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Avoidable loads on steam shell boilers

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Steam boiler systems are subject to a series of loads resulting in a certain level of stress on the boiler body. In addition to insufficient water quality, two main factors play a key role here: Influences due to the design and settings as well as influences on the part of consumers. The following article describes avoidable loads on boiler systems and enables readers to gain an insight into proper planning, design and setting, right up to the operation of the systems.

Saturated steam is used as a heat transfer medium in a multitude of commercial and industrial companies of all sectors. Heating, cooking and cleaning processes are supported in the food and drink industry. The textiles sector uses the heat transfer medium primarily for subsequent treatment and refinement of materials. Laundries and dry cleaners heat washing machines or use the steam for ironing and drying processes. In hospitals, ultra-pure steam is used to sterilise surgical instruments, to supply a connected industrial kitchen or for air humidification of the air-conditioning system. The construction materials industry requires saturated steam for many processing, heating and drying operations, such as autoclaving lime-sand bricks. But steam is also an indispensable heat transfer medium in many other sectors, for instance in the paper and cardboard industry, the chemical industry or the pharmaceutical industry.

Most of the these steam applications require saturated steam or gently superheated steam with outputs up to 200 t/h, pressures up to 30 bar and steam temperatures up to 300 °C. One or several shell boilers are usually used for steam generation. Compared with water tube boiler systems, these are usually the better alternative in the required performance range, as purchase and operation are generally more cost-effective.

The operation of modern steam shell boilers is considered to be unproblematic these days. Nevertheless, the boilers are often subject to a series of loads that are actually avoidable but which have a significant influence on the reliability and service life of energy generators. In addition to insufficient water quality, the other main factors are influences due to the design and settings as well as influences on the part of consumers.

Insufficient water quality

Insufficient water quality resulting in corrosion and the formation of deposits is the main cause of damage. The mechanisms behind this type of damage are considered to be generally known; a more detailed description will not be provided as part of this technical report. Frequent causes of “poor” water quality are:

- Insufficient monitoring or testing of the required water parameters (Figure 1)
- Lack of expertise
- Misinterpretation of measured values or no response to deviations

Damage caused by insufficient water quality can reliably be avoided in the first place by complying with the specified water values (according to EN 12953 Part 10) of the boiler manufacturer. To this end, a sufficient level of expertise in water analysis is essential in addition to using suitable water treatment components. Equipment with fully automatic analysers, which can record and monitor all water parameters such as hardness, conductivity, pH value and condensate purity, is advisable (Figure 2 / Page 3). Further information on this can be found in the technical report “Modern water treatment and water analysis”. These days, digital boiler log books offer a further advance. These analyse the registered measured values, recognise critical deviations immediately and support the user with notes and suggestions for solutions.

Influences due to design and setting

Excessive boiler capacity relative to the actually required steam capacity

This problem can often be found in existing systems whose steam demand has been drastically reduced by loss of consumers or the subsequent use of available heat recovery potentials. But new systems can also be affected, for instance if the diversity factors of consumers have been incorrectly evaluated during planning or the power reserves used for calculations were too generous. The consequence is an insufficient steam demand with regard to the boiler capacity, resulting in the burner being switched on and off many times, with the associated thermal cycling. Burners generate temperatures between 1400 and 1700 °C in the furnace. Furnace pre-ventilation is prescribed for every ignition procedure, allowing outdoor air to be drawn in

Figure 1: Consequences of insufficient hardness monitoring

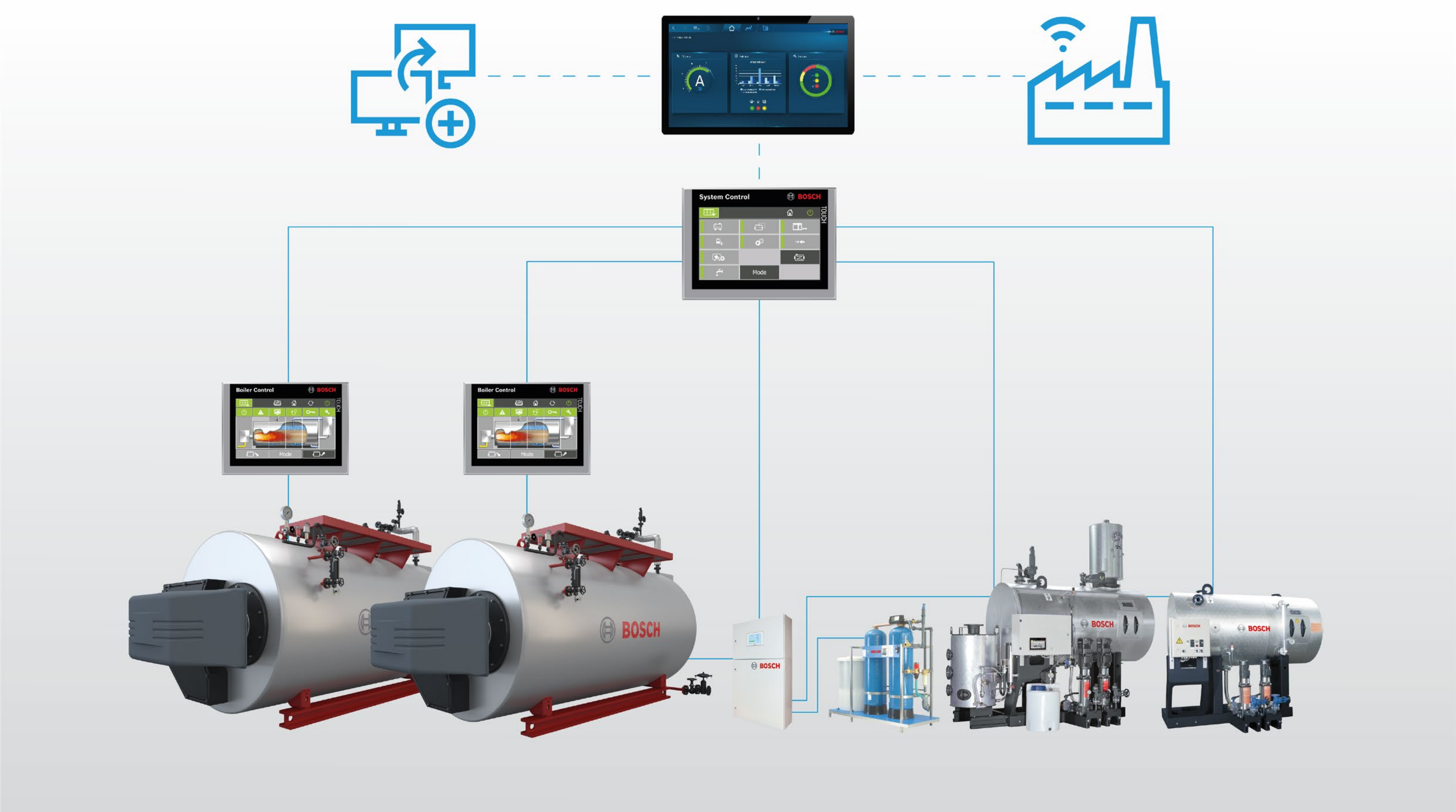

Figure 2: Modern steam boiler system with fully automatic water analysis and monitoring (simplified illustration)

from the boiler house. The hot heating surfaces are cooled by the low air temperatures of 20 to 40 °C. Then the burner ignites and generally receives the signal to proceed to the maximum load stage within a very short time. In extreme low-load phases, the burner frequently already switches off again during start-up, only to then – often shortly afterwards – pre-ventilate and ignite anew.

Due to this constant thermal cycling between heating up and aerating, there are strain differences between the furnace and boiler shell, which can lead to material fatigue over time. In addition to increasing susceptibility to damage, such an operation mode also has a negative influence on economy, as every pre-ventilation process presents a significant thermal loss.

Therefore, there should be less than or maximum four burner switch-on cycles an hour. The following measures are recommended to achieve this:

- Fitting low-load controls, which delay immediate turning up once the burner has been started
- Using power controllers that allow the burner to be kept in the small load stage without a time limitation
- Using burners with a wide control range
- Matching the burner capacity to the actual requirements (i.e. burner modifications or assembly of a burner with a smaller power range)

Insufficient pressure difference between burner switch-on and switch-off points

The performance regulation of the steam boiler is based on the steam pressure measured in the boiler. If the pressure falls short of the adjustable steam pressure $P_{Burner.on}$, the burner will switch on – if $P_{Burner.off}$ is exceeded, the burner will switch off.

If the temperature difference between $P_{Burner.on}$ and $P_{Burner.off}$ is set too low, this has the following consequences:

- Frequent switching on and off due to overshooting of pressure and the associated thermal cycling with its negative consequences
- Strictly set control parameters in the power controller, in order to keep the target value within a narrow control band. In addition to high wear of the control elements in the burner, this leads to premature material fatigue of the heated walls

With a set temperature difference of 10 to 15 % between $P_{Burner.on}$ and $P_{Burner.off}$ (depending on the burner control and boiler operating pressure) with regard to the boiler safety pressure, these problems can be reliably avoided.

Power controllers set too "quickly"

Modern burner managers have the ability to variably input the burner regulating time, i.e. the duration between the low-load burner position and the high-load burner position. At the same time, the reaction speed of the burner to target value deviations can be influenced via the control parameters in the power controller. Shell boilers with their high material share and high water content are a system that is comparatively slow to react. Power controllers that are set too "quickly", possibly together with very short burner regulating times, lead to quickly increasing heat input in the flame tube. On the water side, the steam bubbles forming and rising in the steam chamber are primarily responsible for the removal of this heat input (Figure 3). However, the formation of these steam bubbles is slightly staggered. This leads to brief, local superheating and additional thermal cycling, which accelerate material fatigue in the long term in the area of heated boiler walls.

Commissioning by experts who are proficient in the mutual dependencies between settings on the burner managers and boiler power controllers is expressly recommended. This ensures that the necessary balance between operating pressure consistency and an operation mode that is gentle on the boiler is achieved.

Lack of sequence control concept for multi-boiler systems

With multi-boiler systems without automatic sequence control, the operator is of great importance. Boilers must be switched off manually if the decrease in performance no longer justifies the operation of several boilers. If this does not happen, the consequences are shown as an example in Figure 4 / Page 5. The recording shows that boiler 1 (red, with an output of 10 t/h) can cover the required steam demand (blue) on its own over the entire time period. Frequently switching on boiler 2 (yellow) with the described thermal cycling is therefore entirely superfluous.

In addition, the interaction of the two boilers can be recognised. While boiler 1 (red) is reducing its output, boiler 2 (yellow) is increasing steam production and vice versa. This means that the

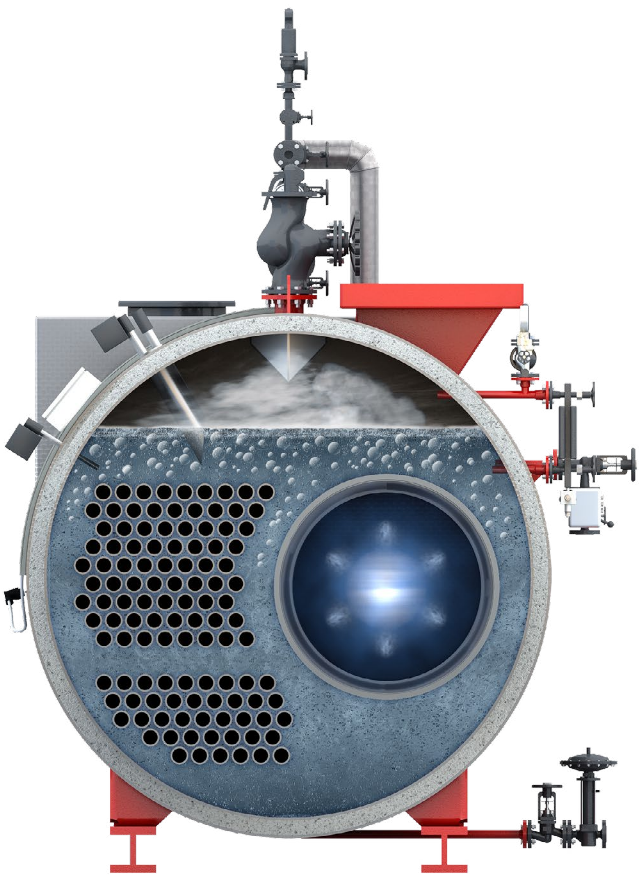

Figure 3: Example illustration of heat dissipation on the highly stressed heating surfaces through steam bubble formation

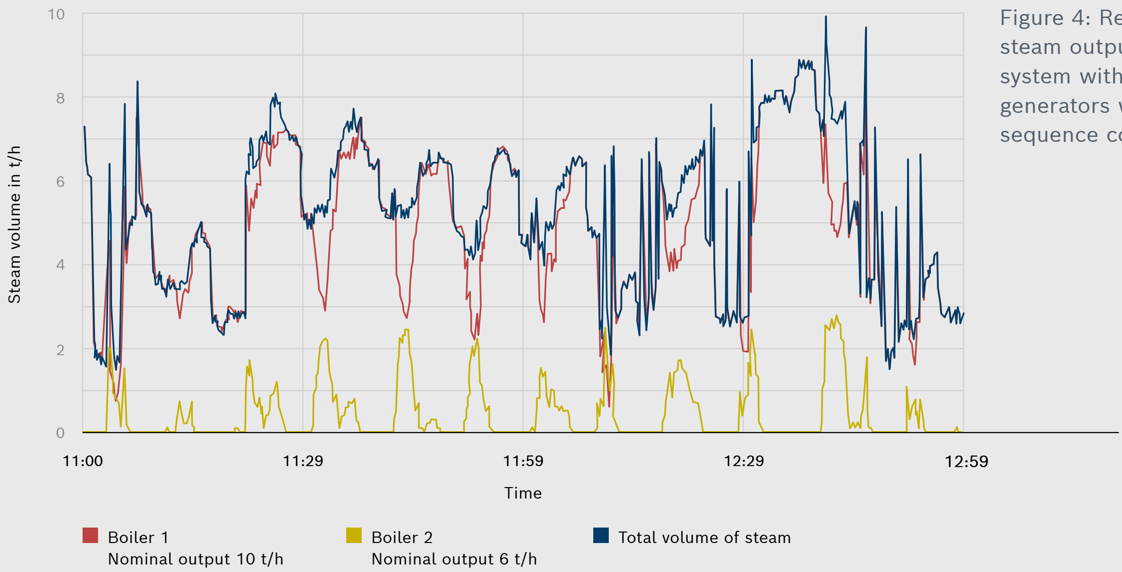

Figure 4: Recording of steam output in a boiler system with two steam generators without sequence control concept

boilers work “against each other” and fire alternately. Unhindered heat dissipation from the heating surfaces can no longer be guaranteed.

A sequence control concept is, therefore, already advisable for boiler systems with two steam generators and absolutely necessary for three or more boilers in one boiler house. The type of sequence control (steam volume or pressure-dependent switching on and off of the boilers) used depends on the number of boilers and on the acceptable pressure fluctuations on the part of the consumer. With sequence controls dependent on the volume of steam, the spectrum of realisable pressure fluctuations can be kept considerably lower.

The steam generators in multi-boiler systems should also be hydraulically separate from each other in order to prevent interaction (for example by non-return valves). In addition, the equipment of the lag boiler must include a base heating coil in order to avoid thermal stratifications of the boiler water during heat maintenance phase.

Influences on the part of consumers

Frequent start-up from cold

Starting up from cold presents the greatest mechanical load for the boiler body (see further information in the technical report “Cold starting of shell boilers”). The reason for this is the larger temperature difference between the flame tube and boiler shell with cold starts – compared with regular operations at operating temperature. The flame tube thrust (difference between boiler shell and flame tube as the length changes) is higher during the start-up process and consequently leads to significant additional tensions that the boiler body must cope with. This load increases if no or only very few steam bubbles can form during the start-up procedure, which is the case, for example, with a closed steam extraction valve. The natural circulation that normally exists in the steam boiler does not start (Figure 5 / Page 6). Thermal stratifications in the boiler (bottom cold, top hot) with additional thermal stresses are the consequence. With very frequent cold starts, these extreme variations in stress can lead to material breaks or, in the worst case scenario, to a complete failure.

When reducing the start-up load, note the following:

- When starting from cold, you should start up with as small a burner load as possible until reaching the operating temperature
- During the start-up process, a small quantity of steam should always be able to escape, in order to start the natural circulation through a steam bubble boost

- Equipment with automatic start-up control, which controls burner operation and load removal depending on the water temperature and pressure so that the loads are reduced to a low level, would be ideal

Long periods in stand-by operation

During heat maintenance or stand-by operation (for example in multi-boiler operation, if the lag boiler is not required), any steam delivery for the relevant boiler is prevented. To this end, depending on the control concept, either the steam extraction valve is closed or the lag boiler operated at a lower pressure than the prevailing network pressure. Firings is only switched on sporadically in this operating mode in order to offset losses due to thermal conduction and radiation. If this status is maintained over a longer time period (longer than three days), thermal stratification begins to appear in the boiler. If boilers kept warm in this way enter normal operation again, the high operating pressure (hot upper area) simulates an immediately available boiler. The boiler control then quickly applies a high burner load to this boiler in the event of corresponding demand. Due to the thermal stratifications in the boiler, extreme thermal stresses arise as a consequence.

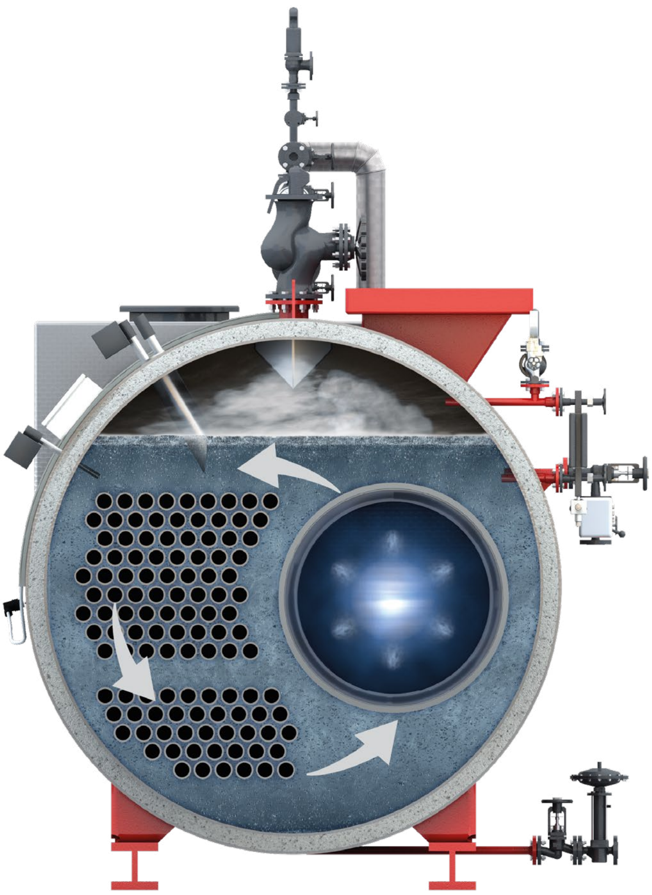

Figure 5: Example illustration of natural circulation within the boiler

The use of heat maintenance coils in the boiler base can help (Figure 6 / Page 7). The steam of this heating coil is heated from below in order to avoid damaging thermal stratifications in the boiler. However, a multi-boiler system or a reliable auxiliary steam provision is necessary for this solution.

Pressure fluctuations due to strong demand fluctuations

In the event of significant load changes, i.e. high load change speeds and associated significant pressure fluctuations, unfavourable flow conditions can occur in the boiler. Steam bubble formation, which is required for the dissipation of heat from the heating surfaces, can remain static or lead to many small bubbles combining to form larger steam bubbles. These do not immediately become detached from the heating surfaces and consequently favour local superheating. As a result, special provisions must be made for boiler systems that supply consumers with greatly fluctuating demands. The aim is to limit the pressure fluctuations in the boiler, independent of the consumers.

The following measures, among others, can achieve this:

- A higher boiler fuse on the pressure side and incorporation of a reducing station between boiler and consumer
- Incorporation of a steam accumulator for load peaks
- Pressure maintenance downstream from the boiler with a controlled steam extraction valve in order to protect the boiler from excessive pressure losses

Summary

The described avoidable causes of boiler loads show that this is a complex topic. It ranges from planning, design and setting right up to the operation of the systems. A conclusive consideration of all relevant problems is not possible within this framework.

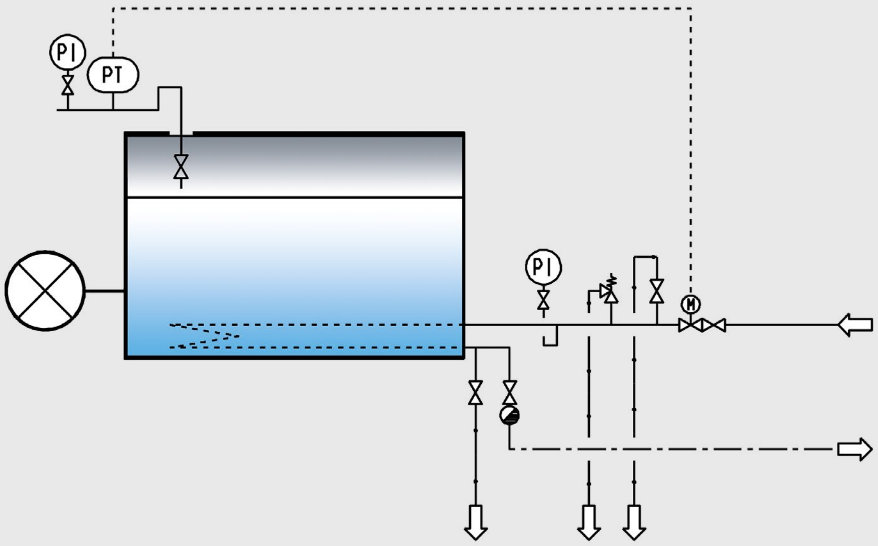

Figure 6: Schematic illustration of a controlled base heating coil

Due to the complexity of steam boiler systems, the following points must be taken into account:

- Steam boiler systems should only be planned by well-versed and experienced contractors, as many of the potential sources of faults can already be avoided upfront
- The quality of the boilers, burners and boiler system components used plays a key role in the smooth and faultless operation of the system
- The correct installation of the system requires a competent plant construction company with knowledge of the interaction of the various boiler house components
- The operation mode and supervision by operating staff are of great importance and have a significant effect on the service life of the steam boiler system. Digital assistance systems with fully automatic data evaluation can offer increased support these days (Figure 7)
- Prevention through maintenance and remote contracts with the boiler manufacturer

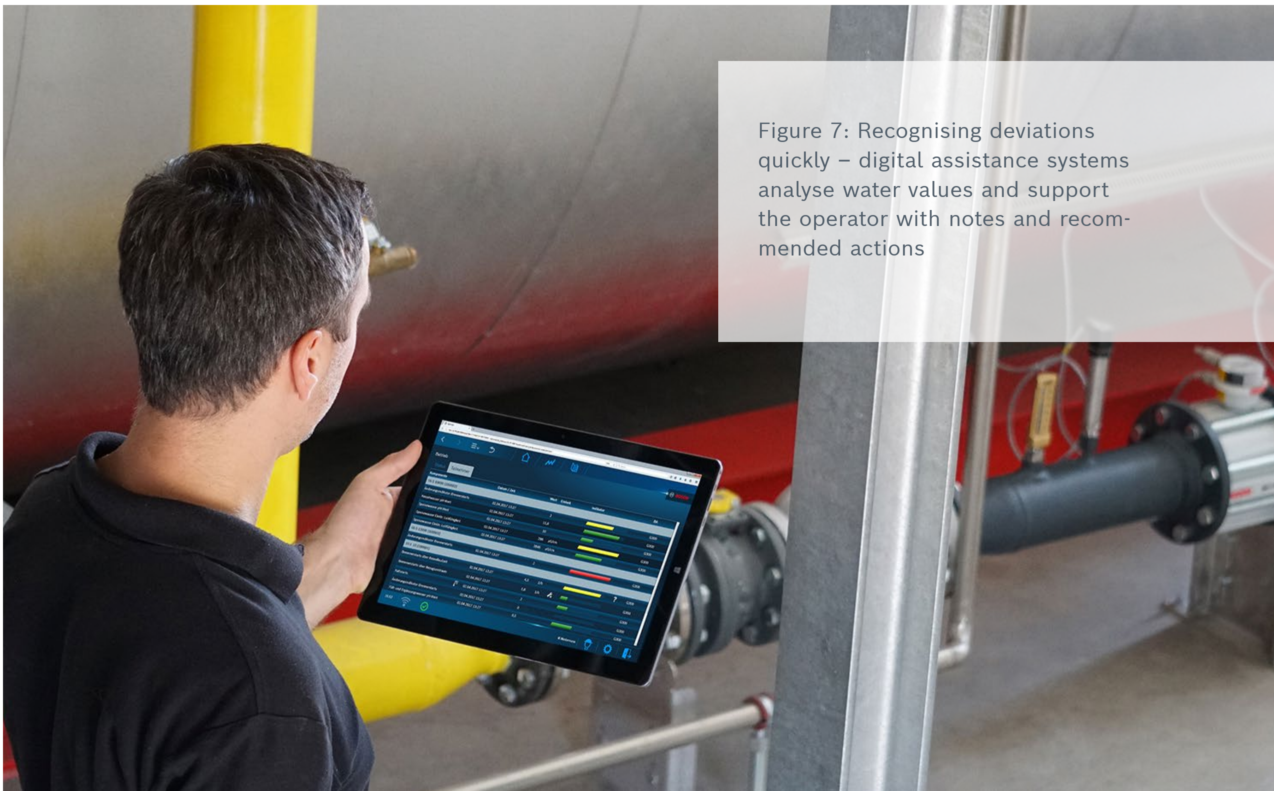

Figure 7: Recognising deviations quickly – digital assistance systems analyse water values and support the operator with notes and recommended actions

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