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⑤④ **Heat treatment of steel elements in fluidized beds.**

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Description

The present invention relates to a process for heat-treating steel wires in a patenting operation in which the austenitized wires are quenched in a first fluidized bed zone and transferred to a second fluidized bed zone where transformation takes place, the first fluidized bed zone is fluidized by a fluidizing gas and the second zone being fluidized by another fluidizing gas, whereby the temperatures of the two zones are controlled independently and whereby the two zones are fluidized by independently controlled supplies of gas.

The present invention also relates to a fluidized bed apparatus for heat-treating steel wires comprising a first fluidized bed zone for quenching wires and a second fluidized bed zone, whereby means are provided for fluidizing the first zone and second zone independently from each other and for controlling independently the temperatures of the first and the second zone.

Such a process and apparatus are known from the German document DE-A-2 032 643 or U.S.A. patent 3 615 083.

Patenting involves heating carbon steel wires into the austenitic phase, generally above 800°C, and then quenching the wires to a chosen temperature at which the wires are held for a sufficient period for generally isothermal decomposition of the austenite to be completed. The temperature is usually in the region of 550°C, with the intention being generally to provide a fine pearlitic structure. The wires will subsequently be drawn.

In general the wires will be of a plain or alloyed steel with a carbon content of from about 0.1 % to more than 1 % and preferably in the range of about 0.25 % to 1.25 %. The wires may be of any cross-section, e. g. square or rectangular, but are preferably common wires with a circular cross-section whose area preferably exceeds 0.15 mm². The term "wire" is intended to extend to e. g. rods, strips and other elongate members.

In a conventional patenting operation the quenching and transformation steps are carried out in a bath of molten lead held at a constant temperature. Although this provides good results in view of the heat absorbing capacity of the molten lead, which gives rise to rapid cooling, there are problems. Apart from the environmental and safety problems of working with molten lead, there can be lead drag out and surface defects caused by lead contamination.

It has been proposed to replace the lead bath by forced gas or air cooling, but this is insufficiently reliable with wire diameters below 5 mm, i. e. the majority of cases in wire drawing plants, and particularly with wire diameters below 2 mm.

It has also been proposed to use heated fluidized bed apparatus, where there are improved heat transfer properties with respect to forced gas or air treatment. A typical fluidized bed installation comprises a refractory furnace construction with two compartments separated by a fixed horizontal plate. The upper compartment forms a long U-shaped vessel in which inert sand particles (silica, alumina, zirconia, and the like) are fluidized and heated by blowing a hot gas through its horizontal bottom plate which for that purpose possesses a plurality of apertures (i. e. being of perforated or slitted metal) or is made of a porous ceramic material such as asbestos sheets or ceramic plate. The lower compartment below the separating gas distribution plate is the gas plenum chamber from which the fluidizing gas is admitted under pressure to the particle container. The fluidized particulate medium, formed of solid particles suspended in a fluidizing gas of adequate velocity (usually between 8 and 15 cm per second for an average particle dimension ranging from 150 to 500 micrometer), behaves nearly like a liquid heat transfer medium and possesses an elevated heat transfer coefficient which is situated between that of forced air cooling and molten lead.

It has been found, however, that the mechanical properties and microstructure of wires treated in such fluidized apparatus are still significantly inferior to those obtained by lead bath treatment. There is a significantly larger incidence of deviations from the ideal fine pearlitic structure, with e. g. substantial amounts of coarse pearlite or bainite being formed. These problems have generally been attributed to the lower heat capacity and transfer properties of a fluidized bed compared to a lead bath, which result in a slow cooling rate and the lack of consistent isothermal transformation conditions.

In an attempt to overcome these problems, particularly with rods or heavy wires, having e. g. a diameter of more than 2.5 mm., it has been proposed in the above-mentioned U.S.A. patent 3 615 083 to use a process for heat-treating steel wires in a patenting operation, in which the austenitized wires are quenched in a first fluidized bed zone and transferred to a second fluidized bed zone where transformation takes place, the first fluidized bed zone is fluidized by a fluidizing gas and the second zone being fluidized by another fluidizing gas. The temperatures of the two zones are controlled independently and the two zones are fluidized by independently controlled supplies of gas.

Nevertheless, tests have shown that the results of this U.S.A. patent 3 615 083 do not provide the necessary improvements in quality, particularly for wires with a diameter of say 3.00 mm. or less and typically 0.7 to 1.5 mm.

During the soaking stage, substantially isothermal transformation should take place. However, the transformation is exothermic and the temperature of the wires will tend to rise. With a lead of substantial thermal capacity, the temperature can be kept almost constant. With a fluidized bed apparatus according to the U.S.A. patent 3 615 083, there can be variations from the ideal temperature caused e. g. by the exothermic nature of the transformation.

The temperature band over which fine pearlitic structures can be obtained reliably is relatively narrow and for the optimum structures is narrower still.

U.S. Patent no. 3 615 083 does not provide a complete solution to these variations from the ideal temperature.

The present invention aims to solve this problem associated with the known fluidized bed techniques.

Thus, having regard to the process disclosed in the U.S.A. patent 3 615 083; the present invention is characterised in that the temperature of the second zone is controlled into a number of individual regions independently from each other by individual heating elements for each region of this second zone.

Apparatus in accordance with the invention is characterised in that the second zone is divided into separate regions and that separately controlled heating elements are provided in the separate regions of the second zone.

The improved control over the second zone which is thus made possible, permits the soaking temperature to be maintained at a more constant level and this further improves the microstructures which can be obtained.

In the context of the two zone fluidized bed used e. g. in patenting as described above, it is not generally necessary for the soaking zone to have auxiliary cooling means, whilst it may be advantageous to have auxiliary heating means. In a preferred arrangement, electric resistance heaters are immersed in successive soaking bed sections. These could be replaced by immersed radiant tube heaters. With such arrangements, the base that heat input from fluidizing gas, i. e. its inlet temperature, is set fairly low and the auxiliary heaters relied upon to bring the bed to the required temperature.

In all the arrangements, regulation of the inlet temperature of the fluidizing gas for either zone can use lean to extra lean mixtures, mix cooling air with the combustion gas, or provide a regulated heat exchanger between the plenum and the combustor.

In a preferred embodiment of the present invention a fluidized bed soaking zone contains, in its longitudinal direction, a number of distinct heat transfer and control compartments, making it possible to adapt locally the energy balance resulting from work load heat, from the heat input by primary fluidization and by auxiliary heaters and from cooling and ambient heat losses, thereby enabling momentarily an improved accuracy of local bed temperature, which temperature can be kept constant over the entire soaking bed length or can be programmed to impose and maintain a predetermined profile from soaking zone entry to exit.

Although the apparatus and processes in accordance with various aspects of the present invention are particularly of use in a patenting operation using conventional quench and soaking temperatures, other possibilities are envisaged. Thus, "step patenting" could be undertaken. In this, the quench temperature is lower, e. g. 400°C, whilst still above Ms, and this is followed by rapid heating to the selected transformation temperature. "Gradient patenting" could also be undertaken by quenching and then transforming through a chosen temperature gradient using separate temperature control of various zones of a fluidized bed. The apparatus could also be used in other processes altogether, such as the formation and subsequent tempering of martensite to produce hard structures. In such processes, the quench temperature will be below Ms. Other possible processes are precipitation hardening, quench hardening and so forth.

In the gradient patenting process the pearlite reaction commences at a low temperature level such as 540 - 560°C and continues to a given degree. This initiates formation of fine sorbite. Thereafter, and e. g. after 10 - 20 % transformation the remaining austenite is decomposed at a higher temperature level such as 600 - 650°C or more. Thus, the cementite growth rate is significantly slower. It is therefore possible to create fine structures, with a small interlamellar distance, without the growth defects encountered with fine pearlites reacted isothermally at higher rates (i. e. at constant lower temperatures).

Wires produced in this manner have improved drawability and strength properties. In fact, the fluidized bed apparatus and method of the preferred embodiments allow the selection of any convenient cooling-transformation curve in the T.T.T.-diagram or the carrying out of a patenting treatment according to a specific curve, e. g. to obtain special effects or particular wire properties. This is not possible with known fluidized bed plants nor with lead baths.

One possibility is to take full advantage of the exothermic nature of the reaction so as to form uniform pearlitic structures with a larger than usual inter-lamellar distance. Thus, the reaction could start at 580 to 600°C and the wires could be allowed to increase in temperature by the effects of the transformation heat (with temperature rises up to 60 - 80°C). Although the wire strength is less, the wire has good deformation properties.

A further problem with the quenching of steel wires in a fluidized bed such as learned in the U.S.A. patent 3 515 083, is the possible oxidation of the surfaces of the wires, producing undesirable scale. We therefore propose using a substantially non-oxidising hot gas to fluidize (and heat) the quenching zone.

Viewed from this aspect, the invention provides an improvement in a process for heat treating of steel wires, in which steel wires from an austenitizing furnace are quenched in a fluidized bed, the improvement being characterized in that the bed is fluidized by substantially non-oxidising exhaust gases from the austenitizing furnace. Apparatus for heat treating steel wires in accordance with this aspect of the invention comprises an austenitizing furnace and a quenching fluidized bed, and is characterized in that means are provided for supplying exhaust gases from the furnace to the bed so as to fluidize the bed.

Such a process and apparatus can be of use in many fields, but is of particular use in the patenting operations.

As at least two fluidized bed zones are used, the exhaust gases can be passed through both zones, either by fluidizing a single bed divided into zones, or by being passed through two separate beds. In the latter case, the exhaust gases may pass sequentially through the two beds.

The exhaust gas preferably has an oxygen content of 5 % by volume or less and preferably no more than 2 % with a target of 1 % maximum. Preferably the content is not more than 0.5 % or most preferably 0.1 or 0.2 %, with a residual carbon monoxide content of not less than 0.1 % and preferably in the range of 0.5 to 2 %.

It is conceivable that other types of non-oxidising gas could be used, even if not obtained from an austenitizing furnace.

In one preferred arrangement, the hot exhaust gas is precoolled in a recuperator, e. g. a waste heat boiler, to a level not exceeding 150°C and subsequently heated to the desired input temperature. This can be done by means of a battery of variable power electric heaters. The inlet temperatures may vary from 100 - 150°C to 450 - 500°C according to the operational stage (i. e. the highest temperature is required at start up) and the wire diameter.

In a fluidized bed apparatus in accordance with the invention, a separate fluidizing gas make-up station is preferably located outside of the basic fluidized bed enclosure. Instead of employing conventional furnace designs (rigid constructions with fixed refractory/metal joints) for building the fluidized bed, it is preferred to use a modular and flexible construction as described in our European Patent 0 181 653 although this choice is not essential for putting the various aspects of the invention into effect. More in particular a preferred construction comprises a main steelbacked refractory enclosure, forming a tunnel-like space covered by a removable or liftable roof, in which at least two separate fluidized bed modules (without incorporated burners) are disposed, respectively a quenching module and one or more soaking modules. A distinct module is preferably made in the form of a two-chamber metal assembly comprising an open vessel for containing the particles and an adjacent gas plenum chamber underneath separated from the particle vessel by a gas distribution bottom plate (with apertures and/or nozzles for admittance of fluidizing gas) and is further improved in that the module parts are integrated in a distinct one-piece assembly. Such modular design, in which combustion heaters are absent, is advantageous in terms of exploitation and maintenance: the individual zone modules are easily mounted in the apparatus enclosure, and if needed, they can be detached from the main frame (such as e. g. for repair) and replaced by other modules.

The soaking zone may comprise one fluidized bed module of suitable length, or a number of smaller modules linked together if a soaking zone of considerable length is desired. Admittance of fluidizing gas to the soaking zone with one or more modules can be by means of a central inlet from a soaking gas station to a common plenum duct extending below the adjoining plenum chambers.

Some embodiments of various aspects of the invention will now be described by way of example only and with reference to the accompanying drawings, in which:

Figs. 1(a) and (b) and 2(a) and (b) show longitudinal sectional views respectively of a standard lead and a conventional fluidized bed patenting installation, and the corresponding wire cooling-transformation curves;

Fig. 3 is a diagrammatic illustration of the relationship between the temperature-time-transformation (T.T.T.) diagram and the cooling-transformation curve of a lead patented and a conventionally fluidized bed patented carbon steel wire;

Fig. 4(a) shows a fluidized bed apparatus in accordance with the U.S.A. patent 3 615 083 or most pertinent prior art;

Fig. 4(b) shows a modification of a fluidized bed according to figure 4(a), but using an exhaust gas of the austenitizing furnace;

Fig. 5(a) shows a schematic view of another example of a fluidized bed using an exhaust gas of the austenitizing furnace;

Fig. 6 shows details of an apparatus in accordance with the invention;

Fig. 7 shows wire cooling and transformation curves obtainable by fluidized bed patenting process in accordance with the invention;

Fig. 8 shows further details of apparatus in accordance with the invention;

Figs. 9(a) and (b) compare the fluctuation of patented wire strength in lead and fluidized bed-patenting; and

Fig. 10 illustrates a number of specially selected fluidized bed-patenting curves.

Referring to Figs. 1a and 2a there are schematically shown a lead (Pb) and a conventional prior art fluidized bed (FB) patenting line, whereby a wire material W, after heating in an austenitization furnace 1 enters a lead bath 2', or a FB-apparatus 2 of usual single zone construction, kept at a constant temperature by suitable means (not shown).

Figs. 1b and 2b depict the changes in wire temperature as a function of time from the austenitizing temperature (Ta) until the patenting holding temperature (Tp) in both cases. Tq schematizes the course of wire temperature during quenching. From a comparison of Figs. 1b and 2b it clearly appears that in a conventional

FB-apparatus transformation start and real wire transformation temperatures shown by curve T_1 and the shading considerably depart from the preferred temperature (T_p), and that the pearlite reaction may occur over a broad range of temperatures. These tend to rise excessively during reaction progress, due to the combined effect of wire recalcence (heat release by transformation) and of the lower heat transfer and heat capacity of a fluidized bed.

In Fig. 3 the wire cooling-transformation curves (FB) obtained by conventional fluidized bed patenting are represented in a T.T.T. diagram in comparison with lead patenting (Pb). The dashed curves (TR) and (TR)₁₀₀ indicate start and end of austenite transformation, and the shaded area (OTB) illustrates the optimum transformation band for obtaining a fine pearlitic structure. It should be noticed that in the case of conventional FB-patenting the temperature departs from the OTB-region. Prior art attempts to remedy this situation, for example by using a precooling unit such as a cold air FB-zone, or by drastically lowering the fluidized bed soaking temperature so as to provide a temperature curve such as T_2 in Fig. 2b, are mostly too critical because of possible bainite formation caused by the degree of undercooling T_2 below T_p .

In Fig. 4a a general embodiment according to the U.S.A. patent 3 615 083 is schematized. There is shown an austenitizing heating furnace 1 and two-zone fluidized bed apparatus 2 with an independent quench zone Q and transformation-soaking zone TR-S. These zones each contain a modular assembly 3, comprising essentially a particle container 4, a plenum chamber 5, a gas distribution plate 6 (such as a perforated plate, preferably with gas pipes or nozzles) which links the container bottom and the plenum upper part, and a gas supply pipe 9 or a gas admittance duct 5' connected to the plenum bottom. A (desirably detachable) pipe connection 8 joins each module of the gas supply duct of a fluidizing gas make-up station 7 (not shown here in detail) where the required gas (in terms of volume and composition) is prepared at a regulable base temperature. This base temperature is determined for each zone according to wire type and selected process and is adjusted during processing according to the prevailing bed conditions related e. g. to start-up or running, change of wire diameter, etc. For the external gas make-up stations, possible installations are gas generators, suitable make-up burners supplying a (preferably lean) combustion mixture, forced air heaters and combinations thereof. The two zones Q and TR-S are separated by a heat insulating wall suitably apertured to permit the passage of wires. The apparatus is designed to handle a number of wires travelling in straight and parallel paths. The wires may pass through a protective hood or the like from the furnace 1 to the quench zone Q.

In Fig. 4b there is shown an alternative embodiment of a two-zone fluidized bed, in which austenitizing furnace exhaust gas is employed for fluidizing first the soaking zone and next the quench zone (or vice-versa when using precooled furnace exhaust gas). In this case the exhaust gas from austenitization furnace 1 is fed by pipe 8 to the fluidized-bed apparatus 2 by means of an extraction-blower 7'. Base temperature adjustment of the gas, before its admittance to the soaking and quench zone modules, is carried out by means of individual appropriate heat exchangers 10 and 10', located at the entry of each zone.

Fig. 5a illustrates another embodiment which is particularly advantageous and wherein the (here not shown) features of the invention may be applied. Here there is shown a gas fired austenitizing heating furnace 1 and a two-zone fluidized bed apparatus 2 with separate quench and soaking modules Q and TR-S, in which the quench zone is fluidized by means of (preferably non-oxidizing) furnace exhaust gas delivered through pipe 8 whereas the soaking zone TR-S is equipped with an independent gas generator or fluidized gas make up station 7, for example a suitable combustor (e. g. a make-up burner). In this particular case the fluidizing base temperature at the quench zone inlet is preferably controlled as follows. First the extracted furnace exhaust gas is precooled, preferably to below 150°C, in a furnace heat recuperator 11, and then it is blown to a regulable heat exchanger 12 (for example an electrical gas heater) to adjust actual gas temperature to an instantly required inlet temperature level which may vary according to momentarily prevailing heat conditions inside the quench bed depending on operational regime, heat input from hot wires, throughput speed, etc. The primary adjustment of quench gas inlet temperature is supplemented by a secondary control system for accurately regulating the temperature inside the quench bed to maintain any desired present value. In practice, the secondary control system takes over completely once full time running operation is fully established, that is when additional heat input from the fluidizing gas is no longer demanded and the quench gas preheating battery can be switched-off. This will be described in more detail below.

The soaking zone TR-S is fluidized and heated by means of hot gas derived from station 7, e. g. a make-up combustor, which supplies a gaseous mixture at a given base temperature to the soaking zone module. The gas inlet temperature level, needed for heating and holding the soaking bed at a constant present (average) temperature, is automatically adapted as a function of actual bed heat balance (work load, recalcence, heat losses, etc.).

Thus both the quench and soaking bed are individually fluidized, heated and temperature controlled in such a way as to maintain a constant bed temperature, which is characteristic for each zone and is adapted according to the wire and desired properties for a given process. In wire patenting for example, the internal quench bed temperature may be varied from 250 to 600°C (to obtain a wire temperature between M_s and a given pearlite reaction temperature), while in the soaking zone the preset temperature can be selected within a range from 450 to 700°C (to obtain a pearlitic structure of variable fineness).

The local bed temperature, may have a tendency to rise at some places above the optimum level at a given transformation stage owing to the previously mentioned recalcence effect (release of transformation heat). From experiments we have found that the degree of recalcence and the location of its temperature pea-

king effect in the soaking zone, may vary with wire diameter, throughput speed and selected transformation curve.

According to the basic features of our invention, there are provided auxiliary heating elements and temperature sensors in the particle bed of the soaking zone module, which elements are grouped and operated in a number of distinct zone compartments making up the complete soaking transformation zone length. The groups are regulated independently by compartment to correct the local soaking zone temperature in combination with the control of primary fluidization heat. To solve the problem of unequal heat losses in the presence of a variable release of transformation heat, the average heat input is divided into a primary and a secondary fraction, with the primary fraction being deliberately chosen below the constant running heating needs. In this way, the auxiliary heaters not only deliver the necessary power to compensate for local heat deficiency, but also a part of the primary heat. As a result possible local bed overheating owing to the wire recalcrescence peak (which may exceed the average bed heat loss) can still be counteracted without affecting the adjacent transformation zones. An additional advantage of this measure is the possibility of having a programmed pearlite reaction, e. g. in steps of different temperature levels and reaction speeds. This has several advantages in practice, such as increased flexibility to carry out patenting right on target (possibly even better than lead patenting), the ability to control the patenting reaction beyond the usually adopted cooling-transformation curves and better productivity in terms of apparatus used due to shorter start-ups and a quicker transition to desired regime operation.

Fig. 6 illustrates how the optimum reaction temperature may be precisely adjusted during transformation progress according to the invention on a wire W. For this purpose the soaking bed TR-S has been divided into a number of sections 13 each of which comprises a set of individual heating elements 14 inside the fluidized bed, a suitable temperature sensor 16 and a heating power regulator 17, connected to a control panel 15. The heating elements are operated at a given base power to keep the soaking bed at a preset temperature, in combination with the heat input of the hot fluidizing gas supplied by the soaking bed gas make-up station. They are further actuated in an increasing or decreasing power sense when local bed temperature drops below or exceeds the prescribed soaking temperature. The heating and fluidizing gas make-up station is disposed outside the main apparatus enclosure. The station is here essentially a combustion device, arranged to prepare a combustion gas mixture at desired rate, temperature and pressure, and comprises a combustion chamber 20 and a gas burner 21 with supply of preferably gaseous fuel 23 (e. g. natural gas) and forced air 22 from blower 7. The gas inlet temperature is fed by line 18 to panel 15. The gas for the quench zone Q, e.g. pre-cooled from a furnace, passes through a heat exchanger 12.

Fig. 7 illustrates the effect of additional temperature correction within the soaking zone on the position of the patenting curves in a T.T.T. diagram. As can be seen wire transformation temperature or pearlite reaction can be forced entirely into the required optimum OTB-region (curve A), by instant correction of local soaking bed temperature whereas otherwise (curve B), i. e. in the absence of individually regulated bed sections, it could escape to a given extent from the optimum transformation band, resulting in a partially annealed (coarser) pearlitic structure.

Fig. 8 shows a more detailed view of a preferred embodiment of a fluidized bed plant utilizing the principles of Fig. 6. Wire W, austenitized in a gas fired furnace 1, passes successively through a quench compartment Q and a separate cooling zone TR-S of fluidized bed apparatus 2. The soaking zone, contains a number of sections 13 with immersed auxiliary bed heaters 14 and related control devices (depicted in Fig. 6 but not again represented here). The combustion air for burner 21 is preferably preheated and for that purpose fed by a blower 7 over a heat recuperator 24 located in the soaking bed exhaust 25.

For combustion chamber 20 the prepared fluidizing gas is piped to the soaking zone module TR/S, which is essentially a metallic assembly disposed in the U-shaped inner space of the FB-furnace, in which assembly the particle vessel, plenum chamber and gas admittance duct are integrated. The particle bed contained in container 4 is fluidized. There is also shown a gas plenum 5 with gas admittance duct 5' and a gas distribution device between the vessel bottom and the adjacent plenum which is preferably a perforated plate 6 having a large number of fluidizing nozzles 6' at regular, short distance from each other (for example in the range of 3 to 20 cm). The nozzles receive fluidizing gas from a plenum chamber, the gas admittance duct 5' of which is connected to a supply pipe 9 of the combustion chamber 20 and make it possible to obtain and maintain an optimum fluidizing velocity (usually around 10 - 12 cm per second) and stable bed conditions. Control means of the soaking bed comprise a control device (not shown here) for regulating the burner 21 to establish and adjust the required soaking gas inlet temperature (primary soaking bed heating and holding at base temperature), and secondary control devices, as explained above in connection with Fig. 6, connected to auxiliary heaters of each soaking zone section to correct the local soaking bed temperature and to augment the base heat input of heat fluidizing gas to the soaking zone (especially useful in starting-up the fluidized bed apparatus).

The quench zone Q comprises one fluidized bed module of the same type as described above for the soaking zone, but of shorter length, preferably between 50 and 250 cm. In principle the zone can be fluidized in the same way as the soaking zone, that is by means of a separate external combustion gas make-up station connected to the quench module. In this embodiment, however, the quench gas is derived from the exhaust of the preceding gas fired austenitizing furnace. The composition of the exhaust gas is adapted so as to reduce and even avoid oxidation of the hot wires during quenching. Thus the exhaust gas mixture entering the quench module has an oxygen content of max. 2 vol %, and preferably not more than 0.5 % to slow down or prevent undesirable surface oxidation. More specifically the oxygen content is preferably limited to 0.1 % max.

for oxidation free quenching, in combination with a small amount of CO of between 0.5 and about 2 % to ensure that oxidation free conditions are met. In the latter case, energy consumption is slightly increased due to non-stoichiometric combustion in heating furnace.

An extraction-blower 8' supplies exhaust gas which passes through a precoolor or exhaust heat recuperator (not shown) to lower the gas temperature, and a regulable electrical gas heater or heat exchanger 12 allowing the fluidizing gas to be supplied to the quench zone at any required inlet temperature level. The primary control contains a control device 34 which regulates power supply 36 of preheater or heat exchanger 12 as a function of quench bed temperature and inlet temperature supplied by lines 33 and 35.

Additional cooling and bed control means are provided to adjust and to maintain a preset temperature inside the quench bed during constant running operation, that is when the heat input of the hot wires largely exceeds the heat removal capacity of the fluidized quench bed with inlet gas preheater switched off. These supplementary cooling means comprise fixed bed cooling means such as immersed water coils (not shown) and regulable bed cooling means. The latter comprises a blower 28 which directs a variable amount of cooling air from a source 29 through pipe 26 onto the surface of the quench bed or even inside the bed. A motorized valve 27 adjusts the rate of cooling air by means of the suitable control system 34 to which it is connected by line 30. The control system 34 measures actual bed temperature by means of sensor 33, compares it with the quench bed temperature and accordingly regulates the motorized valve of the cooling air supply. Alternatively regulable water cooling may be used with heat exchanging coils (pressurized water or boiling water) located inside the particle bed, a variable water flow rate being obtained by means of a motorized control valve.

In use in the patenting of carbon steel wires, the quench zone will be adjusted and maintained at a temperature within a range from 250 to 650°C, preferably from 350 to 550°C for a quench length of 0.5 to 2.5 m and the soaking zone temperature will be adjustable within a range from 450 to 700°C, and preferably a range from 500 to 650°C.

The controls of the various heating and cooling means described above are preferably automatic.

Reference will now be made to certain examples:

Example 1

Steel wires of 1.50 mm diameter and 0.71 % C were treated on different FB-patenting lines and compared with lead patenting. Austenitization temperature and wire speed were the same in each case, namely 920°C and 24 m/minute.

Two different fluidized bed modes were used:

FB1 : conventional fluidized bed apparatus with one immersion zone ; bed temperature setting at $T_{FB} = 560^{\circ}\text{C}$.
 FB2 : fluidized bed with separate quench and soaking zones and individual fluidizing means and zone control, substantially as described in the U.S.A. patent 3 615 083.

Bed temperatures were adjusted as follows:
 temperature control:

$T_q = 500^{\circ}\text{C}$ in the quench zone
 $T_{FB} = 560^{\circ}\text{C}$ in the soaking zone

length of quench zone: 2.5 m
 length of soaking zone: 4.5 m

The properties of the patented wires were as follows:

Table 1

	Tensile strength N/mm^2	Max. spread* Microstructure on wires N/mm^2	
Lead patenting	1240 - 1255	15	Fine pearlite (100 %)
FB1 (prior art)	1140 - 1204	64	Mixed, up to 20 % coarser pearlite
FB2 (invention)	1186 - 1222	36	Fine pearlite + lamellar areas some coarse (5 - 10 %)

(*) max. spread measured on same wire and between different wires according to their position in the furnace.

The results indicate the beneficial effect of the invention (FB-2) on the properties of patented wire as compared to prior art fluidized bed patenting (FB-1).

Example 2

A FB-patenting line of 36 wires was equipped with two-zone fluidized bed apparatus comprising a quench zone of 1.5 m and a soaking zone of 5.5 mm length, each with individual temperature settings. The quench zone was fluidized with different gas mixtures.

Process conditions:

- wire diameter 1.3 mm; 0.69 % carbon steel
- temperature of quench bed: 455°C
- temperature of soaking bed: 530°C
- aust. temp.: 900°C; wire speed: 30 m/min.
- quenching modes according to gas make-up and gas composition in quench zone:

.FB-3: furnace exhaust gas % CO = 0.15; % O₂ = 2

.FB-4: combustion gas from external burner station % CO₂ = 4; % O₂ = 5; % CO = 0

.FB-5: hot air.

The FB-patented wire results were compared to those of lead patented wire, isothermally transformed at 560°C.

Wire properties are tabulated below:

Table 2

T.S. N/mm ²	Striction %	Microstructure	surface oxidation: scale thickness in micrometer
FB-3 1207 - 1221	56.5 - 53.5	fine sorbite + traces lamellar pearlite	0.6 - 0.9
FB-4 1205 - 1222	52 - 57	fine sorbite + traces lamellar pearlite	1.2 - 1.5
FB-5 1191 - 1281	41 - 54	fine sorbite + coarse pearlite + ferrite	1.5
Lead 1224 - 1238 560°C	48 - 55	fine sorbite	1.0 - 1.2

It can be seen that the properties and microstructure of patented wire obtained with the two-zone fluidized bed apparatus are close to lead patented wire, except in case of (less controlled) hot air for quenching. The beneficial effect of using a non-oxidizing quench gas on wire surface oxidation is clearly recognizable.

Example 3

This involved the use of the same FB-patenting line as in Example 2, but with extra temperature regulation of the soaking-transformation zone according to the invention. This zone was divided into 5 subsections with individual heating elements for auxiliary heating and correction of local soaking zone temperature.

Wire: diameter 1.25 mm; 0.73 % C steel Preset temperature: quench zone 550°C soaking zone 520°C

Running-in of line was compared under following circumstances:

A : heating elements of soaking sections switched-on

A1 : inlet gas temperature adjusted at 400°C, sectional heaters of 12 kW total power

A2 : inlet gas temperature at 355°C; sectional heaters with increased heating power (25 kW) to enable both local temperature compensation and base heating support.

B : soaking zone as usual (without using auxiliary heaters) fluidizing gas supplied at about 500°C.

In case A1 effective running was reached in less than 40 minutes and in case A2, less than 30 minutes. In case B the time for attaining the required temperature profile in the transformation zone was more than one hour.

In addition, the distribution and spread of temperature during normal running operation was compared in the different bed sections. The results of temperature measurements are summarised in Table 3.

Table 3

Temperature distribution over length of fluidized bed

	quench zone	sect.1	soaking zone sect.2	sect.3	sect.4	sect.5*
Case A1	440 - 450	495 - 510	515 - 525	510 - 520	510 - 515	485 - 500
Case A2	440 - 450	515 - 525	520	520	520	515 - 520
Case B	440 - 460	490 - 530	520 - 550	525 - 580	540 - 570	450 - 490

Note* temperature of last zone section: temperature drop influenced by FB-furnace exit.

The favourable effect of separate soaking zone control sections on bed temperature equalization is apparent from cases A1 and A2. In case B local particle bed temperatures continue to rise (real wire or transformation temperature is even a bit higher), possibly above optimum level. These unwanted temperature fluctuations could become considerable, such as e. g. on changing wire diameters and when intermittent (stop and go) operation occurs (for example in case of line troubles), which could lead to inferior wire quality and to a larger amount of scrapped wire as is frequently the case with prior art fluidized bed patenting. It also appears from case A2 that a judicious choice of auxiliary heating power (which must be large enough to encompass a broad compensation range) and a lower than usual primary gas temperature gives an excellent flexibility and makes it possible to keep the local temperature very close to the prescribed level.

The wire properties obtained after case A1, A2 and B (with lead patenting as reference) were as follows:

A1 : Tensile strength = 1217 N/mm², mean spread between wires = 12.7 N/mm²

A2 : Tensile strength = 1234 N/mm² = 10.2 N/mm²

B : Tensile strength = 1192 N/mm² = 19.5 N/mm² Lead (560°C): Tensile strength: 1247 N/mm² = 12.4 N/mm²

In Figs. 9(a) and (b) the tensile strength distribution of treated wires (related to their furnace position) according to A1 and B are compared with lead patented wires. The improved consistency of wire properties obtained by conditions A1 are apparent.

Fig. 10 schematically shows a variety of patenting modes which can be selected and carried out correctly when using two-zone fluidized bed apparatus including distinct soaking-zone control compartments in accordance with the invention. In the T.T.T.-diagram curves 1 and 2 illustrate FB-patenting at two different temperature levels; curve 3 illustrates FB-patenting with transformation start at a first temperature and transformation progress and finish at a selected high temperature which can be imposed from any transformation fraction (TR) x onwards (3a, 3b, 3c). Curve 4 is an example of step patenting with austenite undercooling before rapid heating to a suitable temperature for isothermal transformation to pearlite.

A special adaptation relates to continuous martensitic hardening of steel wire by means of a two-zone fluidized bed, which for that purpose is provided with an adapted quench zone for deep cooling, making it possible to carry out a soft quench to below Ms (martensite start temperature) without intersecting the pearlite nose of the T.T.T.-curve, the quench zone being long enough or, if needed, there being an additional cold bed module, to ensure complete transformation of austenite to martensite before entering the soaking zone, where martensite is to be tempered at a preset holding temperature.

An arrangement for patenting steel wires, in particular of small diameter, may use apparatus with only one common particle immersion bed which is fluidized by a gas mixture (supplied from furnace exhaust or make-up burner) at a deliberately chosen "low" base temperature. The immersion or module length is then subdivided in a number of separate control sections in which the first section, used for quenching, is further equipped with fixed cooling as well as with regulable cooling means to remove the excess quenching heat. The second and following module sections, forming the proper transformation zone, are provided with regulable internal heaters of sufficient power for establishing and maintaining a prescribed transformation temperature. In this case the fluidized bed hardware is integrated in one modular construction whereas the heat control and temperature compensation devices form two independant systems, resp. for quenching and for transformation or soaking.

It will be appreciated that, at least in the case of certain aspects of this invention it may not be significant whether a particular installation is considered as a number of separate fluidized beds or as a single bed divided into separate zones. Gradient patenting might be carried out using a number of adjacent, separately fluidized beds, for example.

Claims

1. A process for heat treating steel wires in a patenting operation in which the austenitized wires are quenched in a first fluidized bed zone (Q) and transferred to a second fluidized bed zone (TR-S) where transformation takes place, the first fluidized bed zone is fluidized by a fluidizing gas and the second zone being fluidized by another fluidizing gas, whereby the temperatures of the two zones (Q, TR-S) are controlled independently and whereby the two zones (Q, TR-S) are fluidized by independently controlled supplies of gas, characterized in that the temperature of the second zone (TR-S) is controlled into a number of individual regions (13) independently from each other by individual heating elements (14) for each region (13) of this second zone.

2. A process as claimed in claim 1 characterized in that the temperatures of the individual regions (13) are controlled so as to provide a temperature gradient along the second zone (TR-S).

3. A process as claimed in claim 2 characterized in that the temperature gradient is such that transformation is commenced at a first temperature and is subsequently continued at a second, higher temperature.

4. A process as claimed in claim 3 characterized in that transformation at the second temperature is initiated after between 10 and 20 % of transformation has taken place.

5. A process as claimed in any one of claims 1 to 3 characterized in that there is a rapid undercooling of the austenitized wire followed by a rapid heating to a temperature suitable for transformation.

6. A process as claimed in any preceding claim, characterized in that the temperature of the first zone (Q) is controlled at least in part by auxiliary cooling means (28).

7. A process as claimed in claim 6 characterized in that the first zone (Q) is subjected to continuous cooling by first cooling means and variable cooling by second cooling means (27, 28).

8. A process as claimed in any preceding claim, characterized in that the first zone (Q) is fluidized by substantially non-oxidizing exhaust gas from an austenitizing furnace (1).

9. A process as claimed in claim 8 characterized in that the exhaust gases are cooled and/or heated by auxiliary means (11, 12) before entering the first zone (Q).

10. A process as claimed in claim 8 or 9 characterized in that the exhaust gases have an oxygen content of 2 % or less by volume.

11. A process as claimed in claim 10 characterized in that the exhaust gases include a residual carbon monoxide content to further promote non-oxidizing conditions.

12. A process as claimed in claim 11 characterized in that the carbon monoxide content is between 0.5 and 2 %.

13. A process as claimed in any preceding claim characterized in that the conditions are so controlled as to produce a substantially entirely lamellar pearlitic microstructure.

14. A process as claimed in claim 13 characterized in that the conditions are so controlled as to produce a microstructure consisting substantially of fine pearlite or sorbite.

15. Fluidized bed apparatus for heat-treating steel wires comprising a first fluidized bed zone (Q) for quenching wires and a second fluidized bed zone (TR-S), whereby means are provided for fluidizing the first zone and second zone independently from each other and for controlling independently the temperatures of the first and the second zone, characterized in that the second zone (TR-S) is divided into separate regions (13) and that separately controlled heating elements (14) are provided in the separate regions (13) of the second zone (TR-S).

16. Apparatus as claimed in claim 15, characterized in that the first fluidized bed zone (Q) is provided with fixed cooling means and with additional variable cooling means (27, 28).

17. Apparatus as claimed in claim 15 or claim 16 characterized in that the first zone (Q) is supplied with exhaust gas from an austenitizing furnace (1).

18. Apparatus as claimed in claim 17, characterized in that a pre-cooler (11) and an auxiliary heater (12) are provided for the exhaust gas before it is fed to the first zone (Q).

19. Apparatus as claimed in claim 17 or 18 characterized in that means are provided for passing the exhaust gas

sequentially through the first and second zones (Q, TR-S) and separate temperature control means (10, 10') are provided to control the temperature of the exhaust gas entering the respective zones.

5 Patentansprüche

1. Verfahren zur Wärmebehandlung von Stahldrähten in einem Patentiervorgang, bei dem die austenitisierten Drähte in einer ersten Wirbelbettzone (Q) abgeschreckt und zu einer zweiten Wirbelbettzone (TR-S) übertragen werden, wo eine Umwandlung erfolgt, wobei die erste Wirbelbettzone mit einem Wirbelgas fluidisiert wird, und die zweite Zone mit einem anderen Wirbelgas fluidisiert wird, wobei die Temperaturen der beiden Zonen (Q, TR-S) unabhängig geregelt werden, und wobei die beiden Zonen (Q, TR-S) durch unabhängig geregelte Gaszufuhren fluidisiert werden, dadurch gekennzeichnet, daß die Temperatur der zweiten Zone (TR-S) in einer Anzahl von einzelnen Bereichen (13) unabhängig voneinander durch individuelle Heizelemente (14) für jeden Bereich (13) dieser zweiten Zone geregelt wird.
2. Verfahren gemäß Anspruch 1, dadurch gekennzeichnet, daß die Temperaturen der individuellen Bereiche (13) so geregelt werden, um einen Temperaturgradienten entlang der zweiten Zone (TR-S) zu liefern.
3. Verfahren gemäß Anspruch 2, dadurch gekennzeichnet, daß der Temperaturgradient so verläuft, daß eine Umwandlung bei einer ersten Temperatur beginnt und daraufhin bei einer zweiten, höheren Temperatur fortgesetzt wird.
4. Verfahren gemäß Anspruch 3, dadurch gekennzeichnet, daß eine Umwandlung bei der zweiten Temperatur eingeleitet wird, nachdem zwischen 10 und 20 % der Umwandlung erfolgt sind.
5. Verfahren gemäß jedem der Ansprüche 1 bis 3, dadurch gekennzeichnet, daß eine rasche Unterkühlung des austenitisierten Drahts durchgeführt wird, auf die ein rasches Erwärmen auf eine Temperatur erfolgt, die für eine Umwandlung geeignet ist.
6. Verfahren gemäß jedem der bisherigen Ansprüche, dadurch gekennzeichnet, daß die Temperatur der ersten Zone (Q) zumindest teilweise mit einer Zusatzkühleinrichtung (28) geregelt wird.
7. Verfahren gemäß Anspruch 6, dadurch gekennzeichnet, daß die erste Zone (Q) einer fortlaufenden Kühlung durch eine erste Kühleinrichtung sowie einer variablen Kühlung durch eine zweite Kühleinrichtung (27, 28) unterworfen ist.
8. Verfahren gemäß jedem der bisherigen Ansprüche, dadurch gekennzeichnet, daß die erste Zone (Q) mit einem im wesentlichen nichtoxydierenden Abgas von einem Austenitisierungssofen (1) fluidisiert wird.
9. Verfahren gemäß Anspruch 8, dadurch gekennzeichnet, daß die Abgase mit Zusatzeinrichtungen (11, 12) gekühlt und/oder erhitzt werden, bevor sie in die erste Zone (Q) eintreten.
10. Verfahren gemäß Anspruch 8 oder 9, dadurch gekennzeichnet, daß die Abgase einen Sauerstoffgehalt von 2 Volumsprozents oder weniger besitzen.
11. Verfahren gemäß Anspruch 10, dadurch gekennzeichnet, daß die Abgase einen Restkohlenmonoxydgehalt aufweisen, um nichtoxydierende Bedingungen weiter zu fördern.
12. Verfahren gemäß Anspruch 11, dadurch gekennzeichnet, daß der Kohlenmonoxydgehalt zwischen 0,5 und 2 % liegt.
13. Verfahren gemäß jedem der bisherigen Ansprüche, dadurch gekennzeichnet, daß die Bedingungen so geregelt werden, um eine im wesentlichen vollständig lamellare, perlitische Mikrostruktur zu erzeugen.
14. Verfahren gemäß Anspruch 13, dadurch gekennzeichnet, daß die Bedingungen so geregelt werden, um eine Mikrostruktur zu erzeugen, die im wesentlichen aus feinem Perlit oder Anlaßgefüge besteht.
15. Wirbelbettvorrichtung zur Wärmebehandlung von Stahldrähten, wobei die Vorrichtung eine erste Wirbelbettzone (Q) für das Abschrecken von Drähten sowie eine zweite Wirbelbettzone (TR-S) besitzt, wobei eine Einrichtung vorgesehen ist, um die erste Zone und die zweite Zone unabhängig voneinander zu fluidisieren und die Temperatur der ersten und zweiten Zone unabhängig zu regeln, dadurch gekennzeichnet, daß die zweite Zone (TR-S) in getrennte Bereiche (13) geteilt ist, und daß getrennt geregelte Heizelemente (14) in den getrennten Bereichen (13) der zweiten Zone (TR-S) vorgesehen sind.
16. Vorrichtung gemäß Anspruch 15, dadurch gekennzeichnet, daß die erste Wirbelbettzone (Q) mit einer festen Kühleinrichtung sowie mit einer zusätzlichen variablen Kühleinrichtung (27, 28) versehen ist.

17. Vorrichtung gemäß Anspruch 15 oder 16, dadurch gekennzeichnet, daß die erste Zone (Q) mit einem Abgas von einem Austenitisierungssofen (1) angespeist wird.

18. Vorrichtung gemäß Anspruch 17, dadurch gekennzeichnet, daß ein Vorkühler (11) und ein Zusatzheizelement (12) für das Abgas vorgesehen sind, bevor dieses in die erste Zone (Q) geleitet wird.

19. Vorrichtung gemäß Anspruch 17 oder 18, dadurch gekennzeichnet, daß eine Einrichtung vorgesehen ist, um das Abgas nacheinander durch die erste und zweite Zone (Q, TR-S) zu leiten, wobei getrennte Temperaturregeleinrichtungen (10, 10') vorgesehen sind, um die Temperatur des Abgases zu regeln, das in die entsprechenden Zonen eintritt.

Revendications

1. Procédé de traitement thermique de fils d'acier dans une opération de patentage dans laquelle des fils traités par austénitisation sont trempés dans une première zone à lit fluidisé (Q) et transférés dans une seconde zone à lit fluidisé (TR-S) dans laquelle une transformation est réalisée, la première zone à lit fluidisé est fluidisée par un gaz de fluidisation et la seconde zone étant fluidisée par un autre gaz de fluidisation, de sorte que les températures des deux zones (Q, TR-S) sont réglées indépendamment, et dans lequel les deux zones (Q, TR-S) sont fluidisées par transmission de gaz réglés indépendamment, caractérisé en ce que la température de la seconde zone (TR-S) est réglée dans un certain nombre de régions individuelles (13) indépendamment les unes des autres par des éléments individuels de chauffage (14) pour chaque région (13) de cette seconde zone.

2. Procédé selon la revendication 1, caractérisé en ce que les températures des régions individuelles (13) sont réglées de manière qu'il existe un gradient de température le long de la seconde zone (TR-S).

3. Procédé selon la revendication 2, caractérisé en ce que le gradient de température est tel que la transformation commence à une première température et se poursuit pratiquement à une seconde température plus élevée.

4. Procédé selon la revendication 3, caractérisé en ce que la transformation à la seconde température commence après que 10 à 20 % de transformation ont été effectués.

5. Procédé selon l'une quelconque des revendications 1 à 3, caractérisé en ce qu'il comporte une surfusion rapide du fil austénitique suivie d'un chauffage rapide à une température convenant à la transformation.

6. Procédé selon l'une quelconque des revendications précédentes, caractérisé en ce que la température de la première zone (Q) est réglée au moins en partie par un dispositif de refroidissement auxiliaire (28).

7. Procédé selon la revendication 6, caractérisé en ce que la première zone (Q) est soumise à un refroidissement continu par un premier dispositif de refroidissement et à un refroidissement variable par un second dispositif de refroidissement (27, 28).

8. Procédé selon l'une quelconque des revendications précédentes, caractérisé en ce que la première zone (Q) est fluidisée par des gaz d'échappement pratiquement non oxydants provenant d'un four d'austénitisation (1).

9. Procédé selon la revendication 8, caractérisé en ce que les gaz d'échappement sont refroidis et/ou chauffés par des dispositifs auxiliaires (11, 12) avant entrée dans la première zone (Q).

10. Procédé selon la revendication 8 ou 9, caractérisé en ce que les gaz d'échappement ont une teneur en oxygène inférieure ou égale à 2 % en volume.

11. Procédé selon la revendication 10, caractérisé en ce que les gaz d'échappement contiennent de l'oxyde de carbone résiduel favorisant la création de conditions non oxydantes.

12. Procédé selon la revendication 11, caractérisé en ce que la teneur en oxyde de carbone est comprise entre 0,5 et 2 %.

13. Procédé selon l'une quelconque des revendications précédentes, caractérisé en ce que les conditions sont réglées de manière qu'une microstructure perlitique entièrement lamellaire soit pratiquement formée.

14. Procédé selon la revendication 13, caractérisé en ce que les conditions sont réglées de manière qu'une microstructure contenant pratiquement de la sorbite ou de la perlite fine est formée.

15. Appareil à lit fluidisé destiné au traitement thermique de fils d'acier comprenant une première zone à lit fluidisé (Q) destinée à la trempe de fils et une seconde zone à lit fluidisé (TR-S), dans lequel un dispositif est destiné à fluidiser la première zone et la seconde zone indépendamment l'une de l'autre et à régler indépendamment les températures de la

première et de la seconde zone, caractérisé en ce que la seconde zone (TR-S) est divisée en régions séparées (13), et en ce que des éléments de chauffage réglés séparément (14) sont placés dans les régions séparées (13) de la seconde zone (TR-S).

5 16. Appareil selon la revendication 15, caractérisé en ce que la première zone à lit fluidisé (Q) a un dispositif fixe de refroidissement et un dispositif supplémentaire de refroidissement variable (27, 28).

17. Appareil selon la revendication 15 ou 16, caractérisé en ce que la première zone (Q) reçoit les gaz d'échappement d'un four d'austénitisation (1).

10 18. Appareil selon la revendication 17, caractérisé en ce qu'un appareil de refroidissement préalable (11) et un appareil de chauffage auxiliaire (12) sont utilisés pour les gaz d'échappement avant transmission de ceux-ci à la première zone (Q).

15 19. Appareil selon la revendication 17 ou 18, caractérisé en ce qu'un dispositif est destiné à transmettre les gaz d'échappement successivement dans la première et la seconde zone (Q, TR-S) et des dispositifs séparés de réglage de température (10, 10') sont destinés à régler la température des gaz d'échappement pénétrant dans les zones respectives.

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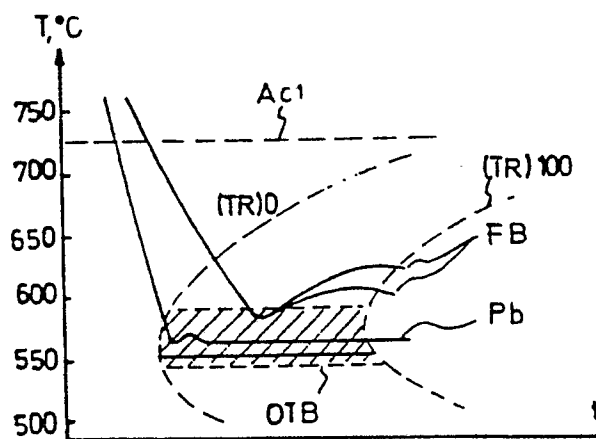
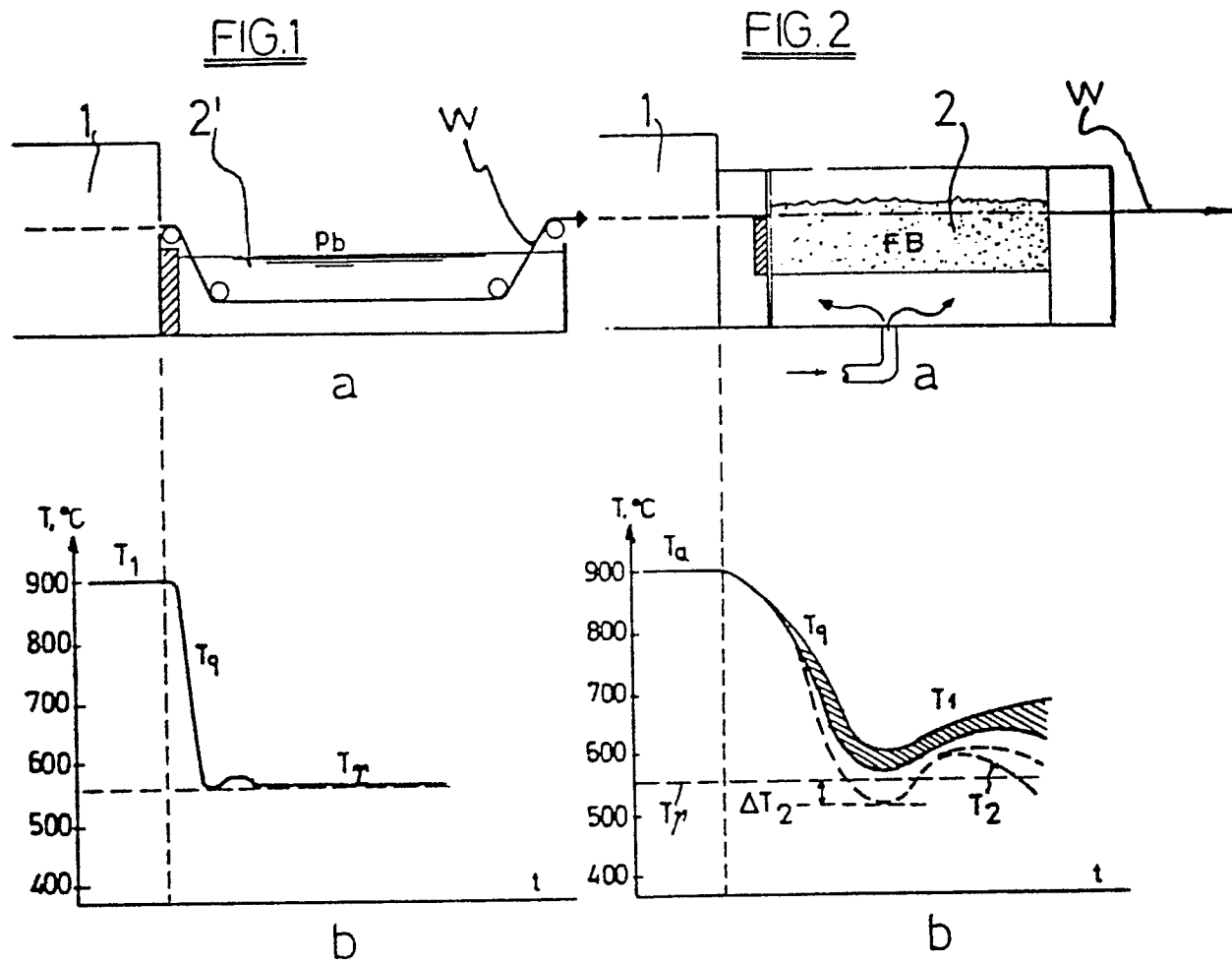
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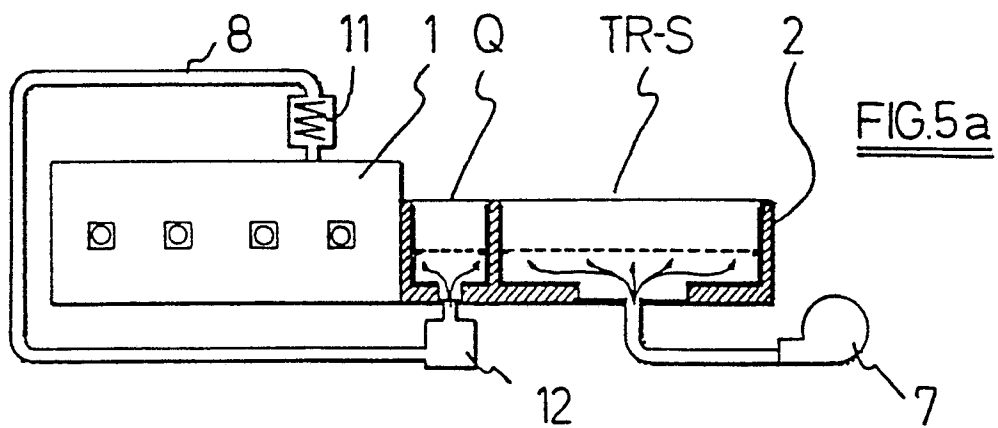
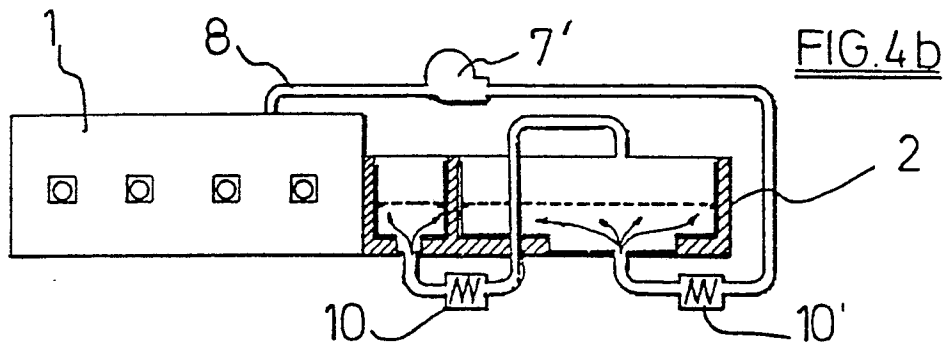
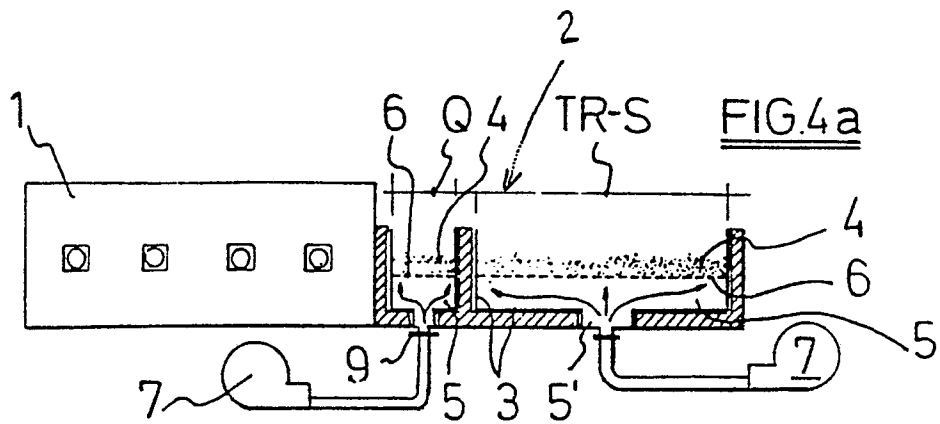
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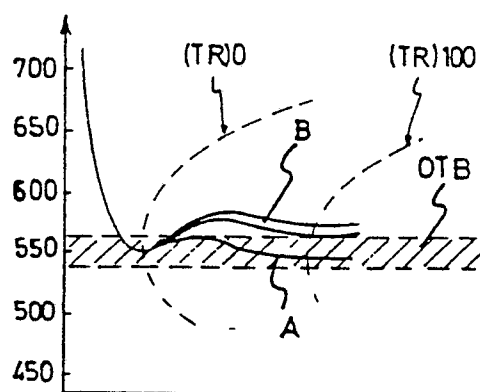
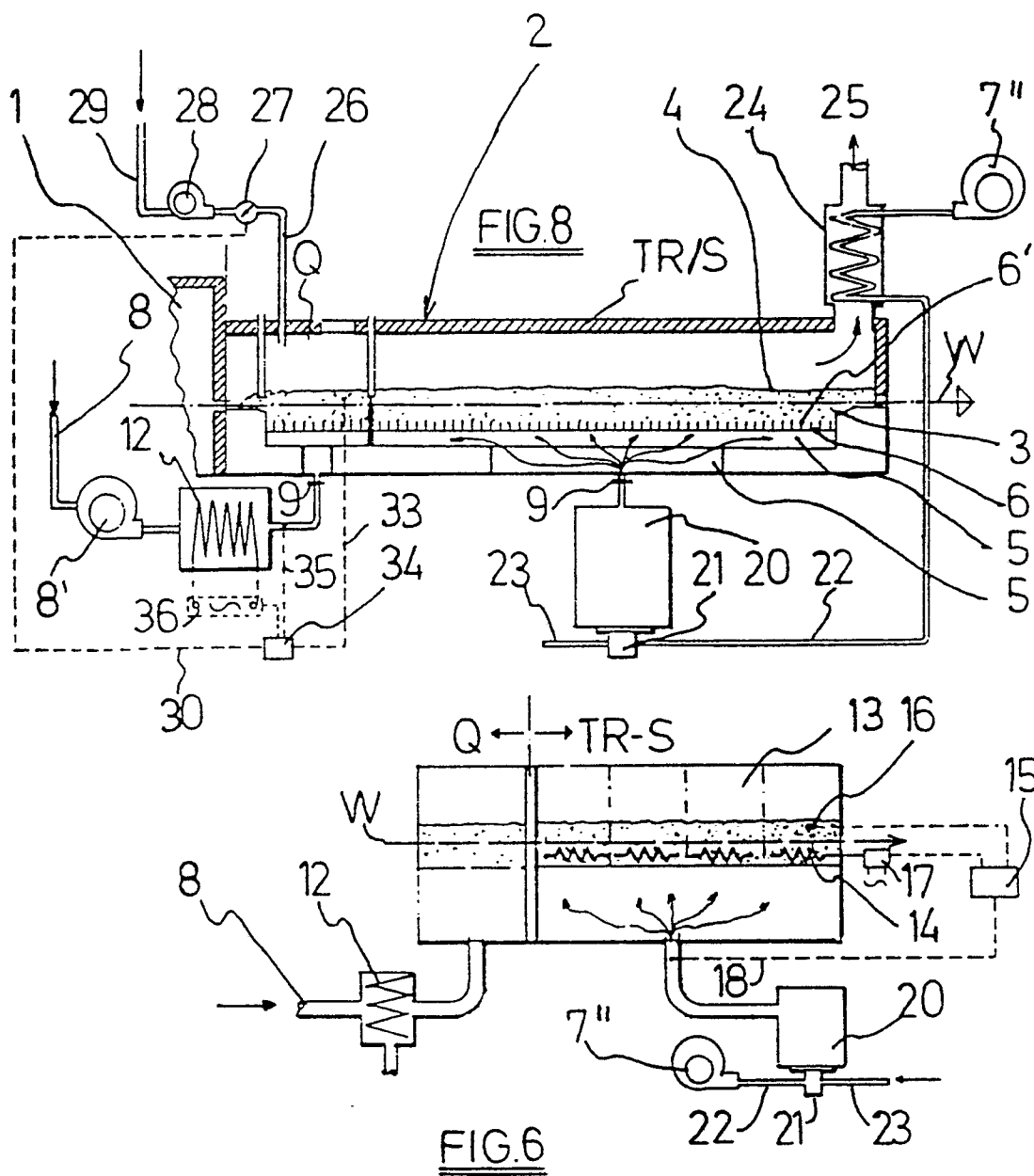
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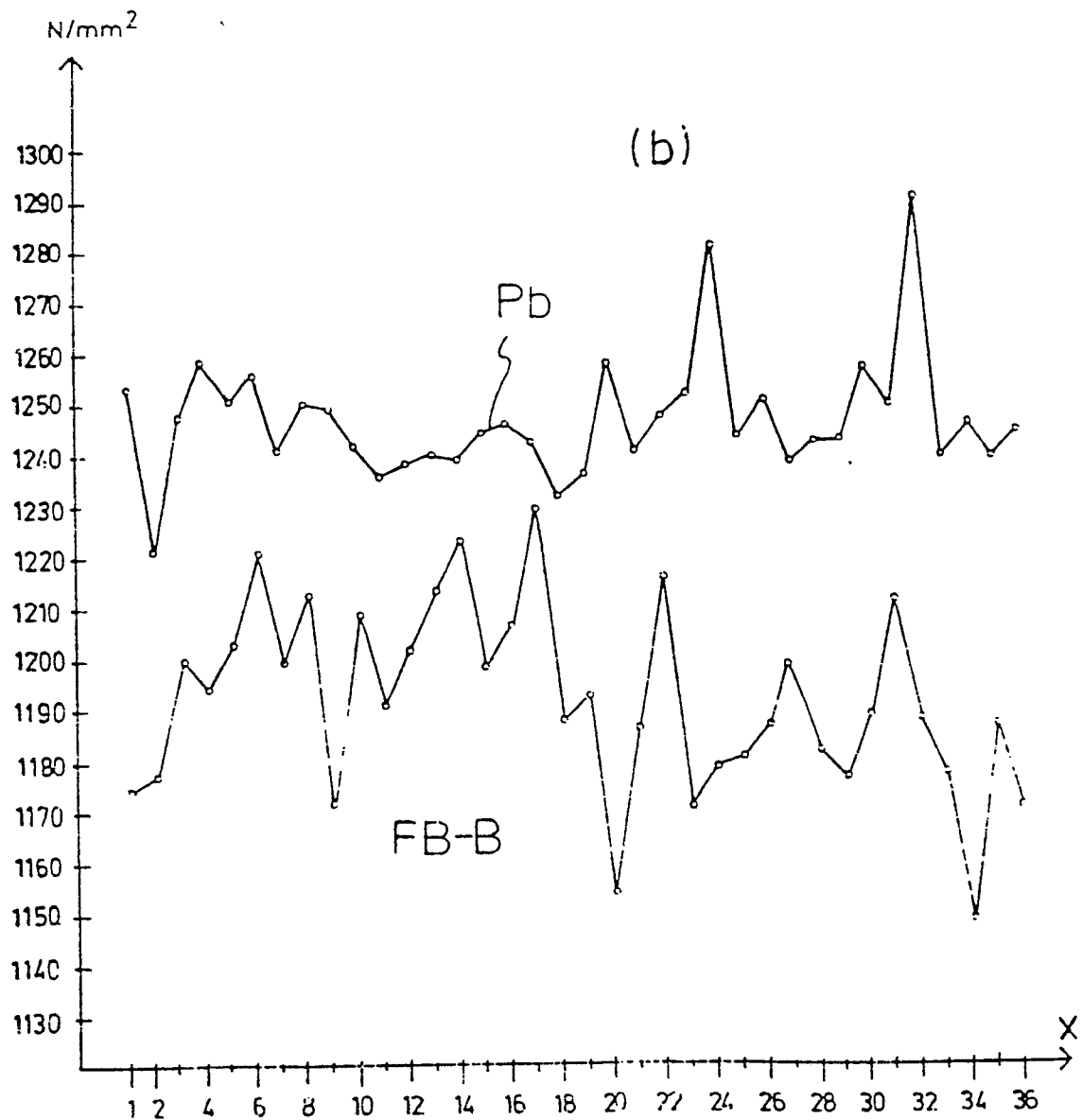
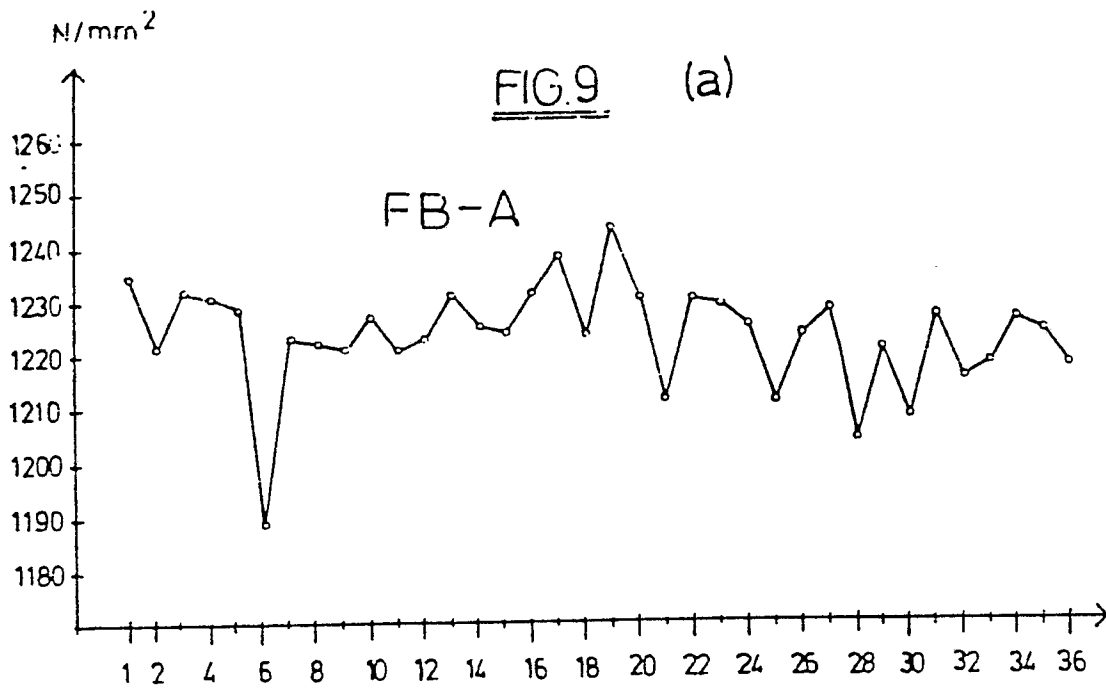
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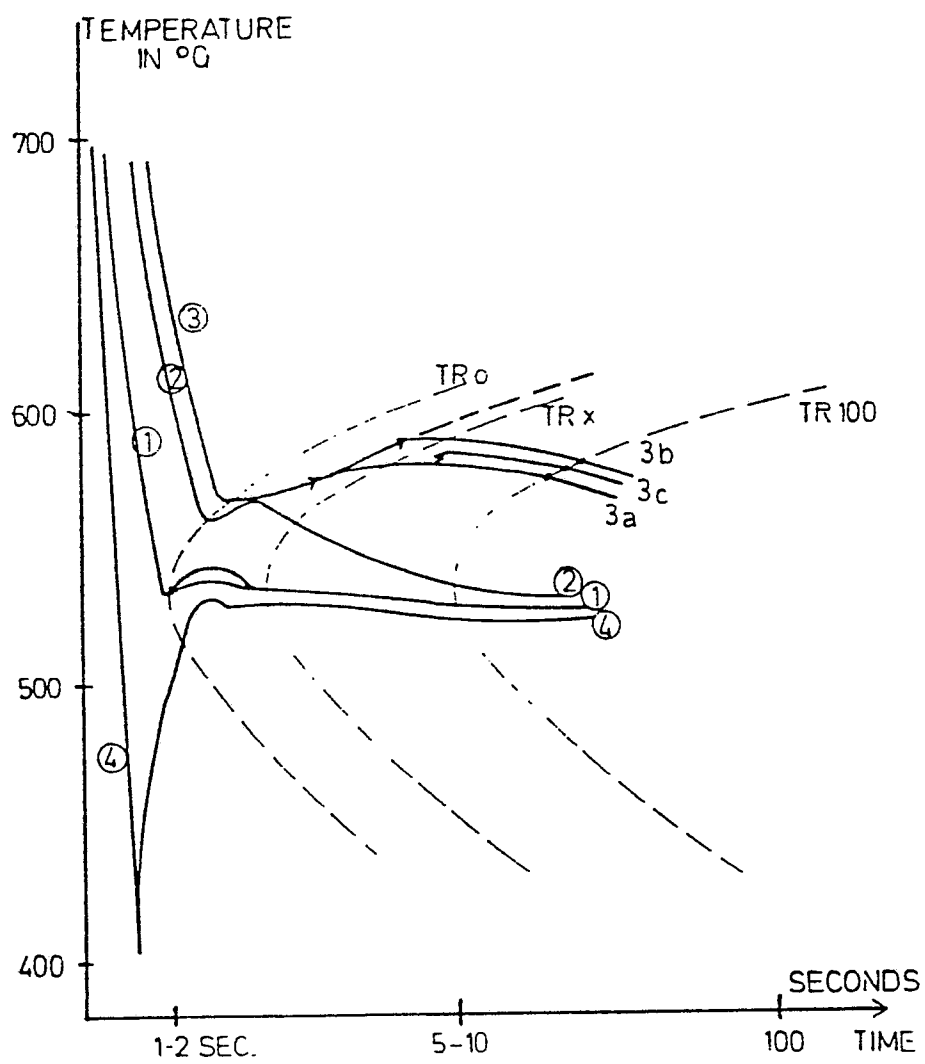


FIG.10