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CONTI AND BATCH HEAT TREATMENT PLANTS FOR WIRE INDUSTRY

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Overview and Latest Technical Enhancements

Different heat treatment processes are available for different types of steel wire as a function of steel grade, process step and metallurgical requirements on the final product.

Depending on the operation mode, these heat treatment processes can be subdivided into two groups of heat treatment plants: On the one hand there are continuously and respectively semi-continuously operated heat treatment plants; and on the other hand, there are batch-operated heat treatment plants.

Typical furnaces for continuously operated heat treatment plants are roller hearth furnaces (with/without protective gas) and rotary table/rotary hearth furnaces (with/without subsequent quench).

As semi-continuously operated heat treatment plants STC[®] furnaces can be categorized.

For the group of batch-operated heat treatment plants HPH[®]- Bell-type furnaces with H₂, HN_x or N₂-atmospheres, chamber furnaces with/without protective gas and with/without subsequent quench are typically furnace types.

The Tenova group with its furnace manufacturers Tenova LOI Thermprocess (Essen, Germany) and Tenova Italimpianti (Genoa, Italy) is the only furnace manufacturing company in the world that is able to offer all above-mentioned furnace types. Due to this advantage, it is possible to select and deliver a furnace design that optimally meets the individual conditions of every customer.

Here in below you find a description and comparison of continuously- and batch-operated furnace designs as well as an introduction to their latest technical enhancements.

Conti Rotary Table/ Hearth Furnaces for solution annealing of wire coils of stainless steel

Process Technology

Stainless steel wire coils require rapid heating up from ambient temperature to a temperature sufficiently high for dissolving the carbon; at the same time, this heating must be slow enough to minimize grain growth. In the next step, the coils need to be cooled down to ambient temperature within very short to keep the carbon dissolved and to prevent inter-crystalline corrosion.

Due to its geometry and the circulating combustion gases, the external layers of the wire coil will heat up more quickly than the internal layers. Aiming at a high and homogenous material quality it is reasonable to heat up the charging material in two phases. In the first phase, the material is heated up to a temperature at which the carbon is dissolved without grain growth. Following a temperature compensation between the external and internal coil layers further heating up to the target temperature takes place including another temperature balance between the external and internal layers. For a division of the heating zones, a raisable and lowerable dividing wall can be installed in the furnace.



▲ Figure 1. Conti Rotary Table Furnace for solution annealing



▲ Figure 2. Conti Rotary Hearth Furnace

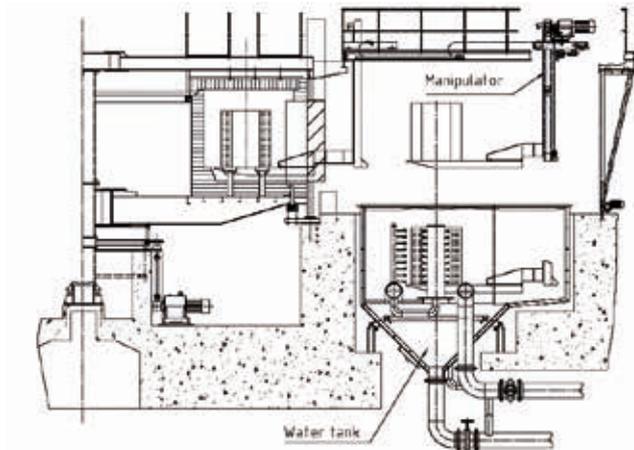
System Features

For the solution annealing of stainless steel wire, Tenova LOI Thermprocess offers open heated rotary table /rotary hearth furnaces with automatic manipulators for charging and discharging and a water or polymer quenching technology. The furnaces feature a compact design. While rotary table furnaces (Figure 1) are mainly used in case of minor throughput rates, rotary hearth furnaces (Figure 2) are applicable for larger throughput rates. Since the furnace interior does not comprise any metallic components, both furnace types are most suitable for heat treatment temperatures of max. 1,200° C required for stainless steel.

The most frequent design features a rotatable hearth on a large ball bearing (Figure 3). In case of the rotary table furnace, the hearth and the internal furnace wall create a

common construction part. Electrical or hydraulic drives at the exterior of the large ball bearing ensure the hearth rotation. Both the external furnace wall and the furnace ceiling are designed as fixed components. A water through with sealing blade at the exterior of the rotary hearth and a sand cup with a sealing blade in the area of the furnace ceiling and at the inner furnace wall are installed to seal the furnace chamber.

The external furnace wall accommodates the furnace doors for charging and discharging. For sealing purposes, every door mechanically presses against its frame. Two stationary separation walls made of refractory material separate the charging and discharging areas in the furnace. Anchored in the furnace ceiling and reaching to the hearth bottom with a certain distance, these separation walls subdivide the two areas into various



▲ Figure 3. Plant structure of a Conti Rotary Table Furnace with water tank

temperature zones. Radiation burners installed in the furnace ceiling heat the furnaces. The manipulator fork places the individual wire coils directly on the ceramic supports of the hearth. These ceramic supports, as well as the hearth, are made of high-quality refractory material. Since the fork arms of the manipulator accurately fit between the ceramic supports during charging and discharging, no charging trays are required for the charging process. Upon discharging, the manipulator places the wire coil directly above the quenching basin before an elevator lowers the wire coil into the water or polymer bath. Nozzles at the exterior and in the middle of the coil ensure media circulation for an optimised heat transfer and prevent steam formation. Moreover, pumps, filters, and re-coolers have been designed for the cooling water.

The applied heating technology meets the latest energetic criteria; e.g. the heat in the waste gas is re-fed to the combustion air and thus to the process via an air heat exchanger. Depending on the performance and temperature level, central recuperators, regenerative burners or recuperative burners may be used. The burner design makes sure an excellent heat transfer is taking place and waste gas emissions (NO_x, CO, CO₂ etc.) are reduced to a minimum.

The effective automation of temperature and material control features an essential component of the state-of-the-art rotary table / rotary hearth furnace.

High-quality armatures and sensors are used which are

coupled with a modern PLC-control including corresponding visualization system.

Envisaging a further automation and optimisation of the production process by exchanging the required material data (quality, dimensions, weight, etc.), it is possible to directly link the furnace control system with the customer's control system. Tenova LOI Thermprocess disposes of its own expertise and programs. Thanks to the networking of the computer systems including the used field devices, these furnaces meet the latest state-of-the-art technology and are Industry 4.0-compatible.

The main advantages are:

- Tall buildings are not required to lift equipment over other equipment.
- The compact design of the plant due to the typical round design with doors.
- Possibility to install two quench tanks to operate with different quenching media (water and polymer)
- Possibility to treat coils without charging trays

The typical results are:

- Solution annealing achieves 100 % uniformity
- Coil temperature uniformity within ± 3 °C
- Maintains temperature within ± 2 °C of set point during soaking period
- Zero material reprocessing

The described rotary table/rotary hearth furnaces are mainly used for throughput rates of max. 10 t/h and for coils with a maximum diameter of 2,000 mm and a weight of max. 2,000 kg.

Batch Furnaces and quench units for solution annealing of special steel wire & rod coils and bars

Process Technology

Semi-finished products of special steels are heat-treated by a variety of processes in order to improve cold

working properties. Fast cooling “Quenching process” is often considered in order to modify the structural conditions of the material.

The accuracy of the heating process, soaking at a suitable temperature and cooling speed are key factors for the final mechanical property of the material and repeatability of the process. They allow the end user to reach highest quality standards, as required on the “High Value” steel product market, such as aerospace and military.

System Design

For this scenario, Tenova offers a technological solution with a set of chamber type furnaces for heat treatment of wire and rod coils arranged close to a stainless steel tank, where the quench process takes place. The compact, circular arrangement reduces the transport time of material from the furnace to quench tank to a minimum, which is an advantage for the ideal quench process.

Standard charging/discharging roller tables and tilting devices complete the plant, designed in a modular way so that it is possible to adapt the design to different productivity.

The heat treatment plant with box-type furnaces has a standardised size, actually up to 3 tons per charge capacity. As an advantage of the modular configuration several furnace units can be combined to match the total capacity to the needs. The optimised design allows pre-assembling in the workshop of the carousel charging/discharging machine, quench tank, furnaces and roller tables with consequent easy installation on site.

Most common configuration, preferred by customers for its compactness, foresees a set of chamber furnaces disposed on a semi-circle with the quench tank in the centre, the carousel charging/discharging machine on the other side of the semi-circle together with charging/discharging roller tables (Figure 4).

With the adaptation of computer control, the plant is operating fully automatic and allows unmanned operation.

Once the coil is positioned on the tilting device, the operator only has to select the relative recipe designed according to the kind of process, material, and grades.



▲ Figure 4. Batch Furnaces incl. quench and manipulators

The computer control automatically initiates all the combustion, quench process and transferring loads functions. The material handling system only requires a forklift for loading and unloading coils on the tilting device. The need for a crane is thus eliminated.

The main advantages are:

- Tall buildings are not required to lift equipment over other equipment
- The compact design of the plant due to the typical “semi-circle arrangement” of the equipment
- Possibility to install two quench tanks to operate with different quenching media (water and polymer)
- Possibility to simultaneously treat different materials with different cycles (theoretically each box furnace can operate a different cycle)
- Possibility to expand the production capacity according to the market demand by adding a new module while keeping the existing handling equipment

The typical results are:

- Solution annealing achieves 100% uniformity
- Coil temperature uniformity within $\pm 3\text{ }^{\circ}\text{C}$
- Maintains temperature within $\pm 2\text{ }^{\circ}\text{C}$ of set point during soaking period
- Zero material reprocessing

Batch HPH® Bell-type Furnaces for spheroidising of rolled wire and recrystallising of drawn wire coils with H₂, HN_x or N₂ atmosphere

Process Technology

Multi-stack Bell-type furnaces (Figure 5) are used in the Wire industry (wire rolling mills and wire drawing shops) for the heat treatment of rolled wire and drawn wire coils. The heat treatment of rolled wire (spheroidising annealing) does not only aim at the low tensile strength indispensable for the subsequent cold forming process but additionally at a defined structure including a globular cementite ratio of min. 90 %. The following feature is typical of this annealing: upon a heating-up time to the conversion temperature Ac1 and a holding time, a controlled slow cooling to a temperature significantly below Ac1 takes place in the heating hood.



▲ Figure 5. Multi-stack Bell-type Annealing Furnace

The drawn wire is subject to one or several recrystallisation heat treatment(s) (depending on the required reduction to the final wire diameter). The final annealing of drawn wire products enables the creation of a recrystallised micro structure of specific hardness, tensile strength, and formability. To ensure top annealing qualities, either 100 % hydrogen, 100 % nitrogen or an individually selectable mix is used as process atmosphere. Thanks to the sophisticated process control system including plausibility checks, protocol-led fault messages and automatic safety reaction, the use of 100 % hydrogen as the protective gas atmosphere have since long proved to be the reliable technology for Tenova LOI Thermprocess HPH® (High-Performance Hydrogen) Bell-type furnaces.

System Features

Figure 6 illustrates the general structure of an HPH®



▲ Figure 6: Bell-type base with stationary charging places
Bell-type annealing furnace.

Since coils of rolled or drawn wire dispose of a relatively high specific volume, Bell-type annealing furnaces with a side-by-side arrangement of several coil stacks on the

annealing bases are used for reasons of economic efficiency and flexibility. The typical bell-type annealing plants for rolled and drawn wire feature a usable diameter of 2,600 to 4,600 mm and stack heights of max. 5,400 mm. Due to its extremely robust design, the long-term tested HPH[®]-annealing base has been developed for a maximum lifetime in case of the increasingly used high-temperature annealing processes of e.g. ball bearing steels. Applying the FEM (Finite Element Method), Tenova LOI Thermprocess has elaborated an optimised base design with stationary, highly resistant charging places (Figure 7) for wire rolling mills and wire drawing shops that both use wire coils with almost identical dimensions.



▲ Figure 7: Optimised base design with stationary, highly resistant charging places

The advantages of this new base design are the easier charging process for the operator and the reduced base weight that results in a shortened annealing and cooling time as well as in a reduced specific energy consumption per annealing cycle. Customers have meanwhile successfully used this latest base design for four years. In addition to carry the charge load, the annealing base has to ensure the protective gas circulation, the so-called HPH[®]-high convection technology. The high recirculation rate of the process gas guarantees the best annealing performance and utmost temperature uniformity in the entire charging area. The recirculation system consists of a 1,300 mm large impeller made of heat-resistant material and a frequency-controlled recirculation motor of max. 95 kW.

Semi Conti Short Time Cycle (STC[®]) Roller Hearth Furnaces for wire & rod coils and bars heat treatment under endothermic gas atmosphere

Process Technology

Semi-finished products of special steels are heat treated by a variety of processes in order to improve their cold working properties. Formerly, continuous furnaces with either large processing capacities or a design for specific applications had been developed and used. In the recent days, trends are changing; the demands have increased for many kinds of small heat treatment furnaces. They feature a higher productivity than conventional special-purpose furnaces and are at the same time capable of high-quality heat treatment. Various kinds of heat treatment (annealing, normalising, carbon restoration, etc.) of wire coils, rod coils, bars, pipes, cold forging parts etc. are possible with a productivity and quality that are higher than those achieved by special-purpose furnaces.

Purified nitrogen and endothermic gas are used as furnace protective gas atmosphere. The endothermic gas atmosphere is fed into the furnace. This atmosphere is supplied according to the processing function value PF (potential factor $(CO)_2/CO_2$); its CO and CO₂ gases are continuously analysed and recorded by the installed infrared analyser. The gas generator design allows the saving of atmosphere gas by controlling produced gas in correspondence to the consumed furnace gas atmosphere, while the stabilised gas composition is maintained. Nitrogen gas is used in the cooling chamber in the case of atmosphere gas cooling.

System Design

The semi-continuous short time cycle (STC[®]) roller hearth furnace has a standardised size from 4 to 56 ton per charge capacity. Due to its modular configuration, the furnace can be pre-assembled in the workshop allowing an easy installation on the site (Figure 8).



▲ Figure 8. Semi-continuous STC[®]-furnace

The equipment consists of a charging table, a furnace proper (heating and cooling), discharging table, a control panel and furnace atmosphere generators. A roller hearth system ensures the transfer and forwarding of all charges. These STC[®] furnaces, with the adaptation of computer control, are fully automatic and capable of unmanned operation. Upon load positioning on the charging table, the operator only needs to select the relative recipe that suits kind of process, material, and grades. Thanks to the computer control all combustion-, atmosphere control- and transferring load functions are automatically fulfilled. The automation and control system is capable of storing up to 200 recipes, making this system quite flexible. The material handling system only requires a forklift for loading and unloading. There is no further need for a crane. Compared with conventional box type furnaces, the STC[®] furnaces are designed to have various heat recovery processes with the result of energy and utility savings:

- The use of ceramic fibre lining, radiant tube combustion type with a recuperator to preheat combustion air, few water-cooled components
- A lock mechanism for the inlet and outlet door of each chamber minimises the furnace atmosphere leakage-assuring an airtight design. Furthermore, the inlet and outlet doors are interlocked so that both cannot be opened at the same time. Consequently, the heating and cooling chamber of the furnace atmosphere is stabilised and the atmosphere gas is not wasted.

The most important difference between a bell-type furnace operated in a hydrogen atmosphere and an STC[®] batch roller hearth furnace operated in endogas concerns the incoming material condition both in wire rod coils as well as in bundled bars: The STC[®] furnaces do not require rolled material to be pickled or mechanical descaled.

Continuous Roller Hearth Furnaces for heat treatment of wire coils under protective or reaction gas atmosphere

Process Technology

Following the forming process, non-alloy or low-alloyed C-steel grades often require a heat treatment in the temperature range of 450 °C to 1,050 °C by stress relieve annealing, recrystallisation, normalising, soft annealing or annealing of spheroidal cementite (GKZ) in indirectly heated continuous roller hearth furnaces (Figure 9). This furnace type is preferably used in case of larger tonnages/hour and a continuous production. A slow and uniform heating, a sufficient holding area and a subsequent material-specific cooling are typical characteristics of this furnace.

The high, constant temperature and the low energy consumption of these mostly gas-heated furnaces ensure reproducible processes and material qualities as well as their individual treatment times. Furthermore, this furnace

type does not require continuous heating- and cooling curves per charge and the related tightness tests.

Wire coils are heat-treated in these continuously operating roller hearth furnace plants by use of various protective gases. The atmosphere gas is determined according to the materials and the requirements their surfaces have to meet upon the heat treatment.



▲ Figure 9. Roller Hearth Furnace for wire coils

Gases classified as neutral protective gases mainly have to prevent oxidation at the metal surface. Moreover, these gases are applied as purging gases for combustible/explosive reaction gases in case of a required, safety-related purging of the furnace atmosphere. The reaction gases have to reduce the already existing oxidation layers and prevent further oxidation of the metal surface. Depending on the material, these reaction gases additionally have to prevent marginal decarburisation or – in some cases – even have to ensure a minor marginal material carburisation in the roller hearth furnace.

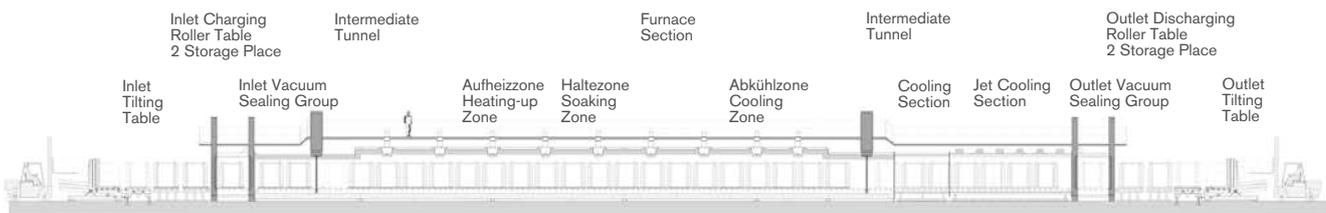
System Features

The typical plant structure of a roller hearth furnace for wire coils (Figure 10) mostly features a lock to separate the ambient atmosphere from the protective/ reaction gas atmosphere in the charging and discharging area. These locks are designed either as vacuum or purging lock. The oxidation affinity of the steel grade needs to be considered during the annealing process. Materials prone to oxidation, in particular, need a vacuum lock. A so-called intermediate area may separate the subsequent furnace chamber from the inlet lock.

To make sure that the carbon content at the material surface is close to the standard tolerances upon annealing, carburising-neutral nitrogen is fed into the furnace chamber. Adding endogas to the nitrogen creates a furnace atmosphere with a defined C-potential that complies with the carbon content of the product to be treated. The CO-ratio in the atmosphere is adjustable between 1 % to 6 %. The control of the furnace atmosphere ensures maintaining the carbon potential. Either a zirconium dioxide probe or a gas analyser continuously monitors the atmosphere state. If the control parameter deviates from the set-point value, the atmosphere is automatically adjusted by enrichment propane or leaning of air.

The metal-dusting effects need to be prevented for the annealing processes that require rather low annealing temperatures in the heat treatment. The targeted carbon potential in the atmosphere and the carbon activity of the material require balancing during the heat treatment.

Direction of Travel ►



▲ Figure 10: Typical plant structure of a roller hearth furnace for wire coils

The furnace atmosphere is adjusted to the respective product by determination of respective set-point values. Different gassing parameters are selected in consideration of various annealing programs.

The subsequent cooling area is separated from the furnace chamber atmosphere by a further intermediate area and doors. Frequency-controlled fans control the cooling process. Jet cooling, slow jet or slow cooling allow implementation of the optimal cooling temperature gradient.

Due to the high requirements of the automotive industry, modern furnace plants are increasingly equipped with C-potential control and in conformity with CQI-9.

Comparison of Batch-Type HPH®-Bell-Type Annealing Furnaces (BAF) with Semi-Continuous-Type STC®-Furnaces and Continuously Operated Roller Hearth Furnaces

Such comparisons are only reasonable if experiences have been made with all furnace types to be compared. Moreover, every application needs to be considered separately. General conclusions can hardly be made.

The following coil data (Table 1) are used in the further explanations:

Steel grade	100 Cr 6
Coil O.D.	1250 mm
Coil I.D.	850 mm
Coil Height	1800 mm
Coil Weight	2000 kg
Rod diameter	10 mm

▲ Table 1. Typical coil data of a rolled wire coil

11 coils with a charge weight of 22 t are annealed in a typical STC®-furnace, whereas a typical bell-type annealing furnace of type 420-400 is charged with 14 coils of a total weight of 28 t.

The following Table 2 represents technical data of three furnace types:

The local marginal conditions, the particularities of the respective plant design and the customer's production conditions are decisive factors for selecting one of these three designs as an optimal solution for a customer.

All furnace types manage to achieve temperature uniformity of $\pm 3\text{ °C}$ within a coil. Upon reaching of the holding time, the control accuracy of all furnace types amounts to $\pm 2\text{ °C}$. Moreover, all furnace types can implement a spheroidising rate of 100 %.

Herein below please find a summary of the main technical advantages of every furnace type:

STC®-Furnace:

- No high hall is required for crane lifting of the equipment. Moreover, the hall crane capacity must be sufficient only for lighter loads.
- Neither numerous foundations nor cellars are required.
- The fact that both wire coils and bars can be annealed in the same furnace represents the essential advantage of an STC®-furnace.
- Using endogas as protective gas prevents decarburisation; repair annealing with the controlled carburising atmosphere is possible.
- A typical STC®-furnace is capable to anneal approximately 8,800 t/y on a floor space of roughly 33 x 10 m by charging 100 % 100Cr6.

HPH®-Bell-type Annealing Furnace:

- The flexibility of a bell-type annealing furnace due to its modular structure and the possibility of large and small batch sizes is second to none.

- No furnace type except a bell-type annealing furnace ensures an absolute gas tightness and the possible use of hydrogen as protective gas with dew points below -60 °C. Instead of hydrogen, nitrogen or any H₂/N₂-mix may be used.
- Consequently, it is possible to offer an extremely wide product range including recrystallisation and bright annealing of drawn wires.
- No endogas generators are required.
- 2 annealing bases including a heating hood and 1 JET-cooling hood can be operated on a floor space of approximately 33 x 12 m. If 100 % 100Cr6 are charged, roughly 11.750 t/y can be annealed.
- The charging material can be supplied as per customer's specific requirements, i.e. either by means of an assembly crane, a forklift truck, feeding roller tables, etc.
- If designed accordingly, a roller hearth furnace allows the heat treatment of both wire coils and wire rods.
- It is possible to use different reaction gases, i.e. monogas, endogas, exogas, hydrogen or cracked gas (ammonia gas) additional as mixtures, etc. according to customer's requirements.
- Using endogas as protective gas prevent decarburisation; repair annealing with the controlled carburising atmosphere is possible.
- The constant temperature guidance without continuous furnace heating-up and cooling ranks among the major advantages of the roller hearth furnace.
- A typical roller hearth furnace allows annealing of approximately 28.000 t/y on a floor space of roughly 98 x 10 m, if 100 % 100Cr6 is charged.

Roller Hearth Furnace:

- Constantly large batch sizes of similar material grades feature an advantage of a roller hearth furnace.
- No high hall is required for crane lifting of the equipment.

	STC-furnace	BAF (420-400)	RHF
Steel grade (100 %)	100 Cr 6	100 Cr 6	100 Cr 6
Stack weight	11 x 2 t = 22 t	14 x 2 t = 28 t	44 x 2 t = 88 t
Charging, pre- and post-purging	0,5 h	3,0 h	0,5 h
Process time (heating-up, holding, cooling)	26 h	23 h	24 h
Total time:	26,5 h	26 h	24,5 h
Furnace capacity:	0,83 t/h	1,08 t/h	3,5 t/h
Typical annual operation time	8.000 h/a	8.400 h/a	8.000 h/a
Max. annual production	1 STC-furnace: 8.800 t/a	2 bases, 1 HH: 11.750 t/a	1 DR 28.000 t/a
Min. space requirement (L x W x H)	33 x 10 x 8	32 x 12 x 13	98 x 10 x 7,5
Crane capacity:	5 t	20 t	5 t
Required crane height	10 m	14 m	10 m

▲ Table 2. Technical data of three furnace types

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Summary

Different heat treatment processes are available for different types of steel wire as a function of steel grade, process step and metallurgical requirements on the final product. Depending on the respective production requirements, a great variety of alternative furnace plant designs is available which are all included in the product range of Tenova's furnace manufacturers.

In general, we distinguish continuously and batch-wise operating heat treatment plants. The respective process-technological and plant-specific particularities of continuous rotary plate furnaces, continuous roller hearth furnaces, semi conti Short Time Cycle roller hearth furnace as well as batch Bell-type annealing furnaces and batch chamber furnaces are explained in this report. The most suitable furnace type can only be selected upon analysis of the customer's individual needs. Furnace manufacturers offering all of these furnace types may give valuable and helpful objective advice.

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