. For deeper analysis of system data, the operator interface can also be conveniently accessed through multiple security levels and visualised remotely.

Benefits at a glance

- Improved energy efficiency – identification of increased energy losses through intelligent data analysis
- Durable boiler system – automatic monitoring of the operating behaviour prevents maloperation
- Increased system availability – wear prognoses allow for optimum maintenance planning
- Greater operational safety – intelligent boiler logbook with automatic evaluation of the test data
- Historical operating data – continuous data acquisition makes system optimisation and troubleshooting easier
- Digital document storage – all important system documents are saved locally and can be retrieved at any time
- Optional remote connection via MEC Remote – sends current system status and reports important events via SMS or e-mail to the operator
- Preconfigured interfaces to process control systems by common protocols (e.g. Modbus, BACnet, OPC UA) for easy and cost-efficient connection

6.5 MEC System

Fig. 226 *MEC System for coloured clear visualisation of location and operating conditions, temperatures and performance of systems*

The overarching MEC (Master Energy Control) System for large-scale plants allows you to combine various system parts, such as boiler, combined heat and power units and storage cylinders, to form an efficient energy system that can be controlled via one intuitive operator interface. Master Energy Control combines intelligent self-diagnosis and optimisation functions with reliable remote technology. Integrated energy monitoring functions continually monitor the energy flows and costs. A range of logged data and meaningful forecasts create transparency to ensure energy-efficient operation.

Construction

- Standard web browser technology provides access via all commercially-available tablets, desktop PCs and smartphones
- Secure access, anytime, anywhere
- Solutions tailored to individual customer requirements with low engineering expenditure
- Interfaces with building services, energy management and virtual power plant systems

Equipment

- Energy efficiency monitoring to EN 50001
- Approved tool as part of an Energy Management System (BAFA, dena)
- Load-limiting and monitoring functions
- Combined heat and power unit module runtime forecast for compliance with subsidy requirements
- Operation and Condition Monitoring

Range of functions

- Coloured, clear visualisation of location and operating states, temperatures and performance of systems
- User management and concept of operation is matched to the system configuration
- Alarm and report management via e-mail and SMS
- Parameter setting via the system control panel (HMI)
- Energy and data monitoring, dashboard, search function

Benefits at a glance

- More efficient and economical operation of your systems and the overall system
- Transparency through energy and data monitoring
- Optimum control of your energy generation systems and energy distribution
- Modern and intuitively-operable user interface
- Multiprotocol-capable
- MEC System for coloured clear visualisation of location and operating conditions, temperatures and performance of systems

6.6 MEC Remote

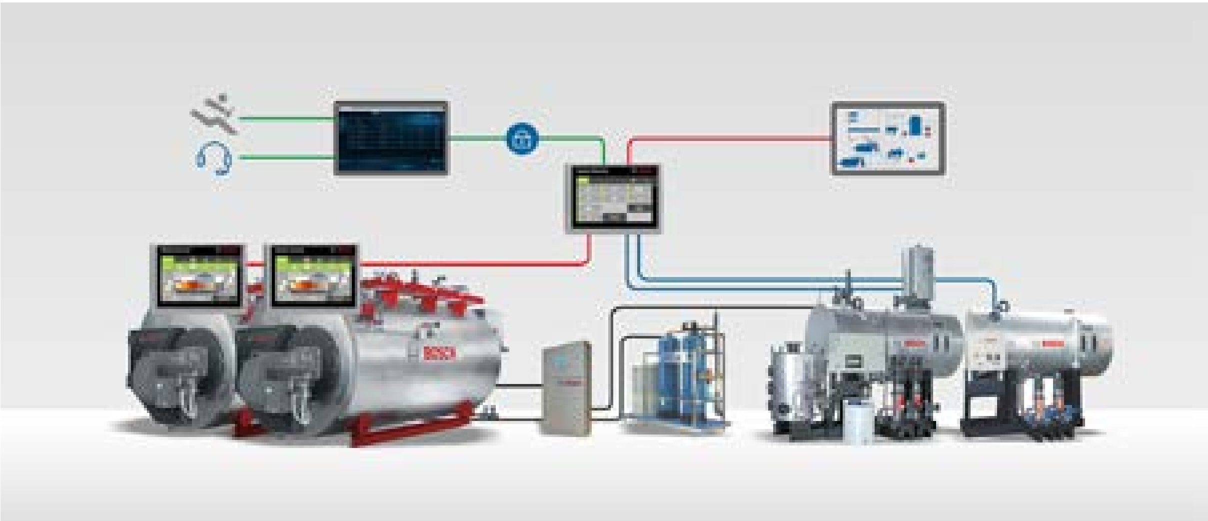


Fig. 227 *Simplified representation of data flows in a system with various controls and MEC Remote*

Using MEC Remote, operators can now gain remote access to their hot water and steam boiler systems conveniently and securely. This means the entire boiler and system control can be visualised using standard Internet-enabled devices.

MEC Remote is therefore the ideal solution for operations:

- in which the overseeing personnel cannot be continuously in attendance
- with multi-boiler systems that are subject to mandatory supervision
- with standby service at the weekends

Bosch boiler controls are compatible with commercially available process control systems. MEC Remote can also be used with systems without process control interface.

Thanks to a general map several systems around the world can also be monitored at the same time. If required, the operator can also be automatically notified via SMS or e-mail about abnormalities and faults. This significantly reduces the monitoring required for systems with high reliability requirements, such as those in constant operation.

A further benefit for operators is the optional remote support which is available from Bosch Industrial Service. The Bosch experts can perform advanced parameter settings, programming (PLC) and troubleshooting directly via the remote maintenance system. When components fail, the service experts can analyse and narrow down the cause remotely and ensure they arrive with the appropriate equipment. This keeps boiler downtimes and service costs to a minimum.

One of the most important requirements for the remote connection is maximum security. This is ensured by the ingenious role concept which controls the access rights and authorised control interventions. The remote access itself has a multi-level security concept. The external data connection can be enabled or disabled in the boiler house on the hardware side via a key. In addition to logging in with user name and password via encrypted data transfer (https), a mobile TAN procedure is used. As is the case with online banking, the access data is sent on the operator’s mobile phone. Instead of being stored in a Cloud, the operating data of the industrial boilers is stored locally on the system. The security concepts for MEC Remote were devised by ESCRYPT GmbH. A regular security audit is performed by Cirosec GmbH.

Benefits at a glance

- Access to operating data, any time, anywhere
- Boiler systems and combined heat and power plants at all locations on one overview screen
- Quick, convenient and cost-effective monitoring of system data
- Secure transmission thanks to a multi-level security concept
- Optional remote support from Bosch Industrial Service
- Notifications via SMS or e-mail for defined events, if required

Tools

1 Symbols

1.1 Physical symbols

Fundamental physical variables

Symbol	Designation	Unit
n	Quantity	
l	Length	mm; m
r	Radius	mm
d	Diameter	mm
s	Wall thickness	mm
u	Velocity	m/s
A	Area	mm^2; m^2
V	Volume	m^3
$\dot{V}$	Volume flow rate	m^3/h
$\dot{V}_n$	Standard volume flow rate	m_n^3/h
m	Mass	kg; t
$\dot{m}$	Mass flow rate	kg/h; t/h
Q	Heat quantity	kJ; kWh; MJ; MWh
$\dot{Q}$	Heat flow rate	kW; MW
t	Time	s; h; a
T	Temperature	K; °C
p	Excess pressure	Pa; mbar; bar
p_{abs}	Absolute pressure	bara
ρ	Density	kg/m^3
ρ_n	Standard density	kg/m_n^3
h	Specific enthalpy	kJ/kg
r	Specific evaporation enthalpy	kJ/kg
c_p	Specific heat capacity	kJ/kgK

Tab. 35 *Fundamental physical variables*

Combustion

Symbol	Designation	Unit
H_i	Net calorific value	kWh/kg; kWh/m_n^3
H_s	Gross calorific value	kWh/kg; kWh/m_n^3
α	Flue gas condensation ratio	kg/kg
λ	Excess air	kg/kg

Tab. 36 *Combustion*

Efficiency

Symbol	Designation	Unit
η	Efficiency	%
q_A	Flue gas loss relative to H_i	%
η_a	Annual degree of utilisation	%

Tab. 37 *Efficiency*

Heat transfer

Symbol	Designation	Unit
λ	Heat conductivity	W/mK
α	Heat transfer coefficient	$W/m^2 K$
k	Heat transition coefficient	$W/m^2 K$

Tab. 38 *Heat transfer*

Fluid mechanics

Symbol	Designation	Unit
ζ	Pressure loss coefficient	
λ	Pipe friction coefficient	

Tab. 39 *Fluid mechanics*

Other

Symbol	Designation	Unit
α	Coefficient of thermal expansion	mm/(m · 100K)
L	Electrical conductivity	µS/cm

Tab. 40 *Other*

1.2 Ratios

Symbol	Designation	Unit
α	Flue gas condensate rate	kg/kg
a	Surface blowdown rate = $m_{BD}/m_{S,boi}$	kg/kg
c	Condensate accumulation rate = $m_{Co,ttl}/m_S$	kg/kg
z	Make-up water rate = m_{MW}/m_S	kg/kg
x	Mass fraction	kg/kg
y	Volume percent or mole percent	m^3/m^3

Tab. 41 *Ratios*

1.3 Operators

Symbol	Designation	Unit
Δ	Differential	
·	Flow rate	e.g.: kg/h; kg/s; ...

Tab. 42 *Operators*

1.4 Indices

General

Symbol	Designation
min	Minimum
max	Maximum
avg	Average
alw	Allowable
ttl	Total
st	Stoichiometric
abs	Absolute
n	Standard temperature and pressure (in standard condition)
b	Operation (in operating condition)
l	Loss

Tab. 43 *General*

Water/steam state

Symbol	Designation
S	Saturation (boiling state)
′	Liquid saturated, boiling water
″	Vaporous saturated, saturated steam

Tab. 44 *Water/steam state*

Location/apparatus/system part

Symbol	Designation
SV	Safety valve
PL	Pressure limiter
boi	Boiler
Sys	(Steam boiler) system
bu	(Combustion) burner
P	(Pipe)work
valve	Valves
C	Consumer
dC	Direct consumer
iC	Indirect consumer
OU	Own use
dea	Deaeration
HL	Heat loss
ES	Expansion loss/steam
HX	Heat exchanger
amb	Ambient

Tab. 45 *Location/apparatus/system part*

Media

Symbol	Designation
A	Air
FG	Flue gas
F	Fuel
MW	Make-up water
PW	Process water

Symbol	Designation
FW	Feed water
S	Steam
HS	Heat-up steam (feed water vessel)
BD	Surface blowdown
VS	Exhaust vapour
Co	Condensate
oCo	Oxygenic condensate
fCo	Oxygen-free condensate

Tab. 46 *Media*

1.5 Piping and instrumentation designations

Letter	Category	Processing function
A	Analysis	Alarm, message
B	Optical measurement (e.g. flame monitoring)	Limitation
C	–	Control
D	Density	Differential
E	Electrical voltage	– (must not be used)
F	Flow rate	Ratio
G	Distance, length, position	– (must not be used)
H	Manual entry, manual intervention	Upper limit, on, open
I	Current	Analogue display
J	Electrical output	– (must not be used)
K	Time-based function	Temporal rate of change, e.g. for acceleration or calculation of a deduction
L	Filling level	Lower limit, off, closed
M	Moisture	– (must not be used)
N	Electrical actuation (all electronic consumers, e.g. motor, heating)	– (must not be used)
O	–	Local or PCS status display of binary signals
P	Pressure	Point (test) connection
Q	Quantity or number, material characteristics*, quality factors*, analysis* (apart from D, M, V)	Integral, quantity or sum

Letter	Category	Processing function
R	Radiation variables	Value recorded
S	Speed or frequency (including acceleration)	Binary control function or switching function (not safety relevant)
T	Temperature	– (must not be used)
U	–	– (must not be used)
V	Vibration, mechanical analysis, torque	– (must not be used)
W	Weight, mass, force	– (must not be used)
X	– (for meanings not listed)	– (for meanings not listed)
Y	Hydraulic or pneumatic actuation (switching, change, restriction by servovalve for example)	Computing function
Z	–	Binary control function or switching function (safety relevant)

Tab. 47 *Piping and instrumentation designations*

The code letters for EMC technology according to EN 62424:2014-05 are used.
* the meaning for Q is taken from the predecessor DIN 19227-1 1993-10.

Example of application of nomenclature to steam boiler equipment:

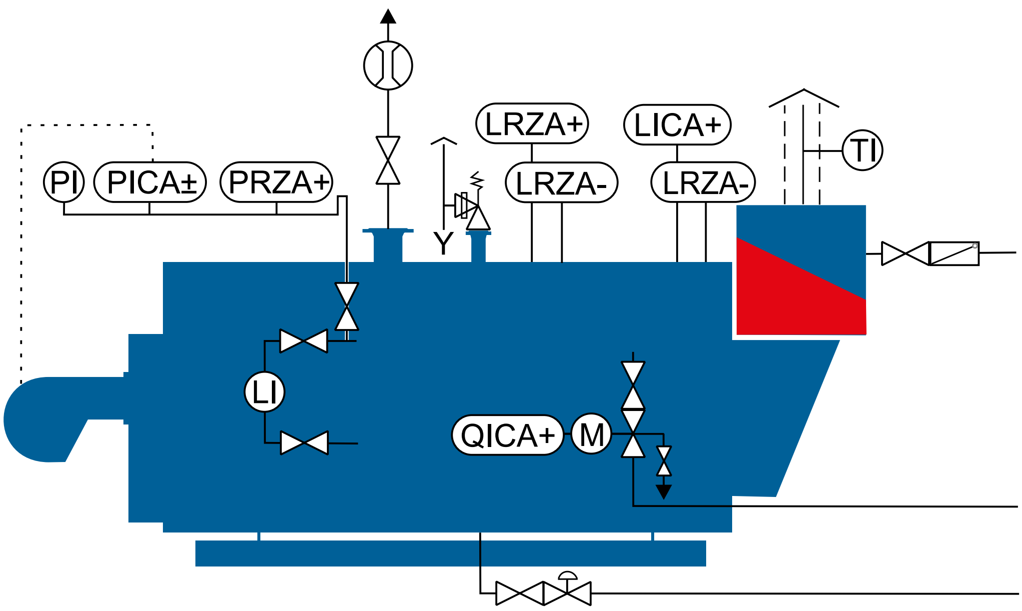
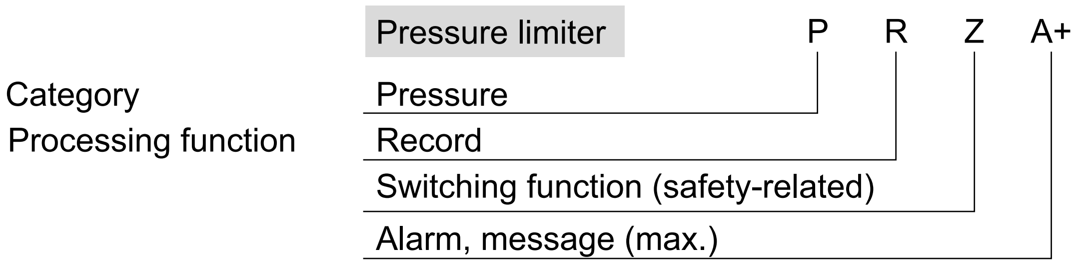
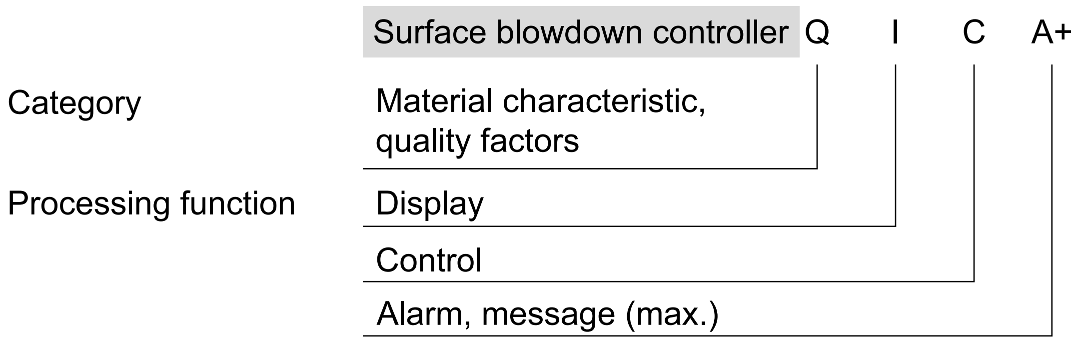


Fig. 228 *Equipment of a steam boiler*

Example 1:



Example 2:



2 Conversion

2.1 Decimal powers

Prefix	Power	Abbreviation	
Exa	10^{18}	E	x 1 000 000 000 000 000 000
Peta	10^{15}	P	x 1 000 000 000 000 000
Tera	10^{12}	T	x 1 000 000 000 000
Giga	10^{9}	G	x 1 000 000 000
Mega	10^{6}	M	x 1,000 000
Kilo	10^{3}	k	x 1,000
Hecto	10^{2}	h	x 100
Deca	10^{1}	da	x 10
Deci	10^{-1}	d	/ 10
Centi	10^{-2}	c	/ 100
Milli	10^{-3}	m	/ 1 000
Micro	10^{-6}	µ	/ 1,000 000
Nano	10^{-9}	n	/ 1,000 000 000
Pico	10^{-12}	p	/ 1,000 000 000 000
Femto	10^{-15}	f	/ 1 000 000 000 000 000
Atto	10^{-18}	a	/ 1 000 000 000 000 000 000

Tab. 48 *Decimal powers*

2.2 Mass

Conversion table, mass

From \ To	kg	t	lb
kg 1		0.001	2.20462
t 1	1,000		2,204.62
lb 15	6.8038936	0.0068038	

Tab. 49 *Conversion table, mass*

2.3 Lengths, areas and volumes

Conversion table, lengths

From \ To	m	in	ft	yd
m 1		39.370079	3.2808399	1.0936133
in 1	0.0253999		0.0833333	0.0277777
ft 1	0.3047999	12		0.3333333
yd 1	0.9143999	36	3	

Tab. 50 *Conversion table, lengths*

Conversion table, areas

From \ To	m^2	in^2	ft^2	yd^2
m^2 1		1,550.0031	10.763910	1.1959900
in^2 1	0.0006451		0.0069444	0.0007716
ft^2 1	0.0929030	144		0.1111111
yd^2 1	0.8361273	1,296	9	

Tab. 51 *Conversion table, areas*

Conversion table, volumes

From \ To	m^3	in^3	ft^3	yd^3
m^3 1		61,023.745	35.314666	1.3079506
in^3 1	$1.638 \cdot 10^{-5}$		0.0005787	$2.143 \cdot 10^{-5}$
ft^3 1	0.0283168	1,728		0.0370370
yd^3 1	0.7645548	46,656	27	

Tab. 52 *Conversion table, volumes*

Conversion factors

Length = Conversion factor x
Area = Conversion factor x^2
Volume = Conversion factor x^3

2.4 Pressure

Conversion table, pressure

From \ To		bar	atm	m WS	m Hg	psi	kgf/cm²
bar	1		0.986923	10.1972	0.7502	14.503769	1.0194
atm	1	1.0132502		10.332315	0.7601403	14.695948	1.0329073
m WS	1	0.0980661	0.0967837		0.0735692	1.4223286	0.0999686
m Hg	1	1.3329778	1.3155465	13.592641		19.333204	1.3588376
psi	1	0.0689475	0.0680459	0.7030723	0.0517244		0.0702851
kgf/cm²	1	0.9809691	0.9681410	10.003139	0.7359230	14.227751	

Tab. 53 *Conversion table, pressure*

Correlation of derived SI units:

bar = 1,000mbar = 10^5 Pa (N/mm²)

i

2.5 Temperature

Conversion table, temperature

From \ To		K	°C	°F
K	300		26.850000	80.330000
°C	1	274.15		33.8
°F	1	255.92777	-17.22222	

Tab. 54 *Conversion table, temperature*

2.6 Energy

Conversion table, energy

From \ To		kJ	kWh	kcal	PSh	BTU	t SKE
kJ	1		0.0002777	0.23901	0.0003774	0.94787	$3.412 \cdot 10^{-8}$
kWh	1	3,600		860.436	1.35864	3,412.332	0.0001228
kcal	1	4.1839253	0.0011622		0.0015790	3.9658173	$1.427 \cdot 10^{-7}$
PSh	1	2,649.7085	0.7360301	633.30683		2,511.5792	$9.040 \cdot 10^{-5}$
BTU	1	1.0549969	0.0002930	0.2521548	0.0003981		$3.599 \cdot 10^{-8}$
t SKE	1	$2.930 \cdot 10^{7}$	8,141.2009	$7.004 \cdot 10^{6}$	11,060.961	$2.778 \cdot 10^{7}$	

Tab. 55 *Conversion table, energy*

3 Fuels

3.1 Fuel characteristics

3.1.1 Gaseous fuels

Excess air	λ	x =	1.20	Input / Result
Standard density, air	$\rho_{n,A}$ [kg/$m^3_{n,A}$]		1.293	

Material value		Unit	Natural gas L	Natural gas H	Propane	Propane Butane	Butane	Natural gas GZ35	Natural gas GZ41.5	Natural gas GZ50
Net calorific value	H_i	$\frac{kWh}{kg_F}$	10.65	13.20	12.87	12.83	12.70	7.98	9.65	10.86
	H_i	$\frac{kWh}{m^3_{n,F}}$	8.83	10.35	25.89	27.96	34.39	7	8	9
Gross calorific value	H_S	$\frac{kWh}{kg_F}$	11.80	14.62	13.98	13.92	13.75	8.86	10.80	12.01
	H_S	$\frac{kWh}{m^3_{n,F}}$	9.78	11.46	28.12	30.34	37.23	7.77	8.95	9.95
Fuel standard density	$\rho_{n,F}$	$\frac{kg}{m^3_{n,F}}$	0.829	0.784	2.011	2.18	2.708	0.877	0.829	0.829
Stoichio-metric air demand	L_{ST}	$\frac{kg_A}{kg_F}$	13.10	16.24	15.57	15.51	15.36	9.84	13.10	13.10
Standard density, flue gas	$\rho_{n,FG,st}$ (λ=1)	$\frac{kg}{m^3_{n,FG}}$	1.2366	1.2374	1.2650	1.2664	1.2699	1.2346	1.2366	1.2366
Standard density, flue gas	$\rho_{n,FG}$ (λ=x)	$\frac{kg}{m^3_{n,FG}}$	1.2451	1.2459	1.2693	1.2706	1.2735	1.2432	1.2451	1.2451
Wobbe index	W_i	$\frac{kWh}{m^3}$	11.03	13.29	20.76	21.53	23.76	8.50	9.99	11.24
Dew point	t_{Co}	°C	56.9	57.0	53.1	52.9	52.4	56.7	56.9	56.9
Water genera-tion[1]	$w_{spec,H2O}$	$\frac{g_{H2O}}{kWh}$	159.4	158.5	126.9	125.4	122.0	161.8	176.0	156.4
CO_2 emis-sions[1]	$w_{spec,CO2}$	$\frac{g_{CO2}}{kWh}$	201.3	202.6	232.6	234.3	238.5	197.6	222.2	197.5
SO_2 emis-sions[1]	$w_{spec,SO2}$	$\frac{mg_{SO2}}{kWh}$	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Flue gas mass flow rate[1]	$\dot{m}_{spec}$	$\frac{kg_{FG}}{kWh}$	1.5700	1.5523	1.5291	1.5288	1.5299	1.6052	1.7329	1.5403

Tab. 56 *Gaseous fuels*

1) relative to H_i

3.1.2 Liquid fuels

Excess air	λ	x =	1.20
Standard density, air	$\rho_{n,A}$ [kg/m$^3_{n,A}$]		1.293

Input Result

Material value		Unit	Fuel oil EL	Fuel oil EL, low-sulphur	Fuel oil SA	Medium fuel oil HL Schwechat	Medium fuel oil CLU3
Net calorific value	H_i	$\frac{kWh}{kg_F}$	11.89	11.89	11.28	11.64	11.40
	H_i	$\frac{kWh}{l}$	9.91	9.91	10.98	9.70	10.59
Gross calorific value	H_S	$\frac{kWh}{kg_F}$	12.70	12.70	11.96	12.38	12.05
	H_S	$\frac{kWh}{l}$	10.59	10.59	11.64	10.32	11.19
Fuel standard density	$\rho_{n,F}$	$\frac{kg}{m^3}$	833.6	833.6	973.6	833.6	928.6
Stoichiometric air demand	L_{ST}	$\frac{kg_A}{kg_F}$	14.45	14.46	13.89	14.19	13.71
Standard density flue gas	$\rho_{n,FG,st}$ (λ=1)	$\frac{kg}{m^3_{n,FG}}$	1.2923	1.2923	1.3063	1.2996	1.3097
Standard density flue gas	$\rho_{n,FG}$ (λ=x)	$\frac{kg}{m^3_{n,FG}}$	1.2924	1.2924	1.3042	1.2985	1.3071
Dew point	t_{Co}	°C	48.6	48.6	46.0	47.2	45.4
Acid dew point	$t_{acid\ cond}$	°C	124.0	97.3	136.4	123.2	141.5
Water generation[1)]	$w_{spec,H2O}$	$\frac{g_{H2O}}{kWh}$	100.5	100.5	88.7	93.7	83.9
CO_2 emissions[1)]	$w_{spec,CO2}$	$\frac{g_{CO2}}{kWh}$	266.4	266.9	285.2	275.8	280.6
SO_2 emissions[1)]	$w_{spec,SO2}$	$\frac{mg_{SO2}}{kWh}$	108.4	2.6	597.9	99.2	1 213.8
Flue gas mass flow rate[1)]	$\dot{m}_{spec}$	$\frac{kg_{FG}}{kWh}$	1.5420	1.5434	1.5668	1.5484	1.5311

Tab. 57 *Liquid fuels*

1) relative to H_i

3.2 Dew point of flue gases

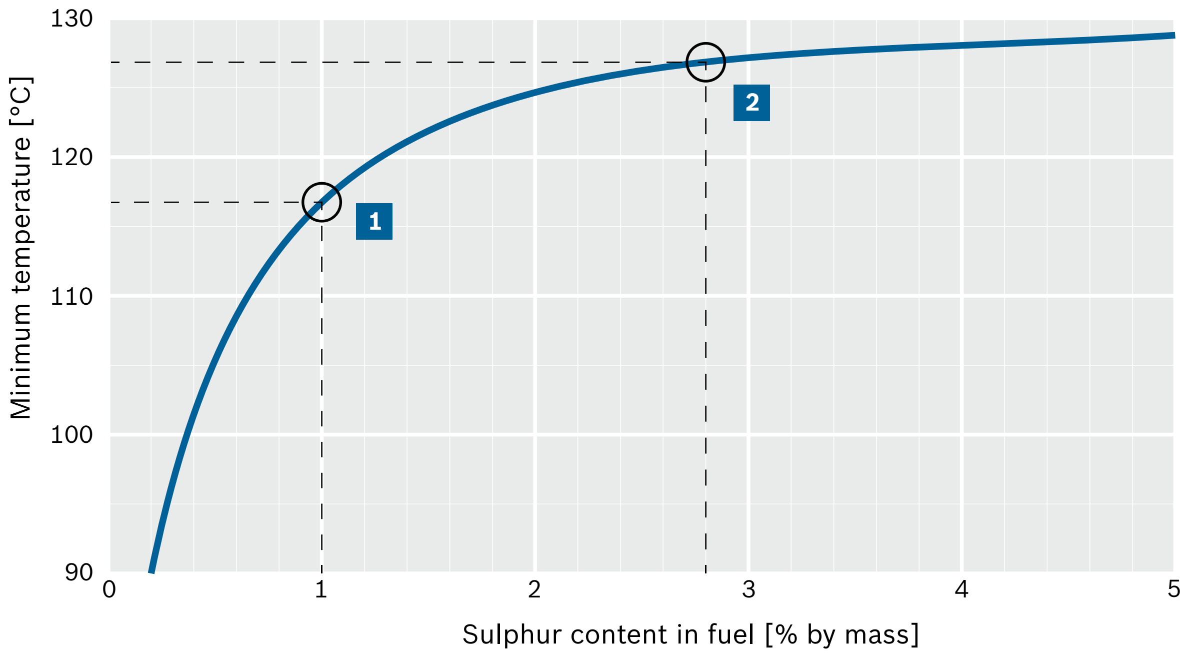


Fig. 229 *Minimum feed water temperature as a function of fuel sulphur content*

1 Fuel oil SA

2 Fuel oil S

3.3 Pinch-point diagrams, boiler system

3.3.1 Pinch-point diagram for gas

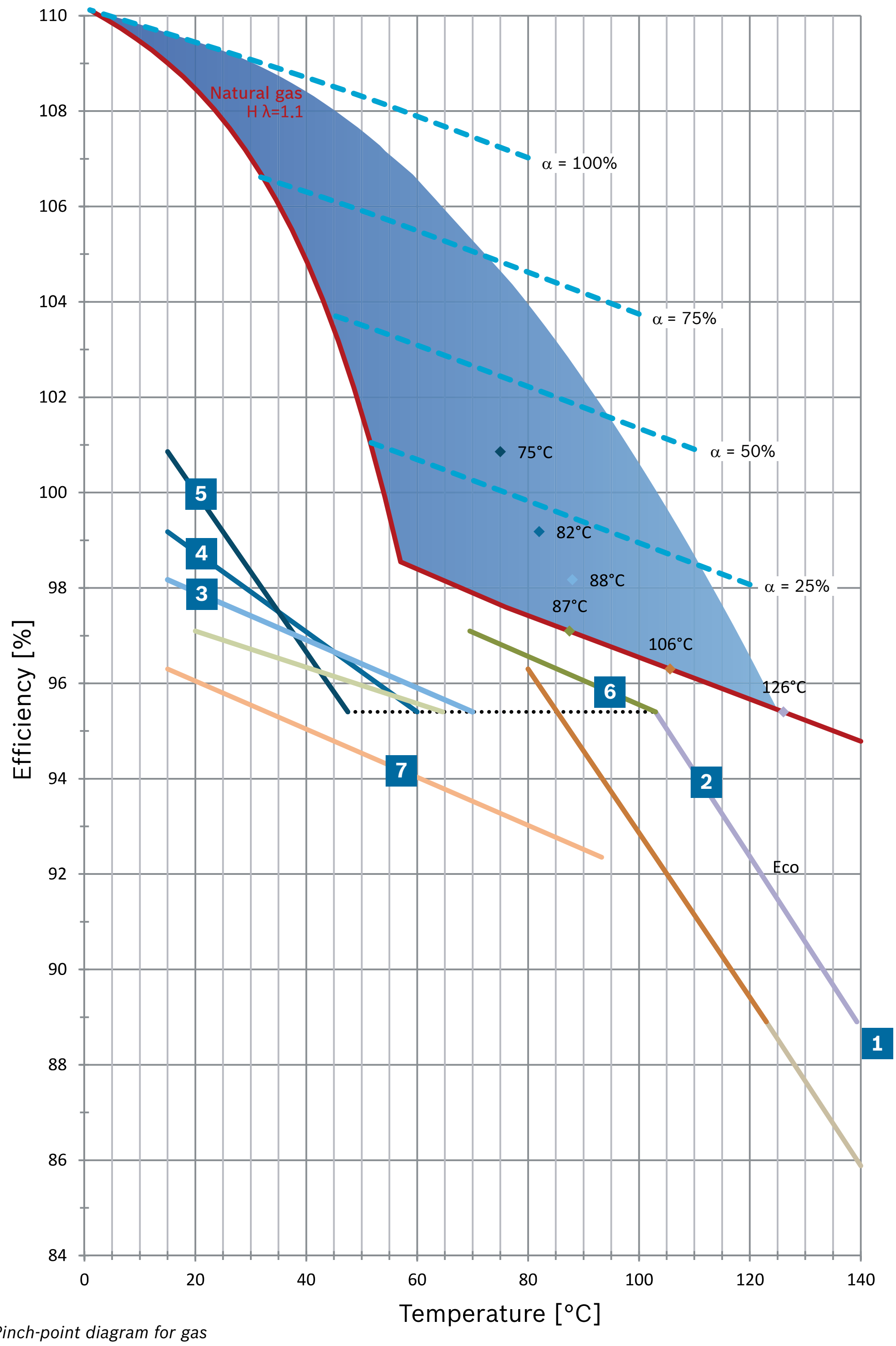


Fig. 230 *Pinch-point diagram for gas*

1 Boiler

2 Boiler + economiser

3 Boiler + economiser + condensing heat exchanger (with z = 0.3 / α = 12%)

4 Boiler + economiser + condensing heat exchanger (with z = 0.5 / α = 20%)

5 Boiler + economiser + condensing heat exchanger (with z = 1 / α = 34%)

6 Boiler + economiser + air preheating (20°C to 65°C)

7 Boiler + economiser + feed water cooling (with z = 0.3)

Example:

Condensate accumulation rate	$c = \dot{m}_{Co} / \dot{m}_S$
Make-up water rate	$z = 1 - c$
UL-S	10,000 x 16
System steam output	10,000kg/h with p_{avg} = 13 bar
Surface blowdown rate	5%

Case	Component	Efficiency	
		Component parts	Total
1	Boiler	88.9%	---
2	Boiler + economiser	88.9% + 6.5%	95.4%
3	Boiler + economiser + condensing heat exchanger (with z[1] = 0.3 / α[2] = 12%)	88.9% + 6.5% + 2.8%	98.2%
4	Boiler + economiser + condensing heat exchanger (with z = 0.5 / α = 20%)	88.9% + 6.5% + 3.8%	99.2%
5	Boiler + economiser + condensing heat exchanger (with z = 1 / α = 34%)	88.9% + 6.5% + 7.6%	100.9%
6	Boiler + economiser + air preheating (20°C to 65°C)	88.9% + 6.5% + 1.7%	97.1%
7	Boiler + economiser + feed water cooling (with z = 0.3)	88.9% + 6.5% + 0.6%	96.0%

Tab. 58 *Case studies for combinations of measures for optimum heat recovery*

[1] z = make-up water rate

[2] α = condensate accumulation rate

3.3.2 Pinch-point diagram for oil

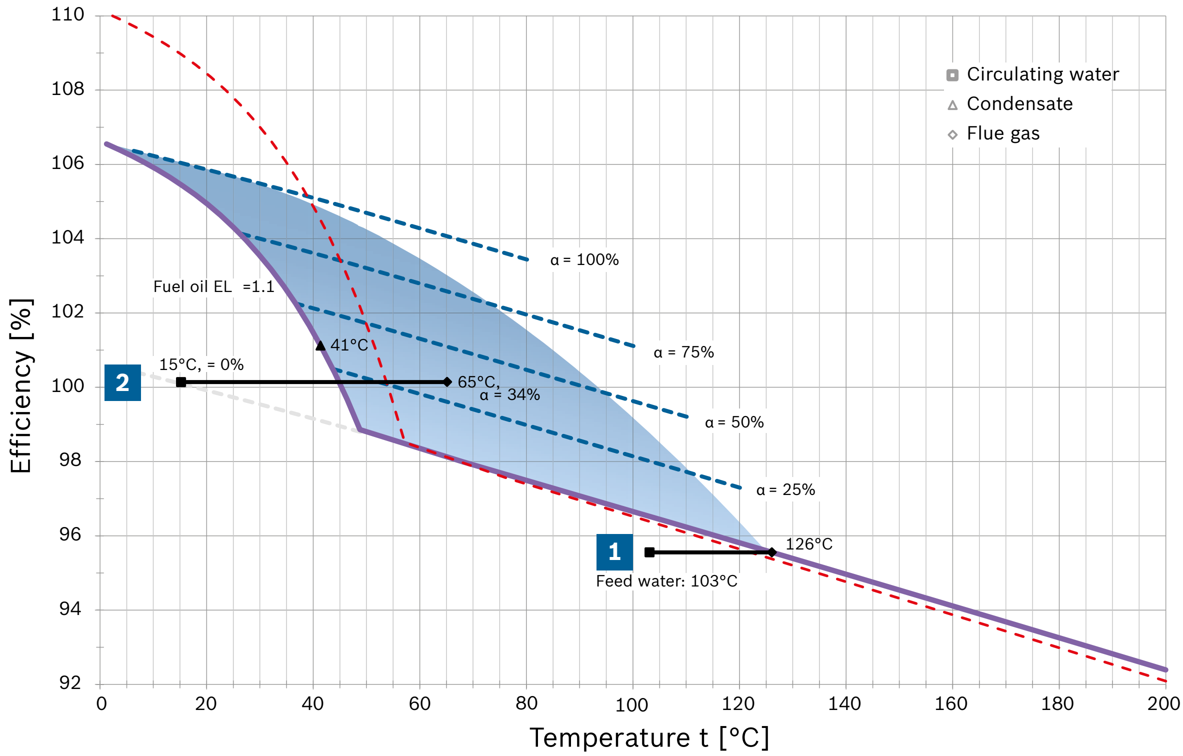


Fig. 231 *Pinch-point diagram for oil*

1	Boiler
2	Boiler + economiser

4 Basic principles of water vapour

4.1 Boiling pressure and temperature

The diagram shows the pressure-temperature curves with the boiling curve. Please also observe the notices on reading logarithmic graphs.

→ Tools – Chapter 4.3.1: Reading logarithmic graphs, page 404

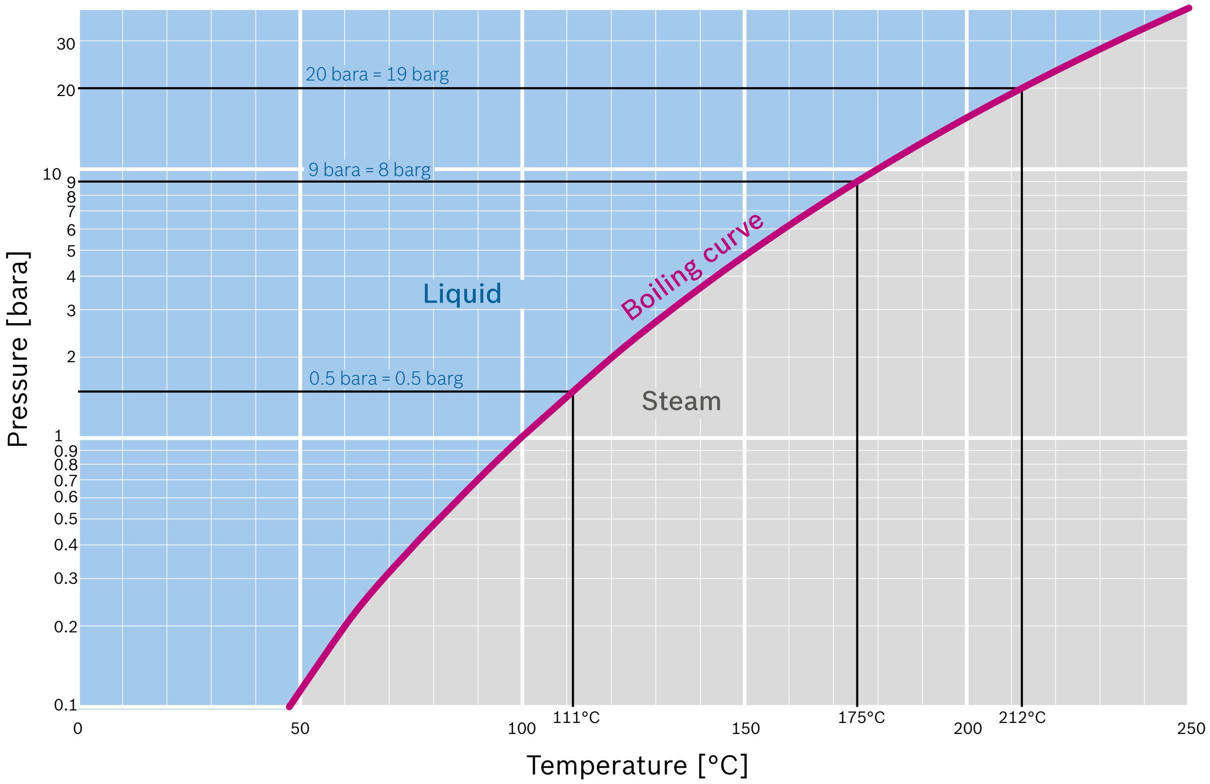


Fig. 232 *Pressure-temperature chart of water with boiling curve and areas for steam and water (logarithmic representation)*

4.2 Water vapour table

4.2.1 Physical characteristics for water and steam according to IAPWS IF-97

Positive pressure p [bar_g]	Absolute pressure p [bar_a]	Boiling temperature t [°C]	Enthalpy: Water h' [kJ/kgK]	Enthalpy: Saturated steam h'' [kJ/kgK]	Enthalpy: Evaporation r [kJ/kgK]	Density: Water ρ' [kg/m³]	Density: Saturated steam ρ'' [kg/m³]
– 0.9	0.1	45.8	191.8	2 583.9	2 392.1	989.8	0.0682
– 0.8	0.2	60.1	251.4	2 608.9	2 357.5	983.1	0.1308
– 0.7	0.3	69.1	289.2	2 624.6	2 335.3	978.3	0.1913
– 0.6	0.4	75.9	317.6	2 636.1	2 318.5	974.3	0.2504
– 0.5	0.5	81.3	340.5	2 645.2	2 304.7	971.0	0.3086
– 0.4	0.6	85.9	359.8	2 652.9	2 293.0	968.0	0.3661
– 0.3	0.7	89.9	376.7	2 659.4	2 282.7	965.4	0.4229
– 0.2	0.8	93.5	391.6	2 665.2	2 273.5	962.9	0.4791
– 0.1	0.9	96.7	405.1	2 670.3	2 265.2	960.7	0.5349
0.0	1.0	99.6	417.4	2 674.9	2 257.5	958.6	0.5903
0.1	1.1	102.3	428.8	2 679.2	2 250.4	956.7	0.6453
0.2	1.2	104.8	439.3	2 683.1	2 243.8	954.9	0.7001
0.3	1.3	107.1	449.1	2 686.6	2 237.5	953.1	0.7545
0.4	1.4	109.3	458.4	2 690.0	2 231.6	951.5	0.8086
0.5	1.5	111.4	467.1	2 693.1	2 226.0	949.9	0.8625
0.6	1.6	113.3	475.3	2 696.0	2 220.7	948.4	0.9162
0.7	1.7	115.1	483.2	2 698.8	2 215.6	947.0	0.9697
0.8	1.8	116.9	490.7	2 701.4	2 210.7	945.6	1.0230
0.9	1.9	118.6	497.8	2 703.9	2 206.1	944.2	1.0761
1.0	2.0	120.2	504.7	2 706.2	2 201.6	942.9	1.1290
1.5	2.5	127.4	535.4	2 716.5	2 181.2	937.0	1.3914
2.0	3.0	133.5	561.5	2 724.9	2 163.4	931.8	1.6507
2.5	3.5	138.9	584.3	2 732.0	2 147.7	927.1	1.9077
3.0	4.0	143.6	604.7	2 738.1	2 133.3	922.9	2.1627
3.5	4.5	147.9	623.2	2 743.4	2 120.2	919.0	2.4160
4.0	5.0	151.8	640.2	2 748.1	2 107.9	915.3	2.6681
4.5	5.5	155.5	655.9	2 752.3	2 096.5	911.8	2.9189
5.0	6.0	158.8	670.5	2 756.1	2 085.6	908.6	3.1688

Positive pressure	Absolute pressure	Boiling temperature	Enthalpy			Density	
			Water	Saturated steam	Evaporation	Water	Saturated steam
p [bar_g]	p [bar_a]	t [°C]	h' [kJ/kgK]	h'' [kJ/kgK]	r [kJ/kgK]	ρ' [kg/m³]	ρ'' [kg/m³]
6.0	7.0	165.0	697.1	2 762.7	2 065.6	902.6	3.6662
7.0	8.0	170.4	721.0	2 768.3	2 047.3	897.0	4.1610
8.0	9.0	175.4	742.7	2 773.0	2 030.3	891.9	4.6539
9.0	10.0	179.9	762.7	2 777.1	2 014.4	887.1	5.1454
10.0	11.0	184.1	781.2	2 780.7	1 999.5	882.6	5.6358
11.0	12.0	188.0	798.5	2 783.8	1 985.3	878.3	6.1256
12.0	13.0	191.6	814.8	2 786.5	1 971.7	874.3	6.6149
13.0	14.0	195.0	830.1	2 788.9	1 958.8	870.4	7.1039
14.0	15.0	198.3	844.7	2 791.0	1 946.3	866.6	7.5929
15.0	16.0	201.4	858.6	2 792.9	1 934.3	863.1	8.0820
16.0	17.0	204.3	871.9	2 794.5	1 922.6	859.6	8.5713
17.0	18.0	207.1	884.6	2 796.0	1 911.4	856.2	9.0611
18.0	19.0	209.8	896.8	2 797.3	1 900.4	853.0	9.5513
19.0	20.0	212.4	908.6	2 798.4	1 889.8	849.8	10.0421
20.0	21.0	214.9	920.0	2 799.4	1 879.4	846.7	10.5336
21.0	22.0	217.3	931.0	2 800.2	1 869.2	843.7	11.0259
22.0	23.0	219.6	941.6	2 800.9	1 859.3	840.8	11.5191
23.0	24.0	221.8	952.0	2 801.5	1 849.6	837.9	12.0132
24.0	25.0	224.0	962.0	2 802.0	1 840.1	835.1	12.5082
25.0	26.0	226.1	971.7	2 802.5	1 830.7	832.4	13.0044
26.0	27.0	228.1	981.2	2 802.8	1 821.5	829.7	13.5016
27.0	28.0	230.1	990.5	2 803.0	1 812.5	827.0	14.0000
28.0	29.0	232.0	999.5	2 803.2	1 803.6	824.4	14.4997
29.0	30.0	233.9	1 008.4	2 803.3	1 794.9	821.9	15.0006
30.0	31.0	235.7	1 017.0	2 803.3	1 786.3	819.4	15.5028
31.0	32.0	237.5	1 025.5	2 803.2	1 777.8	816.9	16.0064
32.0	33.0	239.2	1 033.7	2 803.1	1 769.4	814.5	16.5115
33.0	34.0	240.9	1 041.8	2 803.0	1 761.1	812.1	17.0180
34.0	35.0	242.6	1 049.8	2 802.7	1 753.0	809.7	17.5260

Tab. 59 *Physical characteristics for water and steam according to IAPWS IF-97*[1)]

1) Source: http://www.iapws.org/relguide/IF97-rev.pdf

Positive pressure	Boiling point	Dynamic viscosity		Heat conductivity	
		Water	Saturated steam	Water	Saturated steam
p [bar_g]	t [°C]	η' [μPas]	η'' [μPas]	λ' [W/mK]	λ'' [W/mK]
– 0.9	45.8	587.5	10.49	0.6357	0.0199
– 0.8	60.1	465.9	10.94	0.6508	0.0211
– 0.7	69.1	408.9	11.23	0.6588	0.0219
– 0.6	75.9	373.5	11.45	0.6641	0.0225
– 0.5	81.3	348.6	11.64	0.6678	0.0230
– 0.4	85.9	329.7	11.79	0.6707	0.0234
– 0.3	89.9	314.7	11.93	0.6730	0.0238
– 0.2	93.5	302.3	12.05	0.6748	0.0241
– 0.1	96.7	291.9	12.16	0.6763	0.0245
0.0	99.6	282.9	12.26	0.6776	0.0248
0.1	102.3	275.1	12.35	0.6787	0.0250
0.2	104.8	268.2	12.43	0.6796	0.0253
0.3	107.1	262.0	12.51	0.6804	0.0255
0.4	109.3	256.4	12.59	0.6811	0.0258
0.5	111.4	251.4	12.66	0.6817	0.0260
0.6	113.3	246.8	12.73	0.6822	0.0262
0.7	115.1	242.5	12.79	0.6826	0.0264
0.8	116.9	238.6	12.85	0.6830	0.0266
0.9	118.6	235.0	12.91	0.6834	0.0268
1.0	120.2	231.6	12.96	0.6836	0.0270
1.5	127.4	217.5	13.21	0.6846	0.0278
2.0	133.5	206.8	13.42	0.6849	0.0286
2.5	138.9	198.3	13.61	0.6849	0.0293
3.0	143.6	191.2	13.77	0.6846	0.0299
3.5	147.9	185.2	13.92	0.6842	0.0305
4.0	151.8	180.1	14.05	0.6836	0.0310
4.5	155.5	175.5	14.18	0.6829	0.0316
5.0	158.8	171.6	14.30	0.6821	0.0320
6.0	165.0	164.7	14.51	0.6804	0.0330
7.0	170.4	159.1	14.70	0.6786	0.0338
8.0	175.4	154.3	14.87	0.6766	0.0346

Positive pressure	Boiling point	Dynamic viscosity		Heat conductivity	
		Water	Saturated steam	Water	Saturated steam
p [bar_g]	t [°C]	η' [μPas]	η'' [μPas]	λ' [W/mK]	λ'' [W/mK]
9.0	179.9	150.2	15.02	0.6747	0.0354
10.0	184.1	146.6	15.17	0.6726	0.0361
11.0	188.0	143.4	15.30	0.6706	0.0368
12.0	191.6	140.5	15.43	0.6686	0.0375
13.0	195.0	137.9	15.54	0.6665	0.0381
14.0	198.3	135.5	15.66	0.6645	0.0388
15.0	201.4	133.3	15.76	0.6625	0.0394
16.0	204.3	131.3	15.86	0.6604	0.0400
17.0	207.1	129.5	15.96	0.6584	0.0405
18.0	209.8	127.7	16.05	0.6564	0.0411
19.0	212.4	126.1	16.14	0.6544	0.0416
20.0	214.9	124.6	16.23	0.6525	0.0422
21.0	217.3	123.1	16.31	0.6505	0.0427
22.0	219.6	121.8	16.40	0.6486	0.0432
23.0	221.8	120.5	16.47	0.6466	0.0438
24.0	224.0	119.3	16.55	0.6447	0.0443
25.0	226.1	118.1	16.62	0.6428	0.0448
26.0	228.1	117.0	16.70	0.6409	0.0453
27.0	230.1	115.9	16.77	0.6390	0.0457
28.0	232.0	114.9	16.84	0.6372	0.0462
29.0	233.9	114.0	16.90	0.6353	0.0467
30.0	235.7	113.0	16.97	0.6335	0.0472
31.0	237.5	112.1	17.03	0.6316	0.0476
32.0	239.2	111.3	17.10	0.6298	0.0481
33.0	240.9	110.4	17.16	0.6280	0.0486
34.0	242.6	109.6	17.22	0.6262	0.0490

Tab. 60 *Physical characteristics for water and steam according to IAPWS IF-97[1)]*

1) Source: http://www.iapws.org/relguide/IF97-rev.pdf

4.2.2 Expansion steam

$$x = \frac{h - h'}{h'' - h'} = \frac{h - h'}{r}$$

F38. *Equation for calculating the mass fraction of expansion steam*

x	Mass fraction of expansion steam [%]
h	Enthalpy [kJ/kg]
h'	Enthalpy of the boiling water [kJ/kg]
h"	Enthalpy of the saturated steam [kJ/kg]
r	Evaporation enthalpy [kJ/kg]

$$x = \frac{919\ [\text{kJ/kg}] - 782\ \text{kJ/kg}]}{2{,}780\ [\text{kJ/kg}] - 782\ \text{kJ/kg}]} = 6.86\ \%$$

B20. *Example calculation for determining the mass fraction of expansion steam*

Pressure before expansion [barg]	Medium temperature [°C]	Enthalpy [kJ/kg]	Pressure following expansion [barg]	Medium temperature [°C]	Enthalpy, boiling water [kJ/kg]	Enthalpy, saturated steam [kJ/kg]	Expansion steam quantity [%]
20.0	215.0	918.7	10.0	184.4	781.6	2,779.6	6.86
	Medium temperature [°C]	**Enthalpy [kJ/kg]**	**Pressure following expansion [barg]**	**Medium temperature [°C]**	**Enthalpy, boiling water [kJ/kg]**	**Enthalpy, saturated steam [kJ/kg]**	**Expansion steam quantity [%]**
	165.0	696.7	0.15	103.5	433.9	2,680.2	11.70
Input	Result						

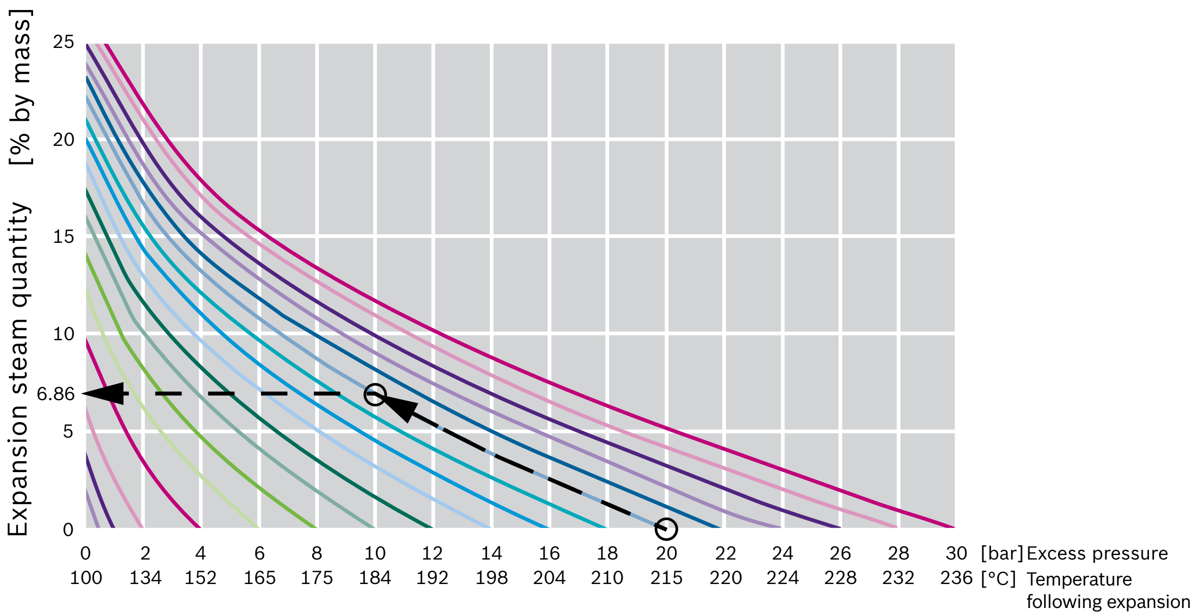


Fig. 233 *Expansion steam*

Example:

If the pressure is reduced from 20 to 10 bar, an expansion steam quantity of 6.86% is generated.

4.3 Density

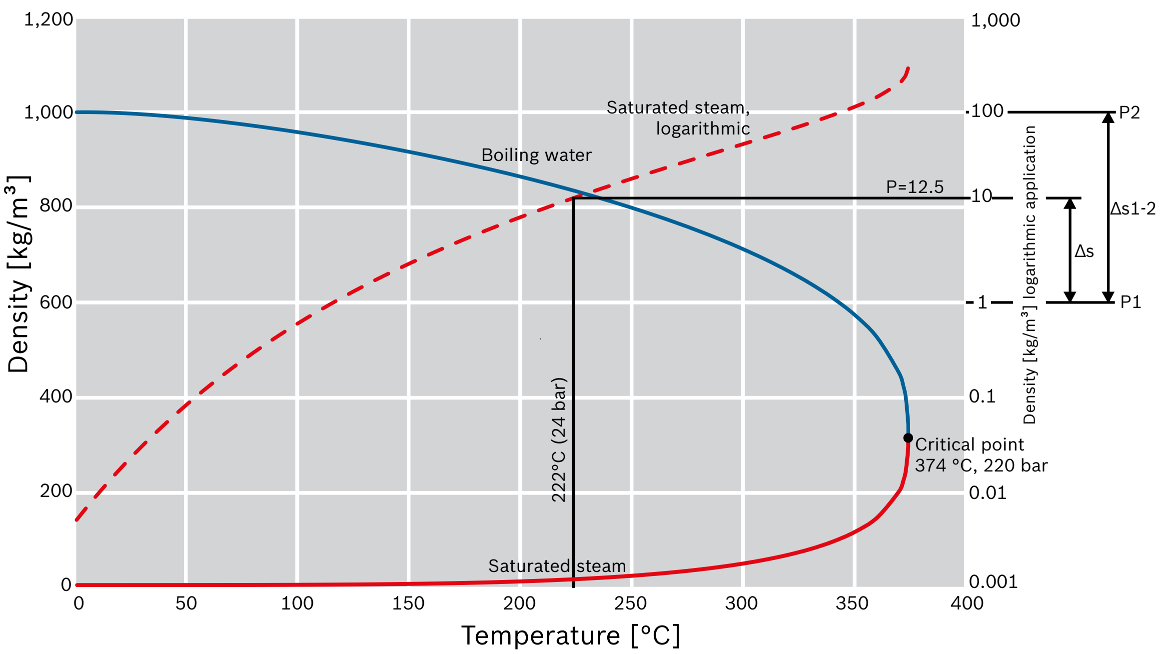


Fig. 234 *Density of saturated steam and water as a function of temperature*

Boiling water

Saturated steam

Saturated steam, logarithmic

4.3.1 Reading logarithmic graphs

Calculation of distances and numerical values

Example, saturated steam density

From value to distance in the graph			Units in the example [1]:
First point on the logarithmic scale	P1	1.0000	kg/m³
Second point on the logarithmic scale	P2	100.0000	kg/m³
Distance between the two points	Δs_{1-2}	27.100	mm
Required point	P	12.5000	kg/m³
Distance between P1 and P	Δs	14.863	mm

$$\Delta s = \frac{(\ln(P) - \ln(P_1))}{\ln\left(\frac{P_2}{P_1}\right)}$$

From the distance in the diagram to the value			
First point on the logarithmic scale	P1	1.0000	kg/m³
Second point on the logarithmic scale	P2	100.0000	kg/m³
Distance between the two points	Δs_{1-2}	27.100	mm
Required point	P	12.4721	kg/m³
Distance between P1 and P	Δs	14.850	mm

$$P = \left(\frac{P_2}{P_1}\right)^{\frac{\Delta s}{\Delta s_{1-2}}} \cdot P_1$$

1) The conversion can be applied to all logarithmic diagrams irrespective of the units

5 Steam systems

5.1 Boiler steam output and combustion output

Input Result

$\dot{Q}_{boi} \approx \dot{m}_S \cdot 0{,}65$

Steam output	10 501	Kg/h	Enthalpy, boiling water	830	kJ/kg
Average operating pressure	13.00	bar	Enthalpy, saturated steam	2,789	kJ/kg
Feed water temperature	103.0	°C	Enthalpy, feed water	432	kJ/kg

$$\dot{Q}_{boi} = \dot{m}_S \cdot (h'' - h_{FW}) \cdot \frac{1h}{3\,600s}$$

Thermal output of boiler	6,876	KW	Boiler efficiency (combustion)	92.0	%

$$\dot{Q}_{bu} = \frac{\dot{Q}_{boi}}{\eta_{bu}}$$

Combustion output	7,474	KW	Net calorific value of fuel	10.4	kWh/kg (kWh/m³n)

$$\dot{m}_F = \frac{\dot{Q}_{bu}}{H_i}$$

Fuel quantity	722.1	kg/h (m³n/h)

5.2 Surface blowdown and bottom blowdown

Input Result

Water parameters

			In the make-up water	L_{MW}	15
			Condensate accumulation rate	c	90 %
In the feed water (via water analysis)	L_{FW}	50	In the feed water	$L_{FW} \approx L_{MW} \cdot (1-c)$	1.500
Boiler water limit value	L_{boi}	2,000	Boiler water limit value	L_{boi}	2,000

$$a = \frac{L_{FW}}{L_{boi} - L_{FW}}$$

Required surface blowdown rate	2.6	%	Required surface blowdown rate	0.1	%
Required surface blowdown	269.3	Kg/h	Required surface blowdown	7.9	Kg/h
Of which 5% via bottom blowdown	13.5	Kg/h	Of which 5% via bottom blowdown	0.4	Kg/h
Absolute	59	KW	Absolute	1.7	KW
% boiler output	0.9	%	% boiler output	0.0	%

5.3 Height formula

Input Result

International height formula

Height	Pressure	Temperature	Density
300	0.97773 bar	13.05 °C	1.191 kg/m³

$$p(h) = p0 \cdot \left(1 - \frac{0.0065 \frac{K}{m} \cdot h}{T}\right)^{\frac{\kappa}{\kappa - 1}} = 1.01325\ \text{bar} \cdot \left(1 - \frac{0.0065 \frac{K}{m} \cdot h}{288.15\ K}\right)^{5.255}$$

$$T(h) = 15 - 0.0065 \frac{K}{m} \cdot h$$

$$\rho = 1.293 \frac{K}{m^3} \cdot \frac{p}{1.01325\ \text{bar}}$$

Standard density, air $\rho = 1.293 kg/m^3$ at 0°C and 1.01325 bar

With temperature conversion

Height	Pressure	Temperature	Density
300	0.97773 bar	40.00 °C	1.088 kg/m³

5.4 Pipework

5.4.1 Dimensions

Pipe wall thicknesses for welded flanges (EN 1092-1:2013-04)

valve	PN 2.5	PN 6	PN 10	PN 16	PN 25	PN 40	PN 63	PN 100
ø	Sp	Sp	Sp	Sp	Sp	Sp	Sp	Sp
17.2	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
21.3	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
26.9	2.3	2.3	2.3	2.3	2.3	2.3	2.6	2.6
33.7	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6
42.4	2.6	2.6	2.6	2.6	2.6	2.6	2.9	2.9
48.3	2.6	2.6	2.6	2.6	2.6	2.6	2.9	2.9
60.3	2.9	2.9	2.9	2.9	2.9	2.9	2.9	3.2
76.1	2.9	2.9	2.9	2.9	2.9	2.9	3.2	3.6
88.9	3.2	3.2	3.2	3.2	3.2	3.2	3.6	4.0
114.3	3.6	3.6	3.6	3.6	3.6	3.6	4.0	5.0
139.7	4.0	4.0	4.0	4.0	4.0	4.0	4.5	6.3
168.3	4.5	4.5	4.5	4.5	4.5	4.5	5.6	7.1
219.1	6.3	6.3	6.3	6.3	6.3	6.3	7.1	10.0
273.0	6.3	6.3	6.3	6.3	7.1	7.1	8.8	12.5

valve **ø**	**PN 2.5** **Sp**	**PN 6** **Sp**	**PN 10** **Sp**	**PN 16** **Sp**	**PN 25** **Sp**	**PN 40** **Sp**	**PN 63** **Sp**	**PN 100** **Sp**
323.9	7.1	7.1	7.1	7.1	8.0	8.0	11.0	14.2
355.6	7.1	7.1	7.1	8.0	8.0	8.8	12.5	16.0
406.4	7.1	7.1	7.1	8.0	8.8	11.0	14.2	
457	7.1	7.1	7.1	8.0	8.8	12.5		
508	7.1	7.1	7.1	8.0	10.0	14.2		
610	7.1	7.1	7.1	8.8	11.0	16.0		
711	7.1	7.1	8.0	8.8	12.5			
813	7.1	7.1	8.0	10.0	14.2			
914	7.1	7.1	10.0	10.0	16.0			
1 016	7.1	7.1	10.0	10.0	17.5			
1 219	7.1	8.0	11.0	12.5				
1 422	7.1	8.0	12.5	14.2				
1 626	8.0	9.0	14.2	16.0				

Tab. 61 *Excerpt from Table A.1 in EN 1092-1:2013-0 – wall thickness for type 11*

A Ø Outer diameter
Sp Wall thickness
PN Nominal pressure stage

Excerpt from Table A.1 in EN 1092-1:2013-0

5.4.2 Pressure and temperature ratings[1)]

The pressure and temperature ratings of flanges is based on the material groups.
The following materials and groups are customary in the area of steam boilers:

Material group	Description	Material number
3E0	Unalloyed steels with guaranteed strength characteristics at higher temperatures	1.0352 P245 GH 1.0460 P250 GH
3E1	Unalloyed steels with defined characteristics up to 400°C, upper yield point > 265N/mm²	1.0426 P280 GH
4E0	Low alloy steels with 0.3% molybdenum	1.5415 16Mo3
12E0	Standard carbon content, stabilised with Ti or Nb	1.4541 X6CrNiTi18-10 1.4550 X6CrNiNb18-10 1.4941 X6CrNiTiB18-10
15E0	Standard carbon content, alloyed with molybdenum, stabilised with Ti or Nb	1.4571 X6CrNiMoTi17-12-2 1.4580 X6CrNiMoNb17-12-2

Tab. 62 *Pressure-temperature assignment*

1) Source: EN 1092-1:2013-04 Table 9, G.2.2, G.3.2, Table D.1

Notices regarding the following tables and diagrams:

- In accordance with flange standard EN 1092-1:2013-04
- Only the lower range and therefore the highest pressures are assumed as reference value for the thickness vR; lower permissible pressures PS may need to be used for larger flange dimensions and therefore thicker raw material
- When using austenitic materials, differentiations are not only made in the material group, but also sometimes in the individual material. The standard materials are subsequently used:
  - 12E0 > 1.4541
  - 15E0 > 1.4571
- RT (room temperature) = – 10°C – +50°C
- Linear interpolation between the table values is to be used
- PN nominal pressure stage
- PS permissible pressure [bar]
- TS permissible temperature [°C]

PN 10

TS [°C]		RT	100	150	200	250	300	350	400	450	460	470	480	490	500	510	520	530
PS [bar]	3E0	10.0	9.2	8.8	8.3	7.6	6.9	6.4	5.9	3.2	–	–	–	–	–	–	–	–
	3E1	10.0	10.0	10.0	10.0	9.7	8.8	8.0	7.3	4.0	–	–	–	–	–	–	–	–
	4E0	10.0	10.0	10.0	10.0	9.7	8.5	8.0	7.4	6.9	6.4	5.9	5.4	4.9	4.4	3.5	2.8	2.2

Tab. 63 *Excerpt from table G.2.1–3 – PN 10 for ferritic materials*

TS [°C]		RT	100	150	200	250	300	350	400	450	500	550	560	570	580	590	600
PS [bar]	12E0	10.0	9.9	9.3	8.8	8.4	7.9	7.6	7.4	7.2	7.0	6.7	6.1	5.6	5.0	4.5	4.0
	15E0	10.0	10.0	9.8	9.3	8.8	8.3	8.0	7.8	7.6	7.5	7.4	7.4	7.3	6.7	6.0	5.5

Tab. 64 *Excerpt from table G.4.1–3 – PN 10 for austenitic materials*

PN 16

TS [°C]		RT	100	150	200	250	300	350	400	450	460	470	480	490	500	510	520	530
PS [bar]	3E0	16.0	14.8	14.0	13.3	12.1	11.0	10.2	9.5	5.2	–	–	–	–	–	–	–	–
	3E1	16.0	16.0	16.0	16.0	15.6	14.0	12.9	11.8	6.4	–	–	–	–	–	–	–	–
	4E0	16.0	16.0	16.0	16.0	15.6	13.7	12.9	11.9	11.0	10.2	9.4	8.6	7.8	7.0	5.6	4.4	3.5

Tab. 65 *Excerpt from table G.2.1–4 – PN 16 for ferritic materials*

TS [°C]		RT	100	150	200	250	300	350	400	450	500	550	560	570	580	590	600
PS [bar]	12E0	16.0	15.8	14.9	14.1	13.4	12.7	12.2	11.8	11.6	11.3	10.8	9.8	8.9	8.1	7.3	6.5
	15E0	16.0	16.0	15.6	14.9	14.1	13.3	12.8	12.4	12.2	12.0	11.9	11.8	11.7	10.7	9.7	8.8

Tab. 66 *Excerpt from table G.4.1–4 – PN 16 for austenitic materials*

PN 25

TS [°C]		RT	100	150	200	250	300	350	400	450	460	470	480	490	500	510	520	530
PS [bar]	3E0	25.0	23.2	22.0	20.8	19.0	17.2	16.0	14.8	8.2	–	–	–	–	–	–	–	–
	3E1	25.0	25.0	25.0	25.0	24.4	22.0	20.2	18.4	10.1	–	–	–	–	–	–	–	–
	4E0	25.0	25.0	25.0	25.0	24.4	21.4	20.2	18.6	17.2	16.0	14.7	13.5	12.3	11.0	8.8	7.0	5.5

Tab. 67 *Excerpt from table G.2.1–5 – PN 25 for ferritic materials*

TS [°C]		RT	100	150	200	250	300	350	400	450	500	550	560	570	580	590	600
PS [bar]	12E0	25.0	24.7	23.3	22.1	21.0	19.8	19.1	18.5	18.1	17.7	16.9	15.3	14.0	12.7	11.4	10.2
	15E0	25.0	25.0	24.5	23.3	22.1	20.8	20.1	19.5	19.1	18.8	18.6	18.5	18.3	16.7	15.2	13.8

Tab. 68 *Excerpt from table G.4.1–5 – PN 25 for austenitic materials*

PN 40

TS [°C]		RT	100	150	200	250	300	350	400	450	460	470	480	490	500	510	520	530
PS [bar]	3E0	40.0	37.1	35.2	33.3	30.4	27.6	25.7	23.8	13.1	–	–	–	–	–	–	–	–
	3E1	40.0	40.0	40.0	40.0	39.0	35.2	32.3	29.5	16.1	–	–	–	–	–	–	–	–
	4E0	40.0	40.0	40.0	40.0	39.0	34.2	32.3	29.9	27.6	25.6	23.6	21.6	19.7	17.7	14.0	11.2	8.9

Tab. 69 *Excerpt from table G.2.1–6 – PN 40 for ferritic materials*

TS [°C]		RT	100	150	200	250	300	350	400	450	500	550	560	570	580	590	600
PS [bar]	12E0	40.0	39.6	37.3	35.4	33.7	31.8	30.6	29.7	29.0	28.3	27.0	24.5	22.4	20.3	18.2	16.3
	15E0	40.0	40.0	39.2	37.3	35.4	33.3	32.1	31.2	30.6	30.0	29.9	29.6	29.3	26.8	24.3	22.0

Tab. 70 *Excerpt from table G.4.1–6 – PN 40 for austenitic materials*

PN 63

TS [°C]		RT	100	150	200	250	300	350	400	450	460	470	480	490	500	510	520	530
PS [bar]	3E0	63.0	58.5	55.5	52.5	48.0	43.5	40.5	37.5	20.7	–	–	–	–	–	–	–	–
	3E1	63.0	63.0	63.0	63.0	61.5	55.5	51.0	46.5	25.5	–	–	–	–	–	–	–	–
	4E0	63.0	63.0	63.0	63.0	61.5	54.0	51.0	47.1	43.5	40.3	37.2	34.1	31.0	27.9	22.2	17.7	14.1

Tab. 71 *Excerpt from table G.2.1–7 – PN 63 for ferritic materials*

TS [°C]		RT	100	150	200	250	300	350	400	450	500	550	560	570	580	590	600
PS [bar]	12E0	63.0	62.4	58.8	55.8	53.1	50.1	48.3	46.8	45.7	44.7	42.6	38.7	35.4	32.1	28.8	25.8
	15E0	63.0	63.0	61.8	58.8	55.8	52.5	50.7	49.2	48.3	47.4	47.1	46.6	46.2	42.3	38.4	34.8

Tab. 72 *Excerpt from table G.4.1–7 – PN 63 for austenitic materials*

5.4.3 Flow speed

Medium	Area of application	Recommended speed
Steam	0 –1 bar	20 – 25m/s
	1 – 40 bar	30 – 40m/s
Water	Suction line	0.4 (0.25 – 0.6) m/s
	Pressure line	2 (1.5 – 3) m/s
Condensate	Steam fraction	15m/s
	Water fraction	2m/s
Flue gas		16.5m/s

Medium	Area of application	Recommended speed
Oil	Light fuel oil intake side	0.5m/s
	Light oil discharge side	1m/s
	Heavy fuel oil intake side	0.3m/s
	Heavy fuel oil discharge side	0.5m/s
Natural gas		No specifications Design via pressure loss

Tab. 73 *Standard design speeds (recommended speeds) for pipework sizing*

5.4.4 Pressure loss – guide values for the pressure loss coefficient ζ

Shut-off valve, servovalve, butterfly valve

DN	Kvs value			Pressure loss coefficient ζ 1)		
	Shut-off valve	Servovalve	Butterfly valve	Shut-off valve	Servovalve	Butterfly valve
15	5.3	4	–	2.9	5.1	0.9
20	7.2	6.3	–	4.9	6.4	2.4
25	12	10	26	4.3	6.2	1.7
32	16	16	26.5	6.5	6.5	0.7
40	28.5	25	49.6	5	6.5	0.4
50	43	40	116	5.4	6.2	0.5
65	75	63	259	5.1	7.2	0.3
80	105	100	377	5.9	6.5	0.4
100	170	160	763	5.5	6.2	0.3
125	270	250	1,030	5.3	6.2	0.2
150	405	400	1,790	4.9	5.1	0.2
200	675	–	3,460	5.6	–	0.2
250	1,090	–	5,070	5.2	–	0.2
300	1,460	–	7,430	6.1	–	0.2
350	2,010	–	10,320	5.9	–	0.3
400	2,640	–	13,290	5.9	–	0.2

Tab. 74 *Shut-off valve, servovalve, butterfly valve*

1) The pressure loss coefficient ζ is relative to the nominal diameter DN.

Intermediate flange-type non-return valve, non-return valve, dirt trap

DN	Kvs value			Pressure loss coefficient ζ [1]		
	Intermediate flange-type non-return valve	Non-return valve	Dirt trap	Intermediate flange-type non-return valve	Non-return valve	Dirt trap
15	4.4	5.7	6.9	4.2	2.5	1.7
20	7.1	7.8	10.8	5.1	4.2	2.2
25	12	11.8	17.8	4.3	4.5	2.0
32	19.5	17.9	26.1	4.4	5.2	2.5
40	25	27.5	36.7	6.5	5.4	3.0
50	46	48	61	4.7	4.3	2.7
65	69	77.6	98.6	6.0	4.7	2.9
80	87	109	146	8.7	5.5	3.1
100	122	168	234	10.7	5.7	2.9
125	–	251	376	–	6.2	2.8
150	–	389	394	–	5.3	5.2
200	–	664	652	–	5.8	6.0
250	–	1,017	1,225	–	6.0	4.2
300	–	1,446	1,873	–	6.2	3.7
350	–	2,042	–	–	5.8	–
400	–	2,725	–	_	5.5	_
500	–	4,167	–	_	5.8	_

Tab. 75 *Intermediate flange-type non-return valve, non-return valve, dirt trap*

1) The pressure loss coefficient ζ is relative to the nominal diameter DN.

Pressure loss of water vapour and other gases:

$$\frac{p_1^2 - p_2^2}{2 \cdot p_1} = \lambda \cdot \frac{1}{d} \cdot \frac{\rho \cdot u^2}{2} \quad \text{with isothermal flow } T_2 = T_1$$

$$\frac{p_1^2 - p_2^2}{2 \cdot p_1} = \zeta \cdot \frac{\rho \cdot u^2}{2} \quad \text{with isothermal flow } T_2 = T_1$$

F39. *Pressure loss of water vapour and other gases with isothermal flow*

p_1	Pressure upstream of the pipe section [Pa]
p_2	Pressure downstream of the pipe section [Pa]
λ	Pipe friction coefficient
l	Length of pipe [m]
d	Diameter of pipe [m]
ζ	Pressure loss coefficient

For calculation of pressure loss up to consumer ζ =

ζ steam extraction	→ Tab. 74 Shut-off valve, servovalve, butterfly valve, page 411
+ ζ extension/availability	as a rule following steam extraction
+ n elbow · ζ elbow	Guide value $\zeta_{90°\ elbow} \approx 0.5$
$+ \lambda \cdot \frac{l}{d}$	
+ ζ valves	
+ ζ consumer inlet	if applicable (can be disregarded as a rule)

ρ	Density of flowing medium in kg/m³
u	Average speed at pipe inlet
T_1	Temperature of the medium at the pipe inlet
T_2	Temperature of the medium at the pipe inlet

The deviation compared to adiabatic flow can normally be disregarded.

Pressure loss of liquids

Conversion of Kv value, pressure loss coefficient ζ and flow coefficient Cv

Conversion of Kv value of a valve to the pressure loss coefficient ζ:

$$\zeta = 2 \cdot \frac{A^2}{\left(\frac{K_v}{3{,}600}\right)^2} \cdot 100 = 2 \cdot \frac{\left(\frac{\pi}{4} \cdot d_i^2\right)^2}{\left(\frac{K_v}{3{,}600}\right)^2} \cdot 100$$

F40. *Conversion of Kv value of a valve to the pressure loss coefficient ζ*

Conversion of pressure loss coefficient ζ of a valve to the Kv valve:

$$K_v = \frac{A \cdot 3\,600}{\sqrt{\frac{\zeta}{2 \cdot 100}}} = \frac{\frac{\pi}{4} \cdot d_i^2 \cdot 3\,600}{\sqrt{\frac{\zeta}{2 \cdot 100}}}$$

F41. *Conversion of pressure loss coefficient ζ of a valve to the Kv valve*

Conversion of Cv value (flow coefficient) in metric systems to the Kv value:

$$K_v = C_v \cdot 0.865$$

F42. *Conversion of Cv value (flow coefficient) in metric systems to the Kv value*

5.5 Identification

5.5.1 Pipework

In Germany, pipework is identified according to DIN 2403. The identification must be attached at suitable intervals to operationally-critical or hazardous points and contain the following elements:

- Flow arrow
- Flow material (word, chemical formula, identification number or code)
- Danger pictogram, if applicable (e.g. with combustible gases/fluids, acids and alkalis)

→ Tools – Chapter 5.5.2: Hazardous substances, page 415

Flow material	Group	Group colour	Additional colour	Lettering/ arrow/edge colour
Water	1	Green	–	White
Water vapour	2	Red	–	White
Air	3	Grey	–	Black
Combustible gases	4	Yellow	Red	Black
Non-combustible gases	5	Yellow	Black	Black
Acids	6	Orange	–	Black
Alkalis	7	Violet	–	White
Combustible liquids and solids	8	Brown	Red	White
Non-flammable liquids and solids	9	Brown	Black	White
Oxygen	0	Blue	–	White

Tab. 76 *Identification of pipework according to DIN 2403*

Group colour/additional colour	Identification colours according to DIN 5381
Green	RAL 6032 signal green
Red	RAL 3001 signal red
Grey	RAL 7004 signal grey
Yellow	RAL 1003 signal yellow
Orange	RAL 2010 signal orange
Violet	RAL 4008 signal violet
Brown	RAL 8002 signal brown
Blue	RAL 5005 signal blue
Black	RAL 9004 signal black
White	RAL 9003 signal white

Tab. 77 *Identification colours according to DIN 5381*

5.5.2 Hazardous substances

The hazard symbols (identification of hazardous substances) must be implemented according to the European CLP ordinance.

The ordinance (EC) No. 1272/2008 for classification, labelling and packaging of substances and mixtures (CLP ordinance) adapts the EU legal regulations to the globally harmonised system for classification and identification of chemicals (GHS).

5.6 Heat loss

5.6.1 Pipework and valves

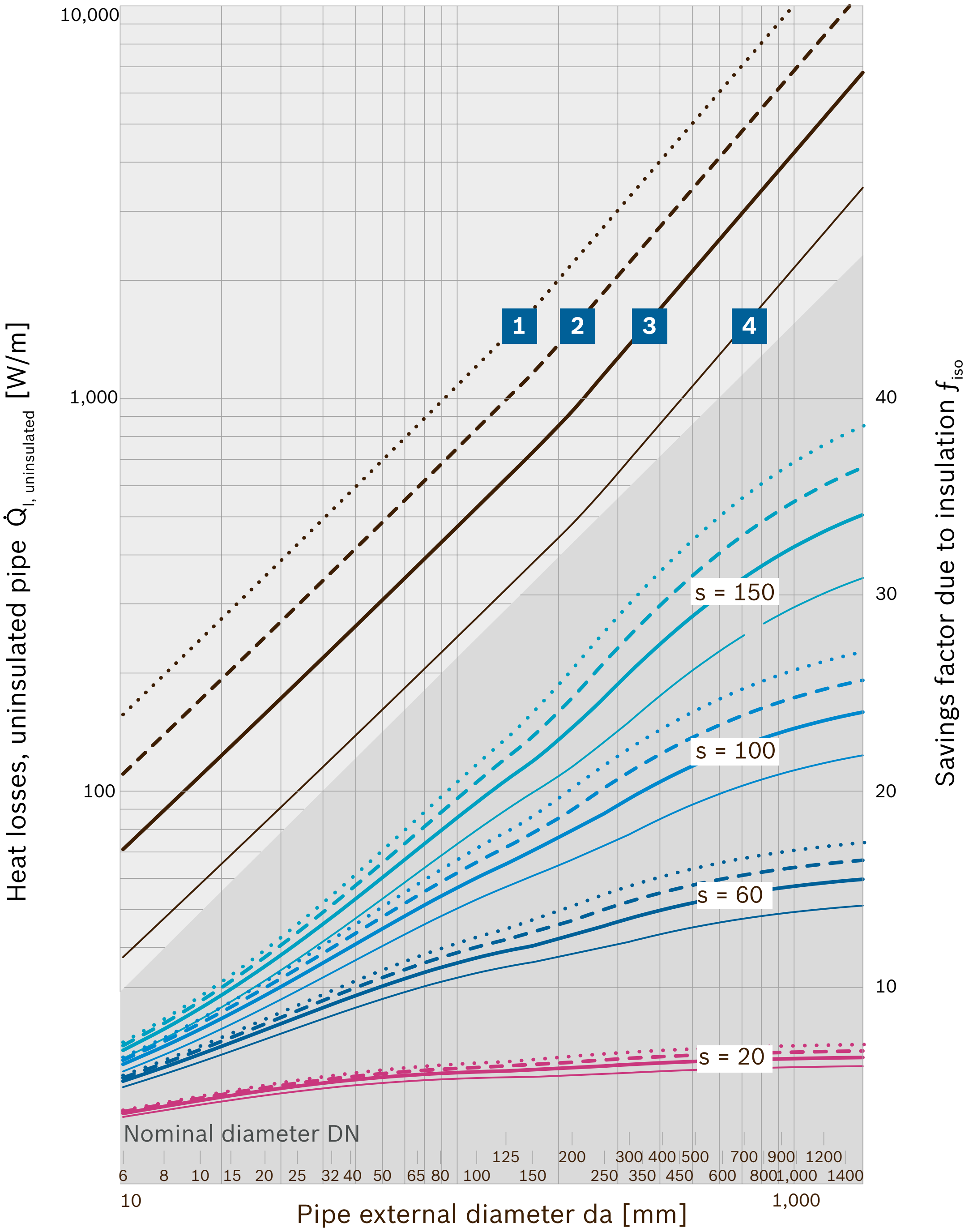


Fig. 235 *Savings factor due to insulation and heat losses in pipework*

1 Medium temperature: 250°C (······)
2 Medium temperature: 200°C (- - - -)
3 Medium temperature: 150°C (——)
4 Medium temperature: 100°C (——)

Insulation thickness s = 150mm
Insulation thickness s = 100mm
Insulation thickness s = 60mm
Insulation thickness s = 20mm

→ Efficiency Chapter 4.1.2: Insulation of pipework, page 289

5.6.2 Container

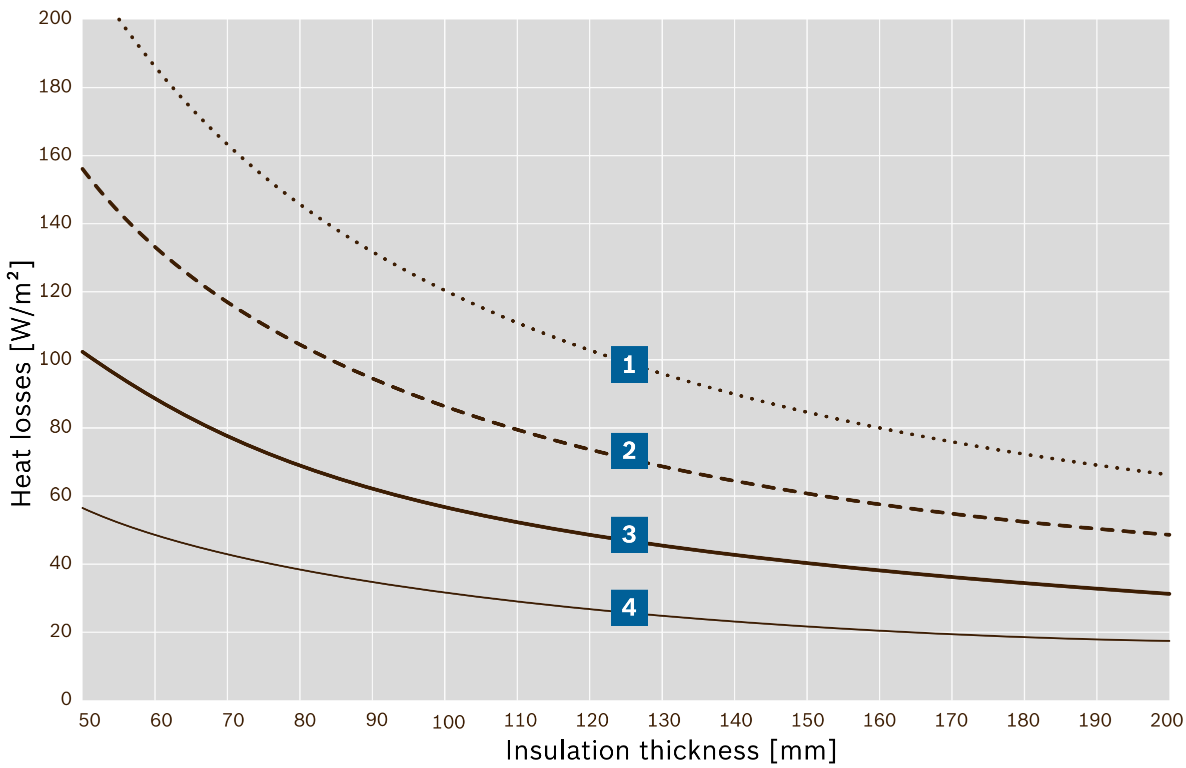


Fig. 236 *Heat loss via the insulated area of the container or boiler surface*

1 Medium temperature 250°C
2 Medium temperature 200°C
3 Medium temperature 150°C
4 Medium temperature 100°C

5.7 Sound

Addition of sound pressure levels

$$L_{p,\,ttl} = 10 \cdot LOG_{10} \sum_{i=1}^{n} 10^{\frac{L_{p,i}}{10}}$$

F43. *Formula for calculating the total sound level*

Frequency evaluation and sound pressure level

Input Result

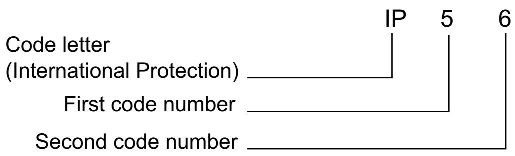
	Frequency f [Hz]										Σ
	31.5	63	125	250	500	1,000	2,000	4,000	8,000	16,000	
dB(A)	−39.4	−26.2	−16.1	−8.6	−3.2	0	1.2	1	−1.1	-6.6	
dB(C)	-3	−0.8	−0.2	0	0	0	−0.2	−0.8	−3	−8.5	

dB	109.2	112.7	118.2	112.2	100.6	97.3	83.1	67.7	63.7		120.5
dB(A)	69.8	86.5	102.1	103.6	97.4	97.3	84.3	68.7	62.6	-6.6	107.1
dB(C)	106.2	111.9	118.0	112.2	100.6	97.3	82.9	66.9	60.7	-6.6	120.0

6 Other

6.1 IP ratings of casings

According to EN 60529 (VDE 0470-1):2014-09



First code number		
	Against penetration of solid foreign bodies:	Against access to dangerous parts with:
0	(not protected)	(not protected)
1	≥ 50mm diameter	Back of hand
2	≥ 12.5mm diameter	Finger
3	≥ 2.5mm diameter	Tool
4	≥ 1.0mm diameter	Wire
5	Dust-proof	Wire
6	Dust-tight	Wire

Tab. 78 *IP ratings of casings – first code number*

Second code number	
0	(not protected)
1	Vertical dripping
2	Dripping (15° inclination)
3	Spray water
4	Splash water
5	Water jet
6	Strong water jet
7	Temporary immersion
8	Continuous immersion
9	High-pressure and high water jet temperature

Tab. 79 *IP ratings of casings – second code number*

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