

SIEMENS

BENSON Boilers for Maximum Cost-Effectiveness in Power Plants



BENSON Boilers – Proven a Thousand Times Over

With over 1000 units built, the BENSON boiler is by far the most widespread once-through boiler.

Principle:

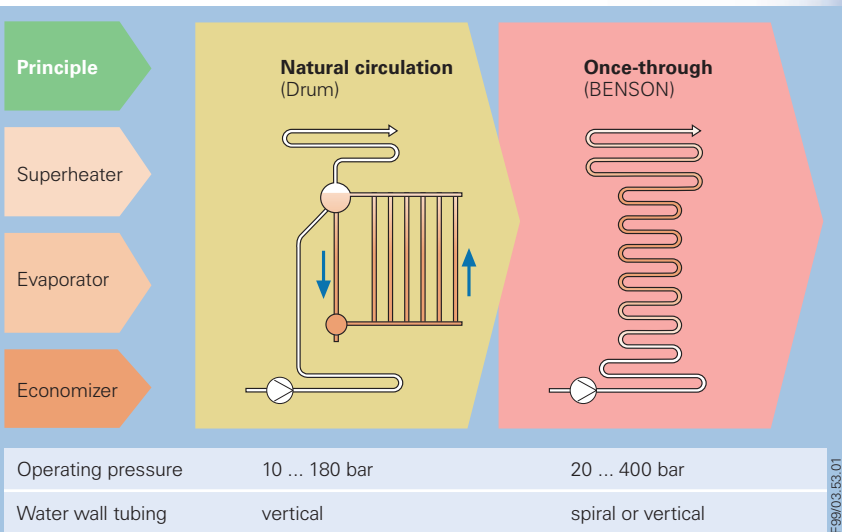
- Water is preheated and evaporated and steam is subsequently superheated in a single pass.
- A feedwater pump generates forced flow in the evaporator.

Most important characteristics:

- Depending on operating conditions, the evaporation endpoint shifts automatically within one or more heating surfaces.
- The system can be operated at subcritical or supercritical pressures.

Siemens and BENSON boilers

In 1922, Mark Benson submitted a patent application for "Generating Steam with any Pressure" – marking the birth of the once-through boiler. Based on the concept developed by Mark Benson, Siemens continued to develop this type of boiler in the mid-twenties while retaining the name BENSON boiler. It was recognized that a once-through evaporator could be operated at both subcritical and supercritical pressure.



Implementation of drum boilers is restricted to subcritical pressures. The BENSON boiler enables realization of both subcritical and supercritical pressures.

BENSON Boilers for Low Life-Cycle Costs

Cost-effectiveness in high-output steam power plants is determined by investment costs, process and component efficiencies, availability, and maintenance costs. The boiler plays a leading role due to its key function in the water/steam cycle and its large contribution to investment costs.



Franken II power plant, Germany
2 × 200 MW
Supercritical pressure, double reheat
Bituminous coal
Boiler manufacturer:
Deutsche Babcock

The transition from subcritical to supercritical steam pressure significantly increases process efficiency, with a considerable decrease in fuel costs. Investigations such as those of the Coal Industry Advisory Board of the International Energy Agency have shown that this reduces life-cycle costs:

The effect of low fuel consumption on electric power generation costs is greater than the only slightly higher investment costs for the power plant.

Overview of the advantages of BENSON boilers:

- Highest achievable plant efficiency with supercritical steam parameters
- High plant efficiency even at part load
- Suitable for all coal grades available on the world market
- Short startup times
- Sliding-pressure operation with high load transients
- Proven thousands of times over and available worldwide
- Continuous further development of this technology.

Licensees	
Austria	Austrian Energy & Environment (SGP/Waagner-Biró)
Denmark	FLS miljø (Burmeister & Wain Energi)
Germany	Babcock Borsig Power (Deutsche Babcock, Steinmüller)
Great Britain	Mitsui Babcock Energy
India	Bharat Heavy Electricals Ltd. (BHEL)
Italy	Ansaldo
Japan	Babcock-Hitachi Kawasaki Heavy Industries
USA	Babcock & Wilcox Foster Wheeler

BENSON technology is available everywhere, as leading boiler manufacturers in all parts of the world have obtained licenses from Siemens.

Highest Efficiency with Supercritical Pressure

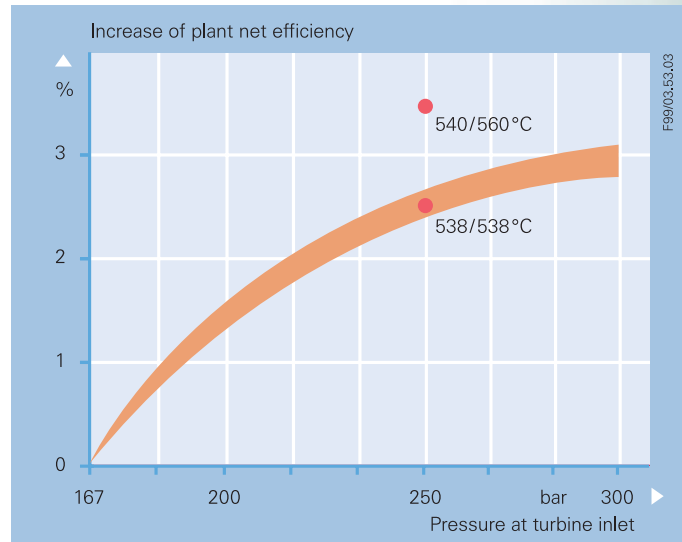
Power plants are currently built for a service life of 30 to 40 years. They must therefore continue cost-effective electric power generation through the year 2040. High efficiency contributes significantly to the cost-effectiveness of steam power plants.

One of the most effective measures for achieving high power plant efficiency is selecting a high design steam pressure. Efficiency increases by roughly 3% on making the transition from 167 bar (e. g. drum boiler) to 250 bar, without significant increases in investment costs. The increased costs for the greater wall thicknesses of the pressure section are largely compensated by the lower costs of the smaller fuel/air/flue-gas path.

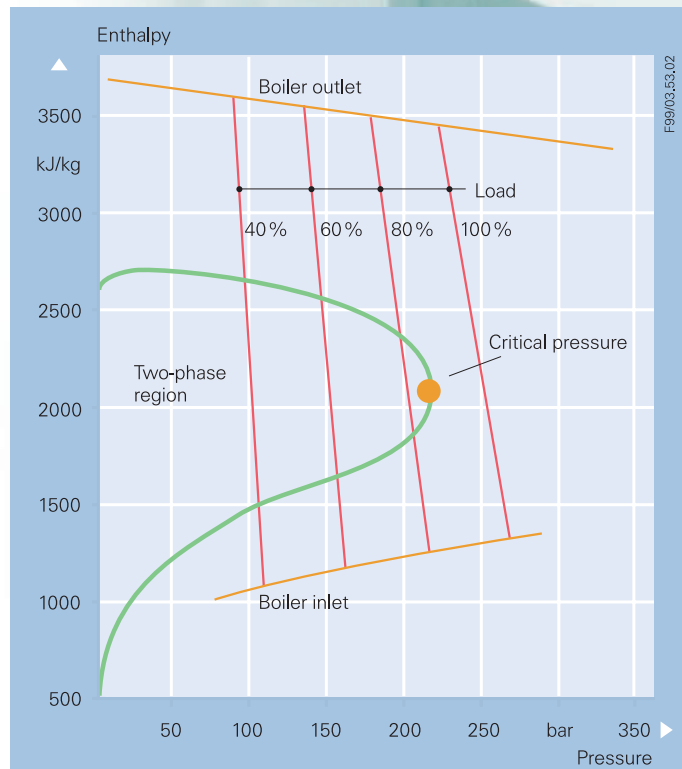
The BENSON boiler can be built with essentially the same design for subcritical and supercritical pressures. Only the dimensions and wall thicknesses of the tubes and headers change with increasing pressure, or the materials limits are shifted.

Main steam properties are selected based only on aspects of cost-effectiveness.

BENSON boilers have been built to date for pressures from 40 to 310 bar.



Increasing steam pressure is the most effective way to increase the efficiency and hence the cost-effectiveness of a power plant.



A BENSON boiler which is designed for supercritical pressures can be operated at any pressure, i. e. also at subcritical pressure.

High Main Steam Temperatures Even at Part Load

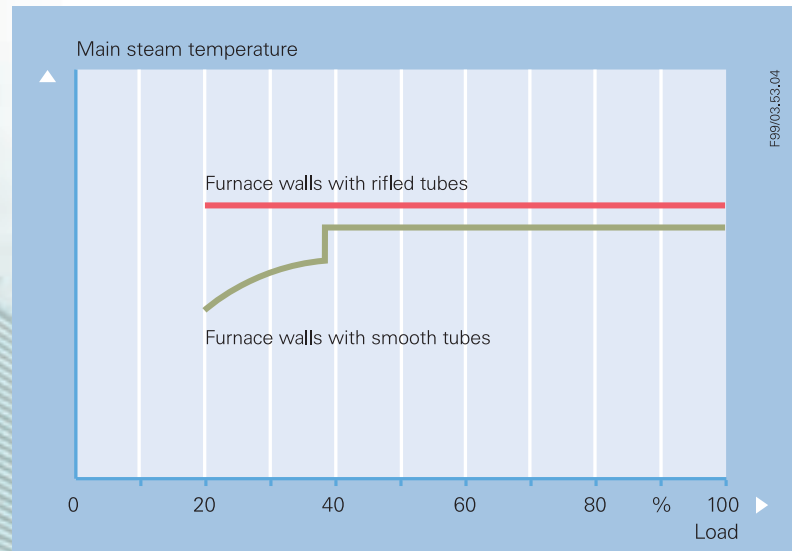


Lippendorf power plant, Germany
 2×936 MW
Steam conditions:
260 bar/554°C/583°C
Lignite
Boiler manufacturer:
Deutsche Babcock

Main steam temperatures in the BENSON boiler are independent of load. This results in a higher process efficiency for the power plant over a wide load range.

The fuel/feedwater flow ratio is controlled in the BENSON boiler such that the desired steam temperature is always established at the main steam outlet. This is made possible by the variable evaporation endpoint. The evaporation and superheating surfaces automatically adjust to operating conditions. In dynamic processes, desuperheaters support maintenance of constant main steam temperature.

Minimum output in once-through operation at high main steam temperatures is 35 to 40 % for furnace walls with smooth tubes and is as low as 20 % if rifled tubes are used.



The variable evaporation endpoint in BENSON boilers enables achievement of high main steam temperatures over a large output range independent of operating conditions.

BENSON Boiler – Suitable for Every Fuel

The size and geometry of the furnace of a BENSON boiler can be optimally matched to the fuel with no restrictions on the water/steam side.

The BENSON boiler enables dimensioning of the furnace based solely on combustion engineering aspects:

- The transition from evaporation to superheating is not fixed in location and can take place at any point in the upper section of the furnace. This enables

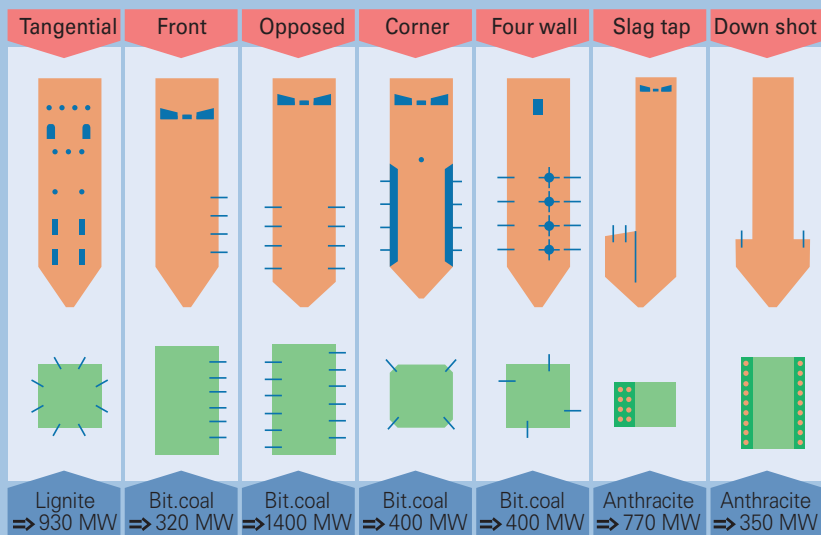
dimensioning of the furnace without restrictions on the water/steam side.

- Forced flow in the evaporator tubes also enables implementation of complex furnace geometries such as for slag tap firing.

The BENSON boiler is constructed with the widest possible range of firing systems. Plants are also constructed with fluidized-bed combustion systems in addition to the examples shown.



Meri-Pori power plant, Finland
560 MW
Supercritical pressure
Boiler manufacturer:
Mitsui Babcock Energy/Tampella



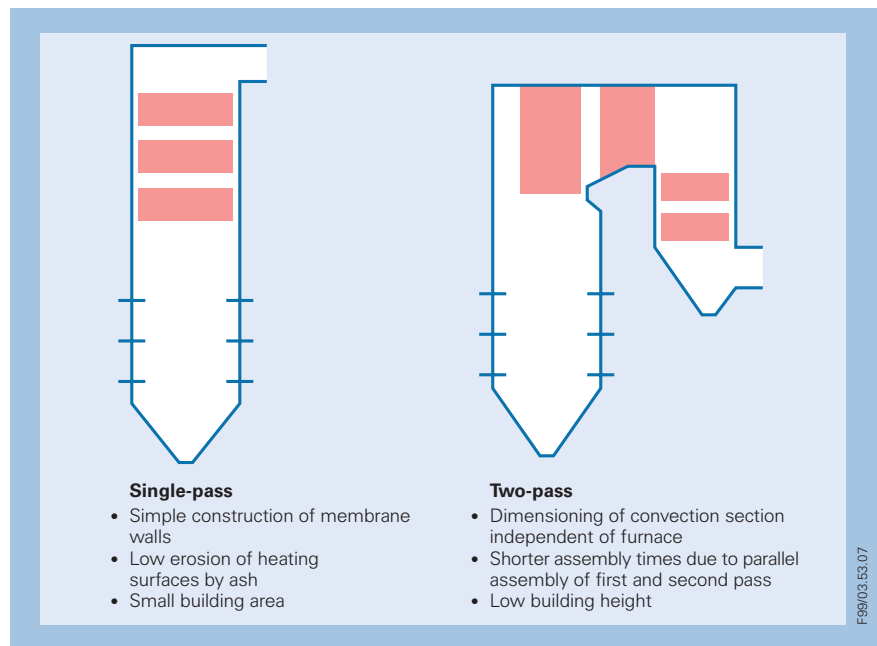
BENSON licensees have extensive experience with the full range of firing systems. Vortex burners are the most prevalent; jet burners are also implemented in tangential firing geometries.

The BENSON boiler design is adapted to the fuel and local conditions.

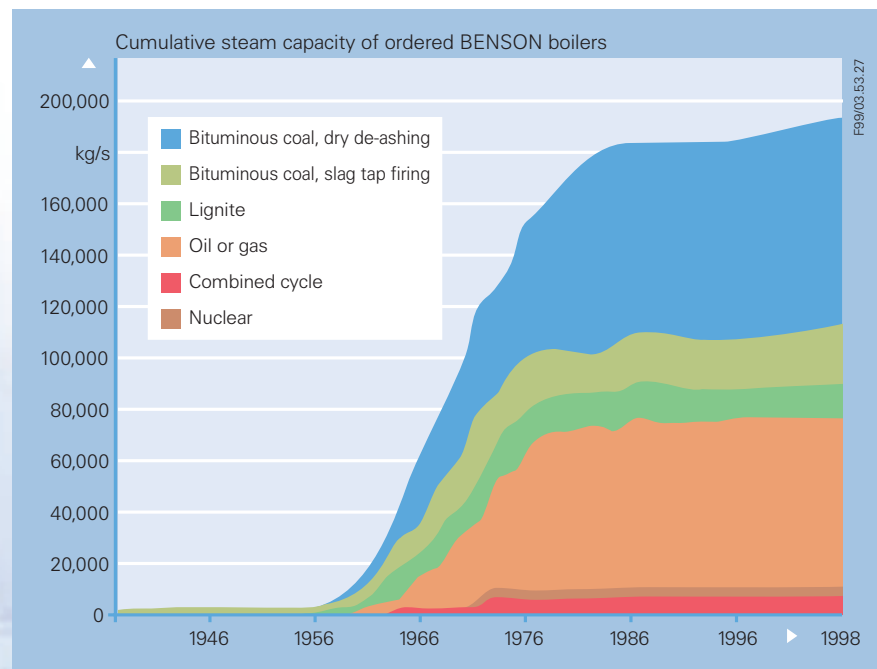
The following concepts have proven themselves for the various fuels:

- Bituminous coal:
Opposed firing, single-pass or two-pass design
- Lignite:
Tangential firing, single-pass design
- Anthracite:
Arch firing (dry or wet ash removal) or opposed firing, single-pass or two-pass design

Even if the coal grade varies within a wide range, steam output and main steam temperature are always achieved in the BENSON boiler.



The two main configurations for the BENSON boiler to date are the single-pass and two-pass design



BENSON boilers are suitable for all fossil fuels as well as for nuclear power plants. More than 1,000 BENSON boilers have been built to date. Their cumulative steam output of 200,000 kg/s corresponds to a power plant output of roughly 220,000 MW.

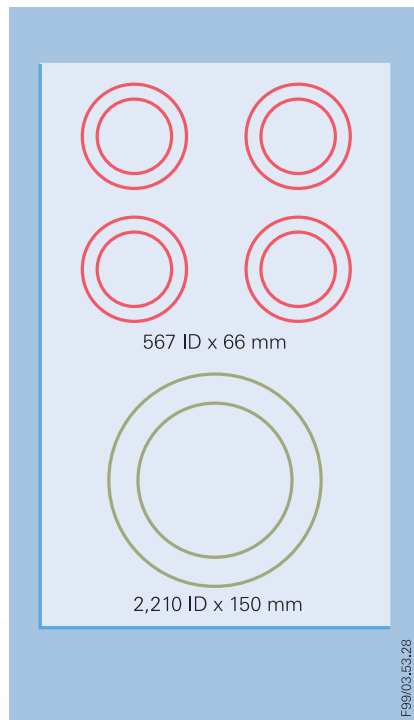
Thermoelastic Construction for Flexible Operation

The thermoelastic construction and small thermal storage masses in the BENSON boiler enable flexible power plant operation with short startup times and large load transients over a wide output range.

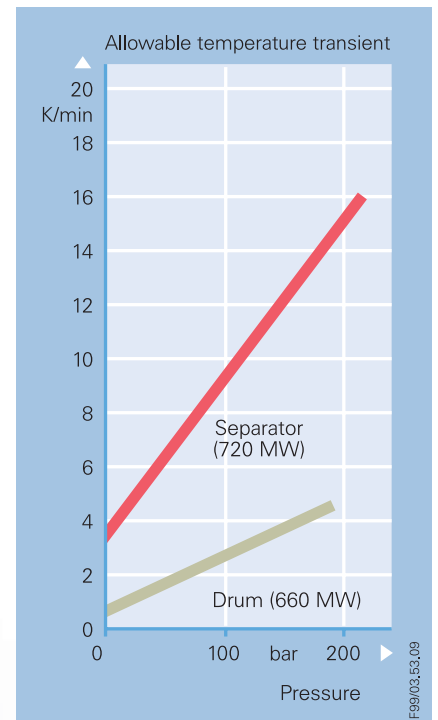
The BENSON boiler is characterized by thermoelastic construction which results in only low thermal stresses due to temperature changes. There is no thick-walled drum at the end of the evaporator; instead there are only several thin-walled separators with high allowable temperature transients.

A further advantageous characteristic of the BENSON boiler are the small thermal storage masses, which also have a positive effect on flexibility.

Short startup times and high output transients over wide output ranges are therefore possible for the BENSON boiler.



Instead of a thick-walled drum, the BENSON boiler has several thin-walled separators configured for parallel flow.



The allowable temperature transients for the separator of a 250-bar BENSON boiler are roughly three times as large as for the drum in a 175-bar drum boiler.



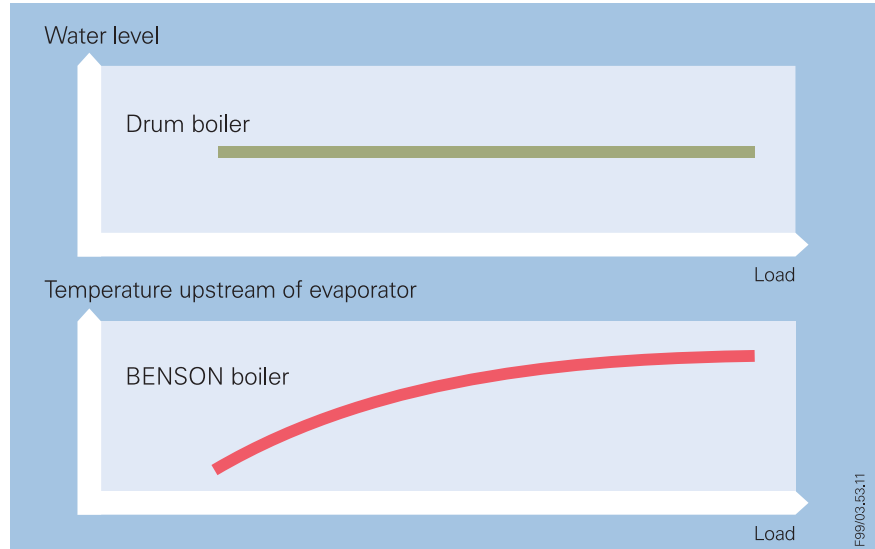
Majuba power plant, South Africa
 3 × 660 MW + 3 × 715 MW
 High-ash coal
 Boiler manufacturer: Steinmüller

Control – Proven and Reliable

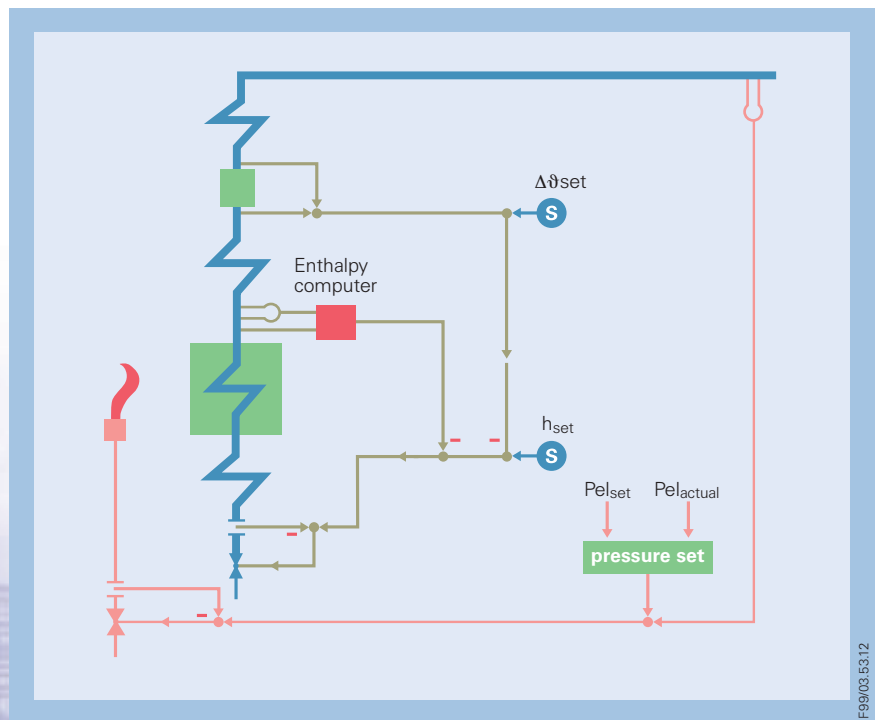
Optimized control concepts and the advantages of the BENSON principle result in exceptional operating behavior.

Control of a BENSON boiler differs from that of a drum boiler primarily only in the control parameter for feedwater control.

The setpoint for this control parameter is automatically acquired in the BENSON boiler from a shift in heat transfer between the evaporator and superheater. This accounts for load dependency, the degree of fouling of the heating surfaces and conditions such as HP feedwater heater out of service. The setpoint is selected such that the main steam temperature always remains constant under all operating conditions.

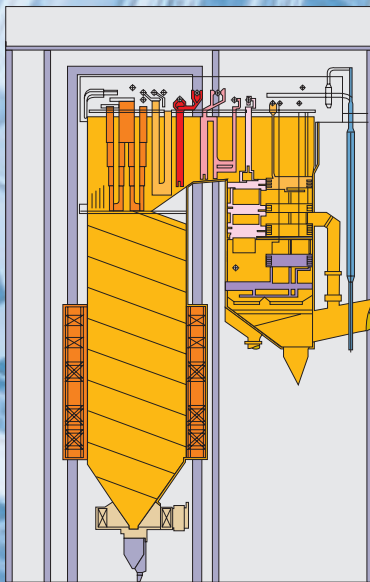


Drum water level is used for controlling the feedwater flow in a drum boiler, while temperature or enthalpy downstream of the evaporator are used in a BENSON boiler.



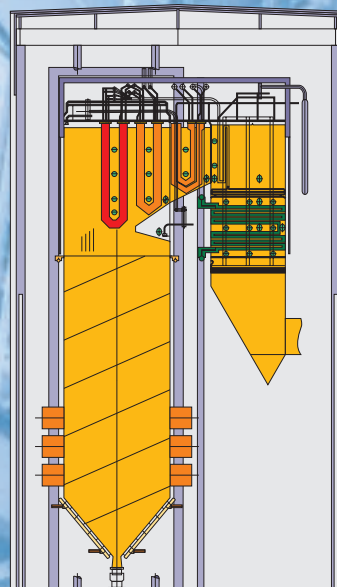
The proven control principles for steam boilers also hold for BENSON boilers. Measured values on the water/steam side influence feedwater control, while those from generator output and steam pressure are used to generate the setpoint for fuel control.

Completed BENSON Boilers



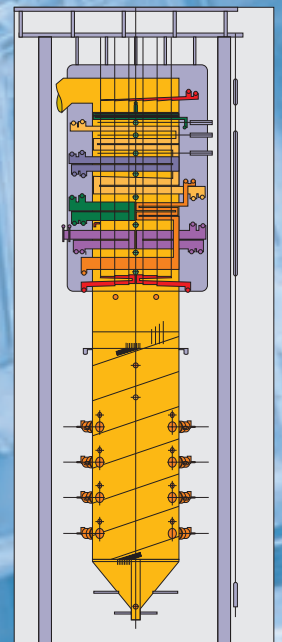
Hekinan power plant, Japan

639 kg/s - imported coal
255 bar/543°C/569°C
Manufacturer:
Babcock-Hitachi



Hemweg power plant, Netherlands

530 kg/s - imported coal
261 bar/540°C/540°C
Manufacturer:
Mitsui Babcock Energy/Stork

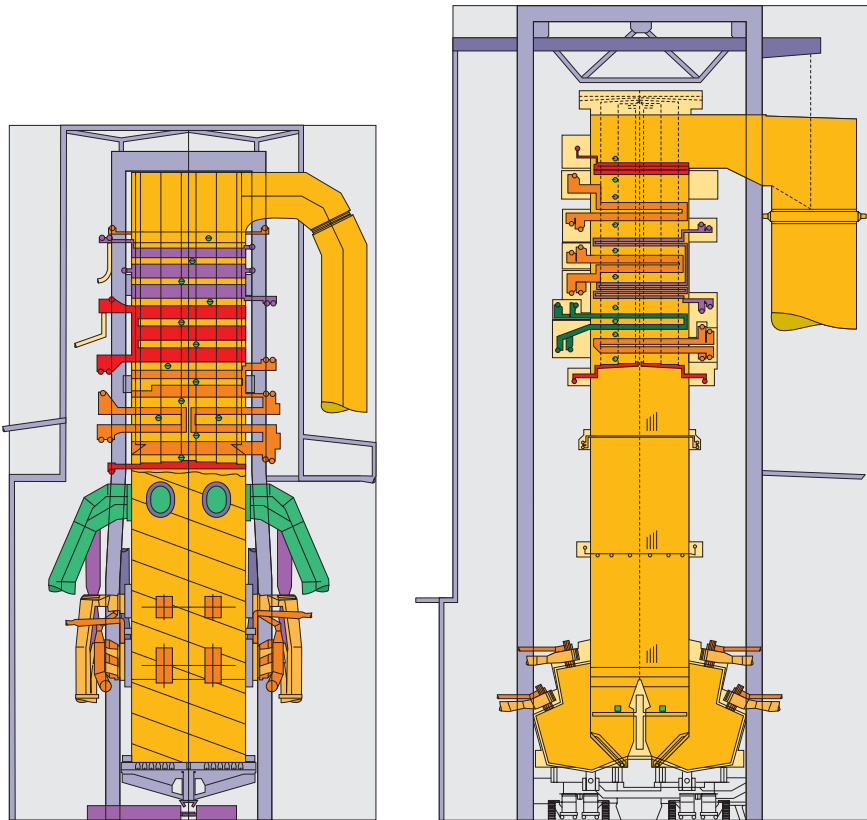


Nordjyllandsvaerket power plant, Denmark

270 kg/s - imported coal
310 bar/582°C/580°C
Manufacturer:
Burmeister & Wain



Furnace (under construction)
in a 936-MW unit at Lippendorf
power plant

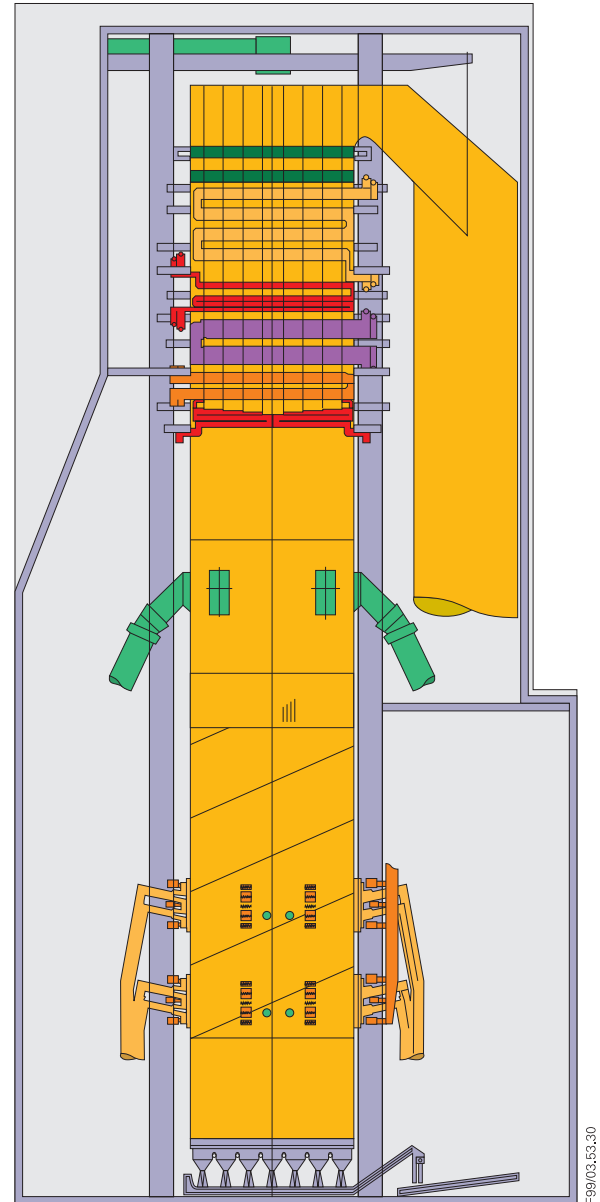


**Aghios Dimitrios power plant,
Greece**

286 kg/s - lignite
242 bar/540°C/540°C
Manufacturer:
AE&E

**Ibbenbüren power plant,
Germany**

600 kg/s - anthracite
220 bar/530°C/530°C
Manufacturer:
Steinmüller



**Lippendorf power plant,
Germany**

672 kg/s - lignite
285 bar/554°C/583°C
Manufacturer: Deutsche Babcock

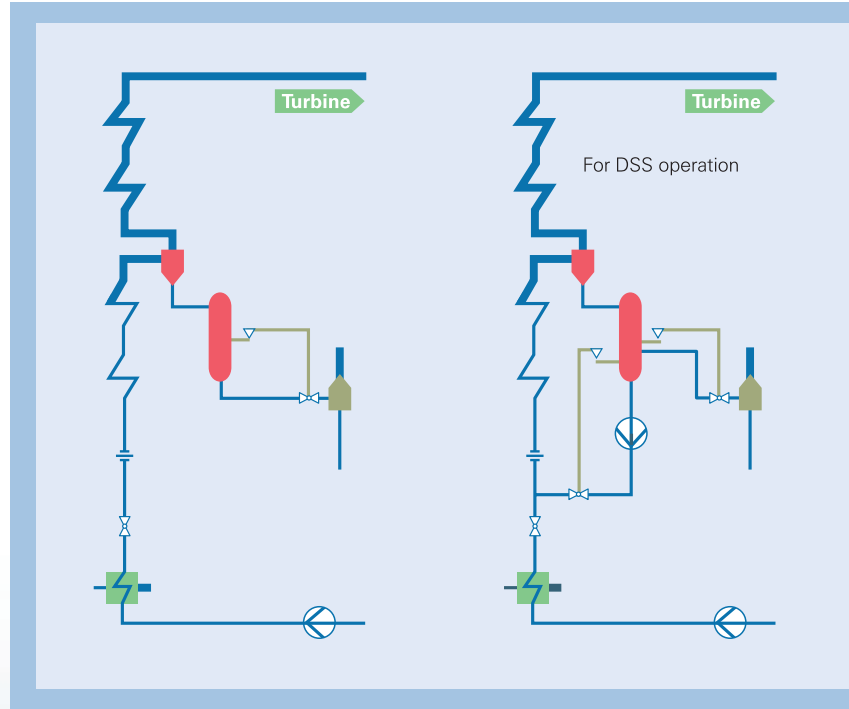
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Startup – Low Losses and Low Thermal Stresses

BENSON boilers with proven startup and bypass systems yield short startup times while imposing the lowest possible stress on materials.

BENSON boilers can be started up easily and rapidly, and with low life-limiting effects on the material, using the same method, from any operating condition. The integrated startup system is in operation only during startup.

The unit is normally equipped with a turbine bypass system. The high-pressure turbine as well as the intermediate-pressure/low-pressure turbines are equipped with separate bypass valves and lines. This enables flow through all superheater surfaces and thus reliable cooling even shortly after ignition.



Mehrum power plant, Germany
660 MW
Daily startup and shutdown
Boiler manufacturer:
Deutsche Babcock/Steinmüller

The BENSON boiler startup system consists of several separators, a collecting vessel and a flash tank. Installation of a circulation pump is cost-effective for frequent startup, as this further reduces startup losses.

Flexible Sliding-Pressure Operation

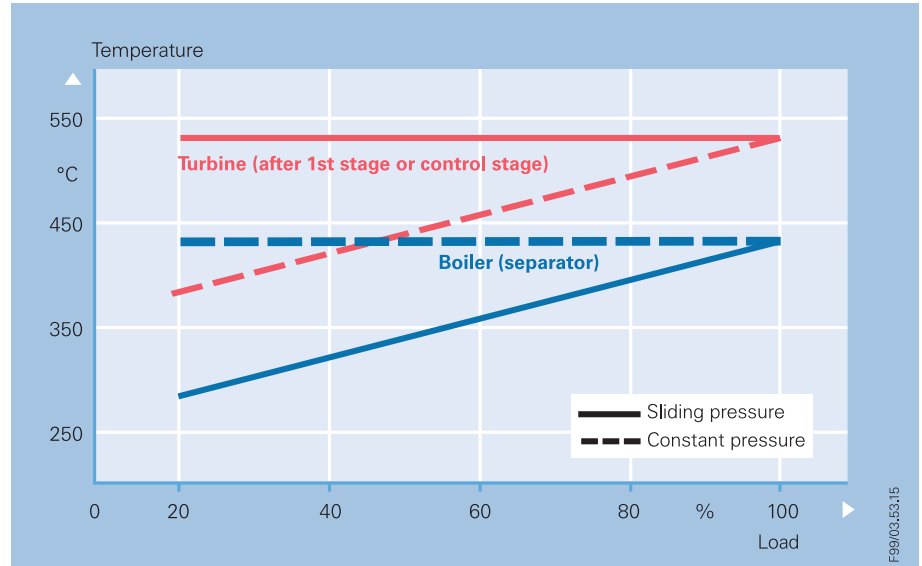
A coal-fired unit with a BENSON boiler can sustain load transients of 4 to 6%/min even over a wide output range.

Temperature changes occur in the boiler and in the turbine during load changes. These can cause thermal stresses in thick-walled components. These are especially high in the turbine during constant-pressure operation. They therefore limit the maximum load transient for the unit. By contrast, in sliding pressure operation, the temperature changes are in the evaporator section. However, the resulting thermal stresses are not limiting in the BENSON boiler due to its thermoelastic design.

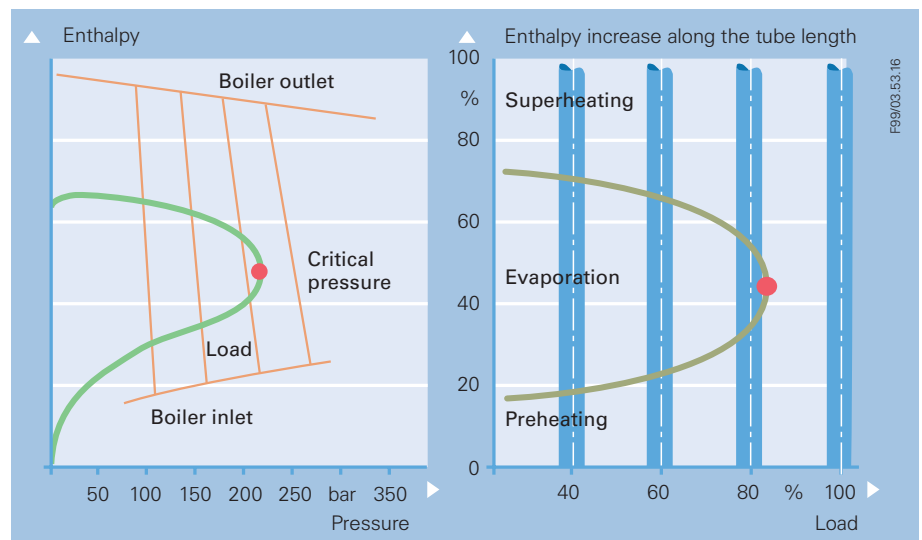
Power plants with BENSON boilers are therefore especially well-suited to sliding-pressure operation. This operating mode is required by most customers worldwide.

As the adjacent figure shows, the advantage of the variable evaporation endpoint becomes especially clear in sliding-pressure operation.

The enthalpy increase in the boiler for preheating, evaporation and superheating changes with pressure. However, pressure is proportional to output in sliding-pressure operation. In a uniformly heated tube, the transitions from preheat to evaporation and from evaporation to superheat shift automatically with load such that the main steam temperature always remains constant.



In fixed-pressure operation, temperatures change in the turbine when load changes, while in sliding-pressure operation, they change in the boiler.



The fractions for preheat, evaporation and superheat change with pressure in the boiler (left). In sliding-pressure operation, the size of the heating surfaces automatically adapts to these conditions (right).

Siemens R&D Ensures the Technological Advantage of the BENSON Boiler

Customers require the highest possible reliability for their plants based on scientifically founded design fundamentals.

The excellent operating experience and high reliability of the BENSON boiler are based on

- intensive research and development at Siemens. The BENSON test rig plays a central role in this.
- continuous exchange of information between Siemens and BENSON licensees and customers as well.

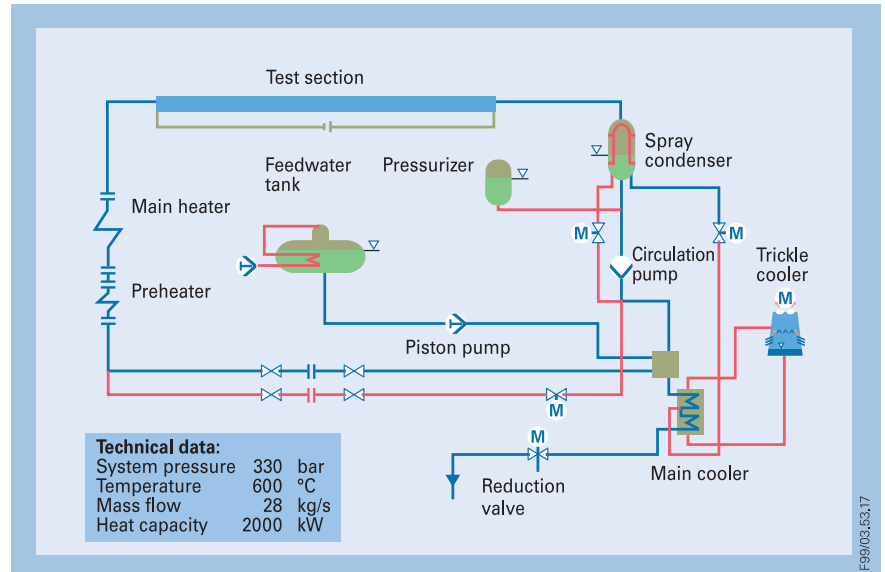
Important tasks for the BENSON test rig are measurement of heat transfer and pressure drop in tubes as well as investigations of thermoelastic components and feedwater considerations.

The test matrix gives an overview of the measurements which have been systematically performed since 1975 for a wide range of parameters.











These measurements enabled generation of scientifically founded design documents as well as such achievements as increasing heat transfer in rifled tubes by approximately 50 % through optimization of rifling geometry.



2 × 1100-MW power plant, USA
Vertically-tubed furnace (UP design)
Boiler manufacturer:
Babcock & Wilcox



The BENSON test rig in Erlangen is one of the highest-performance test facilities for the water/steam cycle anywhere in the world. It is constantly being adapted to current requirements.

Tube geometry	Smooth		Rifled	
Number of measurements (1998)	> 100.000		> 160.000	
Heating	 uniform	 one side	 uniform	 one side
Tube orientation	vertical 	inclined 	horizontal 	vertical  inclined  horizontal 

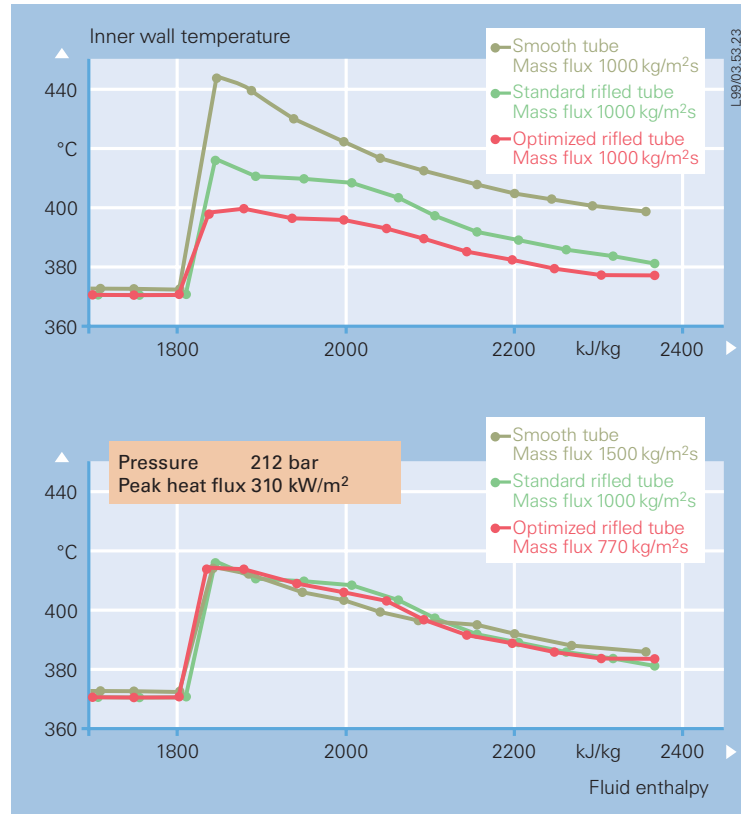
Investigations over several decades have enabled Siemens to establish the world's largest database for heat transfer and pressure drop in tubes.

Rifled Tubes – Design Elements of the Future

The outstanding heat transfer characteristics of rifled tubes enable simplification of the design of the BENSON boiler and further improvement in its operating behavior.

The rifled tube has proven itself in operation in several hundred boilers since the '70s. Siemens uses this experience to significantly improve rifling geometry with regard to heat transfer.

The upper part of the figure shows tube wall temperatures at the same mass flux for a smooth tube, a standard commercial rifled tube and a rifled tube optimized by Siemens. The lower portion of the figure demonstrates how it is possible to reduce mass flux in an optimized rifled tube by roughly half that in a smooth tube at the same wall temperature. This result has led to an innovative further development of the vertically tubed BENSON boiler.



The outstanding heat transfer characteristics of the optimized rifled tube can be utilized to reduce either tube wall temperatures or mass fluxes in rifled tubes.

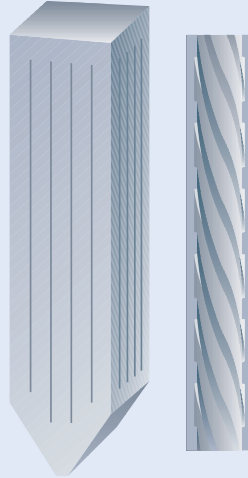
BENSON Boiler with Vertically Tubed Furnace

The vertically tubed BENSON boiler is a reliable design for the future due to its simple design and optimal operating characteristics. Further development of the vertically tubed BENSON boiler has resulted in the generation of a boiler design combining low investment costs, outstanding operating characteristics and high reliability. Its range of application extends from 300 to over 1000 MW.

Of the more than 1000 BENSON boilers constructed to date, roughly 600 have a vertically tubed furnace, most of these with several trains connected in series.

Implementation of optimized rifled tubes with enhanced heat transfer characteristics now enable parallel configuration of all furnace tubes even in vertically tubed BENSON boilers.

Advantages of the BENSON boiler with vertical rifled tubes



Vertically tubed
BENSON boiler

Rifled
tube

Compared to a once-through boiler with a spiral configuration of furnace tubes, a vertically tubed BENSON boiler exhibits a number of advantages in terms of its design and operation:

- Straightforward and maintenance-friendly design for highest efficiency levels,
- Cost-effective manufacture and assembly,
- Welded-on support straps are not required,
- Simple startup system, a startup circulation pump is not required,
- Lowest part loads down to 20% are possible while maintaining high main steam temperatures,
- Reduced slagging of furnace walls,
- The evaporator pressure drop is reduced from 10 bar to 5 bar, low auxiliary power needed for feed pump.

The BENSON boiler with vertical rifled tubes combines the advantages of the BENSON boiler with spiral-wound furnace tubes with the simple design of the drum boiler.



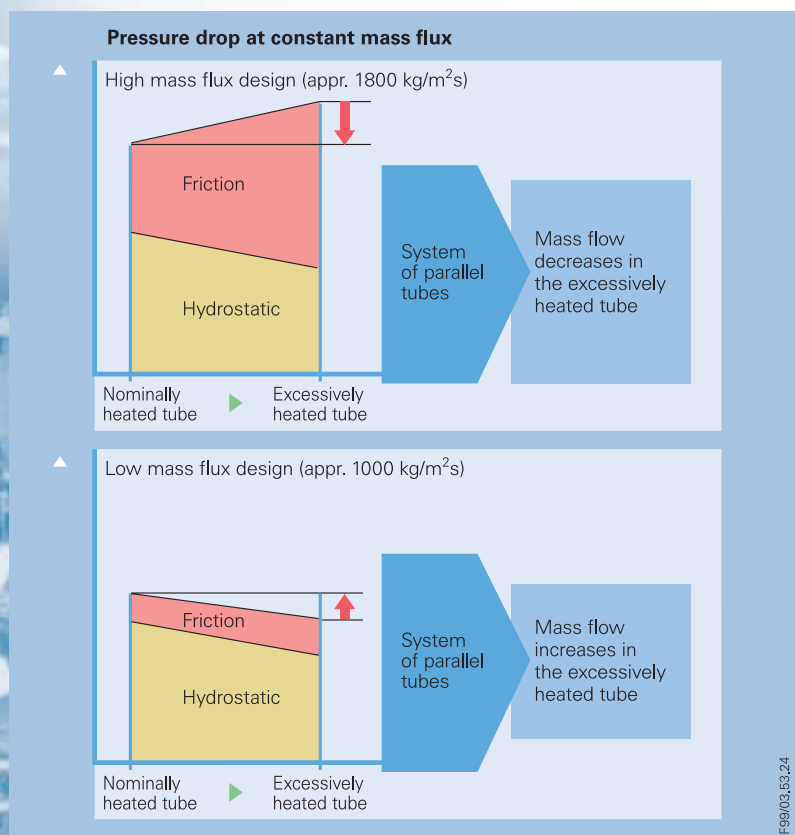
Matsuura power plant, Japan
2 × 1000 MW
UP boiler with vertical tubes and
boiler with spiral-tube furnace
Boiler manufacturer:
Babcock-Hitachi

The special feature of this further development of the BENSON boiler is reduced mass flux in the evaporator tubes. This leads to the following behavior of a single tube with higher heat input:

- The geodetic pressure drop decreases due to increased steam generation, and throughput increases.
- Simultaneously, the pressure drop due to friction increases as a result of the higher steam quality and the higher mass flow.

- However, as the influence of the pressure drop due to friction on the mass flow is only slight, the mass flow through the tube with higher heat input increases.

This favorable behavior of drum boilers is known and is referred to as the natural circulation characteristic. It results in improved cooling of the tube with higher heat input. Installation of flow restrictors for more uniform flow distribution is not required.



In the high mass flux design, mass flow through a tube with higher heat input decreases, while in the low mass flux design it increases, thus reducing possible temperature differences at the evaporator outlet.

BENSON Technology – Best Choice for Modern Power Plants

Siemens milestones in the field of coal-fired power plants:

1882	Separation of radiant and convective heat transfer areas in boiler first proposed by F. Siemens
1924	Siemens obtains patent rights from Mark Benson and develops the BENSON boiler.
1926	Siemens manufactures the first BENSON boiler with 30 t/h
1933	Siemens ceases manufacturing boilers and awards BENSON licenses to several boiler manufacturers
1933	Siemens introduces variable-pressure operation
1949	The world's first high-pressure/high-temperature power plant with once-through boiler (175 bar/610°C, BENSON boiler at Leverkusen, Germany)
1954	The world's first steam turbine with supercritical steam conditions: 300 bar/600°C
1962	First directly water-cooled generator stator and rotor
1963	The world's first boiler with spiral-wound tubes in membrane wall design (BENSON boiler at Freiburg, Germany)
1987	The world's largest coal-fired unit with full arc admission steam turbine, boiler with spiral-wound water walls and sliding pressure operation (900 MW unit with BENSON boiler at Heyden 4)
1994	Siemens proposes vertically tubed water walls in low mass flux design for BENSON boilers
1995	Order for the world's largest steam turbine-generator in tandem design. Rating: 1000 MW (251 bar/575°C/599°C for Niederaußern power plant)
2000	1000 BENSON boilers sold with >700.000 t/h in total

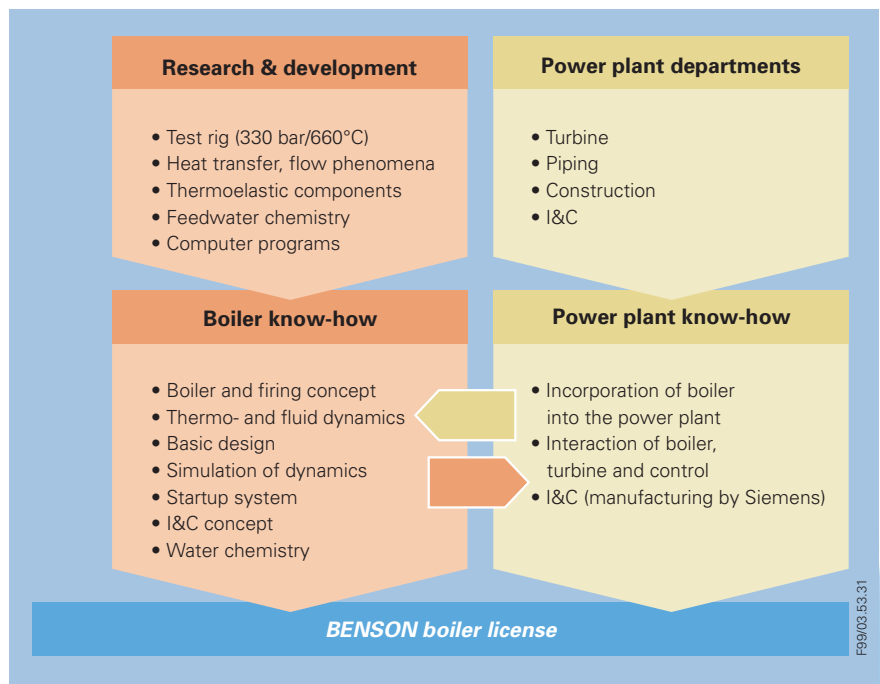
Siemens is the licensor for BENSON boilers. Leading boiler manufacturers around the world make use of this concentrated expertise.

This know-how is continuously extended and updated with continuous development and global exchange of information. In addition to BENSON technology, it also includes interaction of the BENSON boiler with the turbine and with other major components as the basis for cost-effective and reliable power plant operation.

To date over 1000 BENSON boilers have been built worldwide. This constitutes roughly 60 % of all once-through boilers (not including the states of the former Soviet Union).

The following operating parameters have been achieved:

- Output up to 1232 kg/s (4435 t/h)
- Pressure up to 310 bar
- Temperature up to 650°C



Siemens has comprehensive know-how for engineering turnkey power plants. This know-how is the basis for the success of the BENSON boiler – a key component of the plant.

Siemens – Competence in Power Plant Engineering

Siemens Power Generation plans and designs power plants, constructs turnkey plants as a general contractor, participates in erection consortia or works together with architect engineers.

Siemens provides the following services for fossil-fueled power plants:

- Steam turbine power plants with coal, gas or oil firing
- Gas turbine and combined-cycle plants with both gas and steam turbines (unfired combined-cycle, parallel-powered and GUD units)
- GUD plants with integrated coal gasification
- Engine-based cogeneration plants.

Component deliveries:

- Steam turbines up to 1200 MW
- Gas turbines up to 260 MW
- Turbine-generators
- Plant and turbine-generator I&C
- Electrical engineering
- Catalytic reactors and catalysts for nitrogen oxide control.

Manufacture of power plant components is supplemented by comprehensive expertise in the field of BENSON boilers. This combination of first-hand power plant knowledge and free choice of boiler manufacturer is a typical feature of Siemens power plants and ensures high cost-effectiveness and high reliability.

Services

Siemens supports its customers in every phase of a power plant project and its subsequent service life by providing all desired services:

- Grid extension planning
- Project development (generation of feasibility studies, elaboration of financing concepts, support in the licensing phase, formulation of project contracts, cooperation in risk management, participation in the project company with equity capital)
- Plant operation (participation in operations management, service and repairs, upgrading and modernization, backfitting and expansion, personnel training)

Development - Planning - Manufacturing - Supply - Construction - Service

Installed capacity worldwide

Plant type	Overall output (MW)
Fossil-fueled steam power plants	328,000
Gas turbines	92,000
Industrial power plants	27,000
Nuclear power	100,000
Total thermal power	547,000
Hydroelectric	95,000

(including Allis Chalmers, Parsons and Westinghouse)

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Two names – one global company

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Order No.: A96001-S90-A469-V2-7600
Printed in Germany
101502M.WS.04011.
SEK No. 22209