

(43) International Publication Date
20 November 2014 (20.11.2014)

(51) International Patent Classification:

C21B 3/08 (2006.01) **B65G 17/36** (2006.01)
B65G 17/12 (2006.01) **B65G 21/00** (2006.01)

(21) International Application Number:

PCT/EP2014/059882

(22) International Filing Date:

14 May 2014 (14.05.2014)

(25) Filing Language:

English

(26) Publication Language:

English

(30) Priority Data:

LU 92 196 14 May 2013 (14.05.2013)

LU

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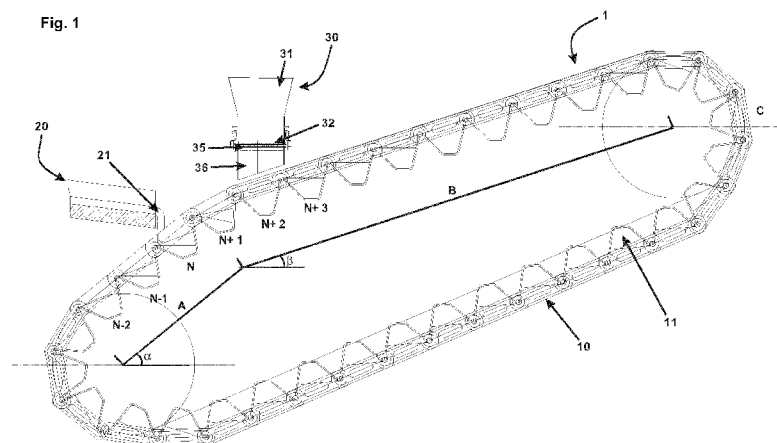
(81) Designated States (unless otherwise indicated, for every kind of national protection available): AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IR, IS, JP, KE, KG, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LT, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(84) Designated States (unless otherwise indicated, for every kind of regional protection available): ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, KM, ML, MR, NE, SN, TD, TG).

Published:

— with international search report (Art. 21(3))

(54) Title: SLAG CASTING APPARATUS AND METHOD OF CONTROLLING SAID APPARATUS



(57) **Abstract:** A method or apparatus for dry slag granulation of hot liquid slag using a casting apparatus comprising an endless conveyor having a plurality of casting moulds, which endless conveyor is arranged to move said casting moulds in a first section from a slag pouring zone through a cooling zone to a discharge zone and in a second section back to the slag pouring zone, comprising the continuous steps of pouring an amount of hot liquid slag into a casting mould in a position N in the slag pouring zone, moving the hot liquid slag containing casting mould in a position within the cooling zone, adding solid metallic particles to the hot liquid slag containing casting mould by dropping an amount of said particles into the mould from a dispensing device arranged above said mould and comprising at least one hopper for storing said solid metallic particles, discharging the cooled solidified slag from the mould in the discharge zone, wherein the amount of liquid slag in the casting mould is controlled by arranging the slag pouring zone in the first section of the endless conveyor to convey the moulds with a first slope angle α which limits the effective maximum filling volume of the mould in the slag pouring zone to a value V_α , any excess slag cascading back to an upstream casting mould in position N-1, N-2, etc. wherein the cooling zone is arranged with a second slope angle $\beta < \alpha$ such that the effective maximum filling volume of the mould in the cooling zone has a value $V_\beta > V_\alpha$ and wherein the amount of metallic particles added by the dispensing device is controlled by actuating of at least one actuated sliding gate arranged at the hopper's outlet.

SLAG CASTING APPARATUS AND METHOD OF CONTROLLING SAID APPARATUS

Technical field

[0001] The present invention generally relates to granulation of slag from the metal industry and more particularly from the iron industry.

Background Art

[0002] Conventionally, metallurgical slag is granulated in water.

[0003] Water quenching ensures fast solidification of the metallurgical slag, which, in the case of blast furnace slag, is a necessary condition for obtaining a valuable product. A water jet is firstly used to fragmentize the hot liquid slag stream into very small particles and to transfer them into a water bath. The energy from the hot slag is withdrawn through direct contact between the hot liquid slag and the water. As this has to happen at ambient pressure, the temperature of the slag is immediately lowered to a temperature level of below 100°C.

[0004] However, a main disadvantage of the water granulation process is that sulphur contained in the hot liquid slag reacts with the water and generates sulphur dioxide (SO₂) and hydrogen sulphide (H₂S).

[0005] Furthermore it must be noted that care must be taken to lower the temperature of the slag sufficiently rapidly and far enough to obtain a vitrified or amorphous slag rather than a (partly) crystallized slag, which is a lot less advantageously priced (about 15 times) in the market.

[0006] It would also be desirable to recover at least some of the heat from the slag in a usable form. To use this potential in an efficient way, it is necessary to rapidly cool down the slag to a temperature level, which is low enough to make the treatment of the material easier but high enough to preserve the energy at a useable level.

[0007] One possibility to overcome the disadvantage of producing noxious gases and to recover at least part of the heat comprises the mixing of liquid slag with cold slag granulates of the same chemistry. The slag can then be subject to heat recovery in a heat exchanger. However, it has been found that due to the high viscosity of the liquid slag, the cold slag granulates and the liquid slag do not

mix easily and thus it is not possible to cool the liquid slag fast enough to obtain vitrified slag.

[0008] A further solution has been proposed in which (cold) solid metallic particles are added to the hot liquid slag (WO 2012/034897, WO 2012/080364). The effect is that the slag rapidly solidifies in a vitreous state without producing noxious gases. Furthermore the solid metallic particles are chemically inert and may be easily separated, recovered and reused (see WO 2012/034897). Finally, the heat from both solidified slag and metallic particles may be recovered in an appropriate device, such as a heat exchanger (see WO 2012/080364).

[0009] In practice, however, the efficiency of the above solution is highly dependent on the appropriate pouring of the slag and the correct dosing of the metallic particles. This is even aggravated by the fact that in general the incoming flow of liquid slag cannot be controlled, unless technically complex or energetically demanding additional equipment, such as actual slag filling level determination in the freshly filled mould, heated or refractory lined transfer ladles and/or equivalent are foreseen. Without such additional measures, any proper metering of the metallic particles becomes complicated and even erratic.

Technical problem

[0010] It is an object of the present invention to provide method for dry slag granulation, as well as a corresponding device, which allow to benefit from the advantages of reduced environmental impact and increased energy recovery potential, while being simple to implement, and both safe and efficient to use.

General Description of the Invention

[0011] To achieve this object, the present invention proposes, in a first aspect, a method for dry slag granulation of hot liquid slag using a casting apparatus comprising an endless conveyor having a plurality of casting moulds, which endless conveyor is arranged to move said casting moulds in a first section from a slag pouring zone through a cooling zone to a discharge zone and in a second section back to the slag pouring zone, comprising the continuous steps of:

(a) pouring an amount of hot liquid slag into a casting mould in a position N in the slag pouring zone,

- (b) moving the hot liquid slag containing casting mould in a position within the cooling zone,
- (c) adding solid metallic particles to the hot liquid slag containing casting mould, e.g. at a position $N+n$ (wherein $1 \leq n \leq 10$, preferably $1 \leq n \leq 4$, in particular $n = 2$) by dropping an amount of said particles into the mould from a dispensing device arranged above said mould and comprising at least one hopper for storing said solid metallic particles,
- (d) discharging the cooled solidified slag from the mould in the discharge zone, wherein the amount of liquid slag in the casting mould is controlled by arranging the slag pouring zone in the first section of the endless conveyor to convey the moulds with a first slope angle α which limits the effective maximum filling volume of the mould in the slag pouring zone to a value V_α , any excess slag cascading or overflowing back to an upstream casting mould in position $N-1$, $N-2$, etc.

wherein the cooling zone is arranged with a second slope angle $\beta < \alpha$ such that the effective maximum filling volume of the mould in the cooling zone has a value $V_\beta > V_\alpha$ and

wherein the amount of metallic particles added by the dispensing device is controlled by actuating of at least one actuated sliding gate arranged at the outlet of the hopper.

[0012] In a further aspect, the invention proposes an apparatus for dry slag granulation of hot liquid slag comprising an endless conveyor having a plurality of casting moulds, which endless conveyor is arranged to move said casting moulds in a first section from a slag pouring zone through a cooling zone to a discharge zone and in a second section back to the slag pouring zone, and

wherein the apparatus further comprises a dispensing device arranged in the cooling zone e.g. at a position $N+n$ (wherein $1 \leq n \leq 10$, preferably $1 \leq n \leq 4$, in particular $n = 2$) above said moulds and comprises at least one hopper for storing solid metallic particles, said dispensing device comprising at least one sliding gate at the hopper's outlet, the actuating of said sliding gate(s) allowing the control of the amount of metallic particles dispensed by said dispensing device,

wherein the slag pouring zone in the first section of the endless conveyor is arranged to allow the conveying of the moulds with a first slope angle α which

limits the effective maximum filling volume of the mould in the slag pouring zone to a value V_α , and wherein the cooling zone is arranged with a second slope angle $\beta < \alpha$ such that the effective maximum filling volume of the mould in the cooling zone has a value $V_\beta > V_\alpha$.

[0013] In the context of the present invention, it shall be noted that the conveying of the moulds in the pouring zone and in the cooling zone is preferably essentially linear, i.e. the slope angle α is essentially constant within the pouring zone and the slope angle β is essentially constant within the cooling zone. Furthermore, in the present context, the positions indicated relative to the position N of the mould being filled in the slag pouring zone are illustrative only. In fact the actual position of the dispensing device in a position indicated by N+n in the present document may be located at a distance d which is not a multiple of the length l of a mould, i.e. the filling of the metallic particles in a mould in position N+n does not necessarily occur when the mould in position N is located under the slag runner. Hence, the distance d between the mould being filled in the slag pouring zone and the dispensing device may be any distance between 0 (dispensing device immediately adjacent to the mould being filled) and 9 l, preferably 0.1 l and 3 l, in particular about 1 l (i.e. n is about 2). In practice, the upper limit is generally dependent on the fact that the slag should still be sufficiently liquid to allow appropriate penetration of the metallic particles into the slag.

[0014] As already mentioned, the main cause of the difficulties in practice is not only the uncontrollable, but also variable flow of slag to cope with, while it is important to have a certain ratio between slag and metallic particles.

[0015] Hence, the first advantage of the present method or apparatus is that the moulds of the endless conveyor are filled with a defined (and thus known) amount of slag. This defined amount of slag is dependent, for a given mould, on the inclination angle of the mould when it is being filled: the steeper the slope the less slag can be filled in the mould until the slag overflows or cascades to the next mould(s) (i.e. the next mould(s) upstream of that being filled). Hence, at a slope angle α , the effective maximum filling volume, i.e. the useful volume, can be defined as V_α . If the slope angle is decreased (less steep or even horizontal), the actual filling level in the mould decreases and the effective maximum filling

volume, i.e. the useful volume of the mould increases to V_β thereby providing room for the solid metallic particles to be added in the cooling zone. Hence, if the slope angle β in the cooling zone is lower than the angle α in the pouring zone, a theoretical maximum amount of metallic particles corresponding to $V_\beta - V_\alpha$ may be added to the mould without risking an overflow or spilling.

[0016] In a preferred embodiment of the invention, the slope angle α in the slag pouring zone and the slope angle β in the cooling zone are chosen such that the effective maximum filling volume of the mould in the slag pouring zone V_α is between 0.25 and 0.75, preferably between 0.30 and 0.60, even more preferably 0.45 to 0.55 times the effective maximum filling volume of the mould in the cooling zone V_β . In particular, the slope angles α and β are chosen such that V_α is about $\frac{1}{2} V_\beta$.

[0017] Although largely dependent on the geometry of the mould, an appropriate angle β is in practice generally situated between 0° (horizontal) and 50° , more preferably between 10° and 40° , whereas angle α is usually 5 to 20° greater than angle β .

[0018] A further general problem associated with the uncontrollable and variable slag flow is that the addition of the (determined amount of) metallic particles must be done within the time frame imparted by the slag flow. The resulting difficulty is thus the limited time available to introduce the required amount addition of metallic particles to the partly filled casting mould, while the conveyor needs to continuously move the moulds further. Hence, an important advantage of the present method is that the use of a sliding gate for metering the amount of solid metallic particles allows for a rapid opening and closing, thereby greatly shortening the time necessary to bring in the correct amount of particles.

[0019] An appropriate sliding gate (valve) generally comprises a sliding plate arranged to close an opening by pushing and/or rotating it, generally along a sliding frame, in front of the opening (in this case the outlet of the hopper). The sliding of the plate may be effected in parallel to the conveying direction of the moulds or preferably perpendicularly to this direction. Hence, in the context of the present invention the sliding movement may be translational (e.g. linear sliding gate), rotational (e.g. linear sliding gate), rotational (e.g. rotary sliding gate; the

axis of rotation being preferably parallel to a plane formed by the opening or perpendicular to that plane) or even a combination thereof (e.g. curve sliding gate). The related term "opening stroke" as it is used herein shall be interpreted accordingly as being the amplitude of sliding movement (pushing and/or rotating) necessary to open the sliding gate.

[0020] In a preferred embodiment of the sliding gate, a stationary plate having a plurality of spaced apart apertures is placed in front of the opening (outlet of the hopper) and thus (only) partly obstructs the outlet. A corresponding movable sliding plate presents corresponding apertures which may be slid in front of the apertures of the stationary plate for opening the gate and slid in a different position to close the apertures of the stationary plate. Preferably these apertures are of roughly rectangular or square shape for linear sliding gates or of roughly sector shape for rotary sliding gates with a rotation axis perpendicular to the opening and the spaces between adjacent apertures in the sliding plate are dimensioned to essentially close the corresponding apertures of the stationary plate. A major advantage of a plurality of apertures is that the stroke of the sliding gate, i.e. the sliding distance between open and closed state, is substantially reduced, which is beneficial in view of the limited time available to effect the action.

[0021] In a further preferred aspect, the sliding gate comprises two or more rows of a plurality of apertures. In such a case, it is even more preferred that the apertures of adjacent rows are provided in a staggered (zigzag) fashion to further improve the uniform distribution of the particles in the slag.

[0022] In a still further aspect, the dispensing device comprises two or more separately controllable actuated sliding gates, each sliding gate being connected to the outlet of the same hopper or of a separate hopper. Advantageously, the dispensing device comprises one (or two) hopper(s) with two separately controllable actuated sliding gates, each sliding gate covering essentially half of the casting mould's surface. The provision of two (or more) independently actuatable sliding gates allows to be more flexible in terms of opening time as the moulds are moving below the dispensing device and in terms of redundancy should one of the gates fail or become clogged.

[0023] The sliding gate or gates is/are actuated by any appropriate means, such as pneumatic means, hydraulic means, and/or by one or more electric motors. Preferably, the actuation of the sliding gate(s) is effected by one or more hydraulic cylinders.

[0024] In a still further aspect, the stroke of the sliding gate(s) is limited, such that the apertures of the stationary plate are not completely closed. The advantage of this practice is double in that the actuation is even faster and that the wear of the sliding gate and the stationary plate are substantially reduced. Indeed, it has been noted that for a given diameter of the metallic particles, it is sufficient to close the sliding gate(s) in order to leave a residual opening of each aperture which generally represents 0.3 to 1.5, preferably about 0.8 to 1.3 times, most preferably between about 1.1 and 1.25 times the diameter of the particles or of the smallest particles if particles of different diameters are used concomitantly.

[0025] In the simplest embodiment, the movement of the moulds in the endless conveyor is constant or predetermined depending on the particulars of the apparatus and the mean slag flow. However, this is generally not satisfactory as such an apparatus would not be able to cope with larger variations in slag flow. Hence, in a further preferred embodiment, the moving of the casting moulds is controlled by monitoring the temperature of at least two (or more) casting moulds immediately upstream (positions N-1 and N-2, etc.) of the casting mould being filled and by varying the speed of the movement in step (b).

[0026] It is particularly preferred to control the apparatus by decreasing the speed of movement in step (b) if the temperature in the casting mould in position N-1 does not significantly increase due to a lack of backflow of hot liquid slag from position N (pouring position) and by increasing the speed of movement in step (b) if the temperature in the casting mould in position N-2 increases due to the backflow of hot liquid slag from the casting mould in position N-1. So, in other words, if the temperature in the mould immediately upstream (N-1) of the mould being filled does not increase to a value near the temperature of the hot liquid slag, i.e. has a temperature well below this value, no slag is cascading back, hence the filling of the mould is at best sufficient, probably however incomplete: the conveyor is slowed down. If on the other hand, only the mould in N-1 is hot

(contains liquid slag) and not mould N-2, the speed of the conveyor is deemed appropriate, the speed is not changed. Finally, if not only the mould N-1, but also the mould N-2 becomes hot, the speed of the conveyor is too low and must be increased.

[0027] The monitoring of the temperature may be done by any appropriate means, such as with a thermocouple or similar; preferably however the monitoring is effected contactlessly, such as by means of pyrometers.

[0028] In a further aspect, the method and apparatus of the invention also integrates means to precisely determine the position of (some of) the moulds, in particular the mould beneath the dispensing device. Any conventional means can be used to this purpose, in particular contact and/or contactless devices such as switches, laser, induction, etc.

[0029] Although the present method, in particular when integrating temperature measurements as described herein, can be used as default regulation method for a dry slag granulation apparatus, it is noteworthy that this method is also particularly adapted to be used as emergency regulation or in exceptional cases, such as in case of failure or during maintenance of a more complex regulation system, due to its simplicity in terms of control components and due to its efficiency.

[0030] In a still further aspect, the method or the apparatus further comprises (means for) the measurement of the actual combined amount of slag and metallic particles, i.e. the amount of the slag/particles mix, in the casting mould after step (c) in a position downstream of position N+n, calculating the amount of metallic particles actually added in step (c) based on the measured combined amount of slag and metallic particles (mix) and the known amount of hot liquid slag and, if the calculated amount of actually added metallic particles does not correspond to the expected amount of metallic particles, adapting the characteristics of the at least one sliding gate.

[0031] The main advantage of this further preferred embodiment is that it allows using the actual measurement of the amount of the resulting slag/particles mix as a feedback for adapting (or correcting) the amount of metallic particles by acting on the dispensing device, in particular on the sliding gate(s) regulation.

[0032] Advantageously, the characteristics of the at least one sliding gate comprise the mass flow of particles $\dot{m}_{\text{particles}}$ as a function of the opening stroke x ($\dot{m}_{\text{particles}}/x$ curve), wherein the opening stroke is the distance by which the sliding gate must be moved between open and closed state (or essentially closed state, see above). In fact, this parameter basically defines the amount of particles flowing through the sliding gate per unit of time depending on the opening of the gate. This parameter can be represented as a discrete curve and may be determined experimentally depending on the particular type of sliding gate and the particular type of particles (see details below).

[0033] In a still further embodiment, the actual combined amount of slag and metallic particles mix in the casting mould after step (c) is measured by determining the height of slag/metallic particles mix h_{mix} in said mould, and by calculating the corresponding volume V_{mix} based on the known shape of the casting mould, as well as the determined mass of metallic particles $M_{\text{particles}}$ based on the difference between V_{mix} and the known volume of slag V_{slag} .

[0034] Preferably, the measurement of the amount is effected by measuring the height of the slag/metallic particles mix within the casting mould contactlessly, such by means of one or more laser range finders. Other means such as radar, acoustical or optical detection etc. may also be used.

[0035] The solid metallic particles are preferably dropped from a height of about 0.1 to 3 m, preferably about 0.2 to 2 m, to obtain a quick and efficient mixing of the slag and the solid metallic particles. The exact height i.e. the exact amount of energy required for the particles to penetrate the liquid slag to the desired depth depends on the composition of the slag, the temperature of the slag, the density and the diameter of the solid metallic particles etc. As the dropping of the metallic particles into the hot liquid slag may cause some spilling or splashing, the dispensing device preferably comprises splash boards arranged at least on the lateral sides below the hopper(s) and sliding gate(s) and which extend approximately to the upper tops of the moulds.

[0036] The solid metallic particles advantageously have a density of at least 2.5 g/cm^3 . Due to the difference of densities between the slag and the metallic particles, the metallic particles and the slag mix thoroughly.

[0037] The solid metallic particles are preferably spherical so as to have good mixing properties and to assure a rapid and efficient cooling of the slag.

[0038] The solid metallic particles preferably have a diameter of at least 2 mm preferably more than 5 mm and most preferably more than 10 mm. The solid metallic particles advantageously have a diameter of less than 80 mm, preferably less than 50 mm and most preferably less than 25 mm.

[0039] The solid metallic particles are preferably made of a metal chosen amongst the group consisting of iron, steel, aluminium, copper, chrome, nickel, their alloys, as well as their alloys with other metals.

[0040] In practice, it is preferred to use steel balls because they are readily available in different diameters.

[0041] During and/or after the discharge of the slag cake from the conveyor, the cake is preferably crushed into particles of a size of about 40 - 120 mm and a bulk density of about 2 - 5 g/cm³, preferably of a size of about 40 - 90 mm and a bulk density of about 2 - 5 g/cm³.

[0042] Thereafter, the still hot slag particles and heated solid metallic particles are preferably charged into a heat exchanger, cooled with a countercurrent flow of cooling gas and discharged from the heat exchanger.

[0043] According to a preferred embodiment, the heat exchanger is subdivided in a plurality of subunits, each of said subunits having a particle inlet port, a particle outlet port, a cooling gas inlet port and a cooling gas outlet port, wherein at least one of the subunits is charged with hot slag particles and heated solid metallic particles through the particle inlet port, cooled slag particles and cooled solid metallic particles are discharged through said particle outlet port from said at least one of the subunits, said cooling gas inlet port and said cooling gas outlet port being closed during the charging and discharging of particles and wherein, simultaneously to the charging and discharging of particles, at least one of the other subunits is cooled by injecting a flow of cooling gas through the cooling gas inlet port and withdrawing a flow of heated cooling gas from said cooling gas outlet port, said particle inlet port and said particle outlet port being closed during the

cooling of particles and wherein the heated cooling gas is used for energy recovery.

[0044] Accordingly, the process according to a preferred embodiment of the invention proposes to use heat exchangers comprising multiple subunits, which are operated discontinuously. As it is advantageous to obtain a constant hot gas flow at the exit of the heat exchanger in order to guarantee the most efficient use of electric power generation cycles, the multiple heat exchanger subunits are operated alternately in a way that an essentially constant hot gas flow is guaranteed. By this, it is possible to obtain an essentially continuous gas handling which is decoupled from the batch type material handling.

[0045] At each moment in time, where one of the heat exchanger subunits is in emptying/filling stage, no cooling gas is flowing through this heat exchanger subunit during emptying/filling.

[0046] The same quantity of particles is filled into and extracted from the exchanger. Meanwhile, no material is entering or leaving the other heat exchanger subunits; they can thus be completely sealed off from the environment during cooling.

[0047] Preferably, one of the subunits is charged with hot slag particles and heated solid metallic particles through the particle inlet port while cooled slag particles and cooled solid metallic particles are discharged simultaneously through the particle outlet port of the same subunit.

[0048] Once the heat exchanger subunit is filled up, the particle inlet and the particle outlet ports are sealed and the subunit is reconnected to the cooling gas stream while another heat exchanger subunit may be disconnected. The cooling gas flow through these heat exchanger subunits does thus not encounter any leakage, thereby preventing dust and energy leaving the system. The heat exchanger subunits thus only need to be depressurized during charging and discharging of the slag.

[0049] According to a preferred embodiment, the hot slag particles and heated solid metallic particles are first charged into an insulated pre-chamber before they are charged into one of the heat exchanger subunits. The pre-chamber is

preferably insulated either by refractory lining or material stone box. The low thermal conductivity of slag gives excellent insulation properties.

[0050] The slag particles and solid metallic particles may also be charged in a post-chamber after cooling and after being discharged from the heat exchanger subunit. In other words, the cycle time and the quantity of particles charged may thus be chosen in such a way that the heat transfer inside the heat exchanger subunits may be controlled and kept quasi-stationary. The outlet gas temperature fluctuation caused by charging/discharging of the heat exchanger subunits will thus be minimized by choosing cycle times accordingly.

[0051] According to a further preferred embodiment, hot liquid slag is solidified in a slag cake and cooled down to about 650°C to 750°C by mixing it with solid metallic particles. Advantageously, the hot liquid slag is mixed with about the same volume, preferably resulting in a mixture containing from about 40% to about 60% volume of solid metallic particles. The required volume of metallic particles depends on the desired target temperature, the density and the heat capacity of the metallic particles, ... For steel spheres, 40% to 60% (volume percentage of total volume) are preferable.

[0052] Preferably, the heat exchanger subunits are operated under a pressure from 1.2 bar to 4 bar i.e. the absolute pressure measured at the bottom of the slag layer in the subunit.

Brief Description of the Drawings

[0053] Preferred embodiments of the invention will now be described, by way of example, with reference to the accompanying drawings in which:

Fig. 1 is a cross sectional schematic view of a preferred embodiment of a dry slag granulation apparatus;

Fig. 2 is a schematic view of some of the components of a sliding gate valve useful for the dispensing device;

Fig. 3 is a perspective top view of an embodiment of a double sliding gate (hopper not represented) with staggered apertures;

Fig. 4 is a cross sectional view of a part of the dry slag granulation apparatus of Fig. 1;

Fig. 5 is a sketch of a further preferred embodiment of a method according to the invention; and

Fig. 6 (a) and (b) illustrate a preferred embodiment a self-correcting method of operating an apparatus as described herein.

[0054] Further details and advantages of the present invention will be apparent from the following detailed description of several not limiting embodiments with reference to the attached drawings.

Description of Preferred Embodiments

[0055] Fig. 1 schematically represents a cross section of a preferred embodiment of a dry slag granulation apparatus comprising a slag caster 1 with a dual slope linear endless conveyor 10 comprising a plurality of casting moulds 11. The moulds 11 are conveyed in a first section from a slag pouring zone A through cooling zone B to a discharging zone C where the moulds are emptied from the solidified slag cakes contained therein. In a second section the now empty moulds are conveyed back to the slag pouring zone.

[0056] The hot liquid slag 21 from slag runner 20 is poured in a casting mould 11 passing beneath the slag runner 20. As the slope angle α is relatively steep, the maximum effective volume V_{α} , i.e. the volume of slag in the mould when the slag overflows to the upstream mould N-1, is smaller than the useful volume V_{β} of the mould when the mould reaches a position ($> N+2$ in Fig. 1) in the cooling zone B where the slope angle β is smaller. Preferably, angles α and β are chosen such that V_{α} is about $\frac{1}{2} V_{\beta}$.

[0057] When the mould containing hot liquid slag reaches a position (e.g. N+2 in Fig. 1 and 4) below the dispensing device 30, a fixed amount of the solid metallic particles 33, such as steel balls, contained in storage hopper 31 is introduced in the mould by opening sliding gate 35 mounted on the hopper's outlet 32 for a predetermined time t . The particles 33 fall into the mould and mix with the hot liquid slag 21 by the action of gravity. The amount of particles essentially corresponds to $V_{\beta} - V_{\alpha}$ (or $\frac{1}{2} V_{\beta}$ if $V_{\alpha} = \frac{1}{2} V_{\beta}$).

[0058] Splash boards 36 may be provided to prevent splashing of liquid slag and steel balls from the mould during charging.

[0059] During introduction of the metallic particles 33 into the hot liquid slag 21, the slag rapidly cools down and solidifies in an amorphous state. The mould now containing a solidified cake of slag and added metallic particles, such as steel balls, then further cools down while proceeding to the discharge zone C where the mould is emptied by turning it upside down. The solidified slag cake is then crushed to pieces and may proceed to a thermal recovering unit (not represented).

[0060] Fig. 2 presents a schematic view of parts of a linear sliding gate valve 35. A preferred sliding gate valve for use in the present invention comprises a stationary plate 353 with a plurality of spaced apart apertures 354. The corresponding sliding plate 351 also presents spaced apart apertures 352, but the location of these apertures is such that apertures 352 may be brought by linear sliding from a closed position wherein all apertures 354 of the stationary plate are (essentially, see above) closed by those parts of the sliding plate without apertures to an open position (by sliding in the direction indicated by the arrow in Fig. 2) where apertures 352 are essentially aligned with apertures 354.

[0061] Fig. 3 represents a top perspective view of a preferred embodiment of a double (linear) sliding gate valve 35 without the surmounting hopper(s) for temporarily storing the metallic particles. For illustration purposes, only one of the valves further comprises a splash board 36 arranged below the valve. The sliding plates 351 of each valve are actuated with respect to stationary plates 353 by separate hydraulic cylinders 355.

[0062] Fig. 4 essentially corresponds to the lower part of the embodiment of Fig. 1 during operation.

[0063] As can be seen in Fig. 4, the casting mould in position N is been filled with hot liquid slag 21 from slag runner 20. If the amount of slag from the runner exceeds the (local) capacity of the mould (V_a), the excess slag overflows to the immediately adjacent mould in position N-1 by gravity. If the amount (flow) from the runner is even higher, the slag from N-1 cascades to mould N-2 (this is actually the situation represented in Fig. 4). Knowing that the moulds arriving from the second section of the conveyor 10 have a temperature which is far from that of

the liquid slag (to simplify this temperature will also be referred to as “ambient” or “cold”, although this temperature will generally be situated between 50 and 300°C or even above), it has been found that by controlling the mould temperature (T_{N-1} and T_{N-2}) of these two positions N-1 and N-2, a simple, yet efficient control of the casting process can be provided (see also below). It is to be understood that more than two temperatures can of course be monitored if deemed necessary or desirable.

[0064] In Fig. 4, mould N+2 is located beneath the dispensing device 30 and is ready to be filled with metallic particles 33. As can be seen, the volume V_α of slag now only represents about half of the available volume V_β due to the change of slope from the slag pouring zone A to the cooling zone B.

[0065] The amount of metallic particles to be added is thus essentially the difference between V_β and V_α , i.e. the volume remaining unfilled in the mould N+2. The casting mould in position N+3 in Fig. 4 shows a mould wherein the metallic particles have been added to the liquid slag. At this point, the slag essentially solidified in an amorphous state due to the instant adding of a substantial quantity of cold particles. It seems clear that the position for inserting the particles indicated by N+2 in Fig. 4 does not necessarily need to be the second position after the filling position as far as the slag is still hot and liquid.

[0066] The exact position of a mould within the conveyor, and in particular its position below the slag runner and/or the dispensing device, can be determined by any known contact or contactless means, such as switches, induction, laser, etc.

[0067] Description of the process – purpose of the regulation

[0068] In the dry slag granulation process, liquid slag 21 is cooled by adding cold metallic particles 33, such as steel balls. The purpose of this cooling is to achieve

- quick cooling of the slag
- a high mix temperature for further heat recovery

[0069] Therefore, the dosing of the steel balls has to be precise and a steel/slag ratio has to be respected.

[0070] To achieve material transportation, a slag caster 10 technology has been chosen. The slag 21 is poured upstream, in the pouring zone A at the start of the conveyor 10 and then the steel balls 33 are added in the cooling zone B, as shown e.g. in Fig. 1 and 4.

[0071] The dosing of the steel balls 33 in the cooling zone B, as well as the slag filling of the mould 11 in position N should be regulated. In the presently described regulation mode, the regulation is done by letting the slag 21 overflow in the next upstream mould in position N-1 and by adding a constant amount of steel balls 33 in each mould as it passes below the dispensing device 30. The overflowing is preferably controlled by varying the speed of the caster 10.

[0072] In such a case, the volume ratio between the steel balls 33 and the slag 21 is fixed.

[0073] Because the charging time is limited, the dosing of the steel balls 33 is done using a sliding gate valve 35, as shown e.g. in Fig. 2 and 3.

[0074] Definition of the shape of the caster

[0075] The volume ratio (λ) between the slag 21 and the steel balls 33 is generally around 1, meaning that the caster has to charge 1 volume of steel balls for 1 volume of slag.

[0076] This ratio is obtained through the particular shape of the caster. As more particularly shown in Fig. 4, the volume available for the slag in the pouring zone A when it is overflowing (V_α) is smaller than the volume available in the cooling zone B at the point where the steel balls are charged (V_β).

[0077] The inclinations or slope angles of the slag caster have been chosen in order to have a relation of $V_\alpha = 1/2 \times V_\beta$.

[0078] The regulation is working with an overflowing of slag (and hence a known quantity of slag in the mould) and the addition of the maximal amount of steel balls.

[0079] Description of a preferred regulation mode

[0080] As it can be seen in Fig. 4, the regulation steps in this operation mode are as follows:

- 1) Incoming of the liquid slag 21 (in an unknown material flow) in the mould 11 in position N
- 2) Measuring of the temperature in the two moulds upstream from the pouring point (moulds in positions "N-1" and "N-2")
 - a. If no high temperature is measured by the temperature sensors (e.g. pyrometers), no overflowing occurs: the caster has to be slowed down
 - b. If high temperature is measured in one mould only (mould "N-1"), overflowing occurs but is limited: the speed is right
 - c. If high temperature is measured in two moulds in positions "N-1" and "N-2", too much overflowing is occurring: the caster has to be accelerated
- 3) Charging of the maximal amount of balls, in the time (t) determined by the speed of the caster

[0081] In a further preferred embodiment, the method comprises additional regulation steps as follows:

1. Incoming of the liquid slag (in an unknown quantity) in the mould in position N. As any excess amount of slag cascades back to an upstream mould, the slag level (h_{slag}), the slag volume in the mould (V_{slag}) and the slag mass in the mould (M_{slag}) are known as they are given by the mould type used and the angle α in the pouring zone. The amount of steel balls necessary for this mould (M_{steel}) is based on a (chosen) slag/steel ratio (λ)
 - a) Adaptation of the caster speed (V_{caster}) based on the temperature measurements as already described
2. Once the mould has reached position N+2, charging of the steel balls
 - a) The opening time (t) of the sliding gate is determined based on the caster speed (V_{caster})
 - b) The opening stroke of the gate (x) is determined based on
 - i. the required steel balls mass M_{steel}

- ii. the opening time (t)
 - iii. the characteristics of the sliding gate ($\dot{M}_{steel}/x$ curve)
3. Once the mould has reached position N+3, measuring of the steel balls/slag mix height (h_{mix}), using a laser
- a) Transposition from that height (h_{mix}) into a mix volume in the mould (V_{mix}). Determination of the steel balls actually added in the mould (M_{steel}').
4. Feedback – adaptation of the sliding gate characteristic
- a) if $M_{steel} = M_{steel}'$, the right quantity of steel balls have been dropped $\rightarrow$ no adaptation of the $\dot{M}_{steel}/x$ curve
 - b) if $M_{steel} \neq M_{steel}'$; the $\dot{M}_{steel}/x$ curve is adapted in order to fit to the measured mix height. This adaptation is described below.

[0082] This further preferred regulation method can be summarized as shown in Fig. 5.

[0083] Adaptation of the gate characteristics

[0084] If the measured quantity of steel balls doesn't fit with the theoretical amount ($M_{steel} \neq M_{steel}'$); the curve $\dot{M}_{steel}/x$ curve should be adapted. A difference ΔM_{steel} is determined, as the charging time t is known, the difference between calculated flow rate and real flow rate is calculated ($\Delta \dot{M}$).

[0085] If $\Delta \dot{M} > 0.2 \times \dot{M}$ then no correction is applied and an alarm is issued. If $\Delta \dot{M} < 0.2 \times \dot{M}$ then correction of the mass flow characteristic curve of the dosing valve will be performed.

[0086] The curve $\dot{M}_{steel}/x$ curve is a discrete curve. The correction of this curve may be done by adjusting the individual opening lengths x_n (see Fig. 6 (a)) for each flow value in the table (see Fig. 6 (b)). The more the position is distant from x the smaller the correction will be.

[0087] The correction applied to x (position comprised between x_i and x_{i+1}) in order to reach the expected flow rate is Δx . The corrected opening length is $x' = x + \Delta x$.

$$\Delta x = \Delta \dot{m} \cdot \frac{x_{i+1} - x_i}{\dot{m}_{i+1} - \dot{m}_i}$$

[0088] Now that the correction Δx for x has been calculated, the position values x_n of the material flow table will be replaced by the corrected values x'_n . The update is done by using the following formulas:

[0089] For x_n values above x :

$$x'_n = x_n + \frac{\Delta x}{K_1} \cdot \left(\frac{N-n}{N-i-1} \right) ; n > i$$

[0090] For x_n values below x :

$$x'_n = x_n + \frac{\Delta x}{K_1} \cdot \left(\frac{n-1}{i-1} \right) ; n \leq i$$

[0091] Limits of calculation:

$$x_{min} \leq x'_n \leq x_{max}$$

x_{min} = minimum allowable opening length of dosing valve

x_{max} = maximal allowable opening length of dosing valve

Where:

x'_n : new value in [mm]

x_n : old value in [mm]

N : is the total numbers of values in the material flow table

n : is the considered position in the material flow table ($n = 1 \dots N$)

K_1 : constant factor to prevent overcorrection ($K_1 \geq 2$)

Legend:

1	casting apparatus
10	endless conveyor
11	casting mould
20	slag runner
21	hot liquid slag
30	dispensing device
31	hopper
32	hopper outlet
33	solid metallic particles, e.g. steel balls
35	sliding gate valve
351	sliding plate
352	aperture in sliding plate
353	stationary plate
354	aperture in stationary plate
355	hydraulic cylinders
36	splash board
A	slag pouring zone
B	cooling zone
C	discharge zone
α	slope angle of the conveyor in the slag pouring zone A
β	slope angle of the conveyor in the cooling zone B
V_{α}	effective maximum filling volume of the mould in the slag pouring zone A
V_{β}	effective maximum filling volume of the mould in the cooling zone B
T_{N-1}	temperature sensor for mould position N-1
T_{N-2}	temperature sensor for mould position N-2
Sh_{slag}	sensor for measuring height of the hot liquid slag
Sh_{mix}	sensor for measuring height of the slag/particles mix

Claims

1. A method for dry slag granulation of hot liquid slag using a casting apparatus (1) comprising an endless conveyor (10) having a plurality of casting moulds (11), which endless conveyor is arranged to move said casting moulds in a first section from a slag pouring zone (A) through a cooling zone (B) to a discharge zone (C) and in a second section back to the slag pouring zone, comprising the continuous steps of:

- (a) pouring an amount of hot liquid slag (21) into a casting mould in a position N in the slag pouring zone,
- (b) moving the hot liquid slag containing casting mould in a position within the cooling zone,
- (c) adding solid metallic particles (33) to the hot liquid slag containing casting mould by dropping an amount of said particles into the mould from a dispensing device (30) arranged above said mould and comprising at least one hopper (31) for storing said solid metallic particles,
- (d) discharging the cooled solidified slag from the mould in the discharge zone,

wherein the amount of liquid slag in the casting mould is controlled by arranging the slag pouring zone in the first section of the endless conveyor to convey the moulds with a first slope angle α which limits the effective maximum filling volume of the mould in the slag pouring zone to a value V_{α} , any excess slag cascading back to an upstream casting mould in position N-1, N-2, etc.

wherein the cooling zone is arranged with a second slope angle $\beta < \alpha$ such that the effective maximum filling volume of the mould in the cooling zone has a value $V_{\beta} > V_{\alpha}$ and

wherein the amount of metallic particles added by the dispensing device is controlled by actuating of at least one actuated sliding gate (35) arranged at the hopper's outlet (32).

2. The method according to claim 1, wherein the slope angle α in the slag pouring zone and the slope angle β in the cooling zone are chosen such that the

effective maximum filling volume of the mould in the slag pouring zone V_{α} is between 0.25 and 0.75, preferably between 0.30 and 0.60, even more preferably 0.45 to 0.55 times the effective maximum filling volume of the mould in the cooling zone V_{β} .

3. The method according to claim 1 or 2, wherein the at least one actuated sliding gate (35) comprises one or more rows of apertures (352), preferably two or more rows of staggered apertures.
4. The method according to any of claims 1 to 3, wherein the dispensing device (30) comprises two separately controllable actuated sliding gates (35), each sliding gate preferably covering about half of the casting mould's surface.
5. The method according to any of claims 1 to 4, wherein the actuation of the sliding gate(s) is effected with one or more hydraulic cylinders (355).
6. The method according to any of claims 1 to 5, wherein the moving of the casting moulds is controlled by monitoring the temperature of at least two casting moulds upstream (positions N-1 and N-2) of the casting mould being filled and by varying the speed of the movement in step (b).
7. The method according to claim 6, wherein the speed of movement in step (b) is decreased if the temperature in the casting mould in position N-1 does not increase due to a lack of backflow of hot liquid slag from position N and wherein the speed of movement in step (b) is increased if the temperature in the casting mould in position N-2 increases due to the backflow of hot liquid slag from the casting mould in position N-1.
8. The method according to any of claims 1 to 7, wherein the closing of the sliding gate(s) is effected such that the apertures (354) of the stationary plate (353) are not completely closed, preferably leaving a residual opening of each aperture which generally represents 0.3 to 1.5, more preferably about 0.8 to 1.3 times, most preferably between about 1.1 and 1.25 times the diameter of the metallic particles.
9. The method according to any of claims 1 to 8, which is used as an emergency regulation.
10. The method according to any of claims 1 to 9, further comprising measurement of the actual combined amount of slag and metallic particles in the casting mould after step (c) in a position downstream of position N+n, calculating the

amount of metallic particles actually added in step (c) based on the measured combined amount of slag and metallic particles and the known amount of hot liquid slag and, if the calculated amount of actually added metallic particles does not correspond to the expected amount of metallic particles, adapting the characteristics of the at least one sliding gate.

11. The method according to claim 10, wherein the characteristics of the at least one sliding gate comprise the mass flow of metallic particles $\dot{m}_{\text{particles}}$ as a function of the opening stroke x ($\dot{m}_{\text{particles}}/x$ curve).
12. The method according to any of claims 1 to 11, further comprising the step(s) of:

- (e) crushing the solidified slag and/or
- (f) recovering heat in a heat exchanger.

13. An apparatus (1) for dry slag granulation of hot liquid slag comprising an endless conveyor (10) having a plurality of casting moulds (11), which endless conveyor is arranged to move said casting moulds in a first section from a slag pouring zone (A) through a cooling zone (B) to a discharge zone (C) and in a second section back to the slag pouring zone, and wherein the apparatus further comprises

- a dispensing device (30) arranged in the cooling zone above said moulds and comprising at least one hopper (31) for storing solid metallic particles (33), said dispensing device further comprising at least one sliding gate (35) at the hopper's outlet (32), the actuating of said sliding gate(s) allowing the control of the amount of metallic particles dispensed by said dispensing device,

wherein the slag pouring zone in the first section of the endless conveyor is arranged to allow the conveying of the moulds with a first slope angle α which limits the effective maximum filling volume of the mould in the slag pouring zone (A) to a value V_{α} , and wherein the cooling zone (B) is arranged with a second slope angle $\beta < \alpha$ such that the effective maximum filling volume of the mould in the cooling zone has a value $V_{\beta} > V_{\alpha}$.

14. The apparatus according to claim 13, wherein the slope angle α in the slag pouring zone (A) and the slope angle β in the cooling zone (B) are chosen such that the effective maximum filling volume of the mould in the slag pouring

zone V_{α} is between 0.25 and 0.75, preferably between 0.30 and 0.60, even more preferably 0.45 to 0.55 times the effective maximum filling volume of the mould in the cooling zone V_{β} .

15. The apparatus according to claim 13 or 14, wherein the at least one actuated sliding gate (35) comprises one or more rows of apertures (352), preferably two or more rows of staggered apertures.
16. The apparatus according to any of claims 13 to 15, wherein the dispensing device comprises two separately controllable actuated sliding gates (35), each sliding gate preferably covering about half of the casting mould's surface.
17. The apparatus according to any of claims 13 to 16, wherein one or more hydraulic cylinders (355) are provided to actuate the sliding gate(s).
18. The apparatus according to any of claims 13 to 17, further comprising a control unit to adapt the speed of movement of the conveyor and temperature sensors (T_{N-1} , T_{N-2}) for monitoring the temperature of at least two casting moulds upstream (positions N-1 and N-2) of the casting mould below the dispensing device, wherein the moving of the casting moulds is controllable by the control unit by varying the speed of the movement of said casting moulds.
19. The apparatus according to claim 18, wherein the control unit can decrease the speed of movement if the temperature in the casting mould in position N-1 measurable by temperature sensor (T_{N-1}) does not increase due to a lack of backflow of hot liquid slag from position N and wherein the control unit can increase the speed of movement if the temperature in the casting mould in position N-2 measurable by temperature sensor (T_{N-2}) increases due to the backflow of hot liquid slag from the casting mould in position N-1.
20. The apparatus according to any of claims 13 to 19, wherein the closing of the sliding gate(s) can be effected such that the apertures of the stationary plate are not completely closed, preferably leaving a residual opening of each aperture which generally represents 0.3 to 1.5, more preferably about 0.8 to 1.3 times, most preferably between about 1.1 and 1.25 times the diameter of the metallic particles.

Fig. 1

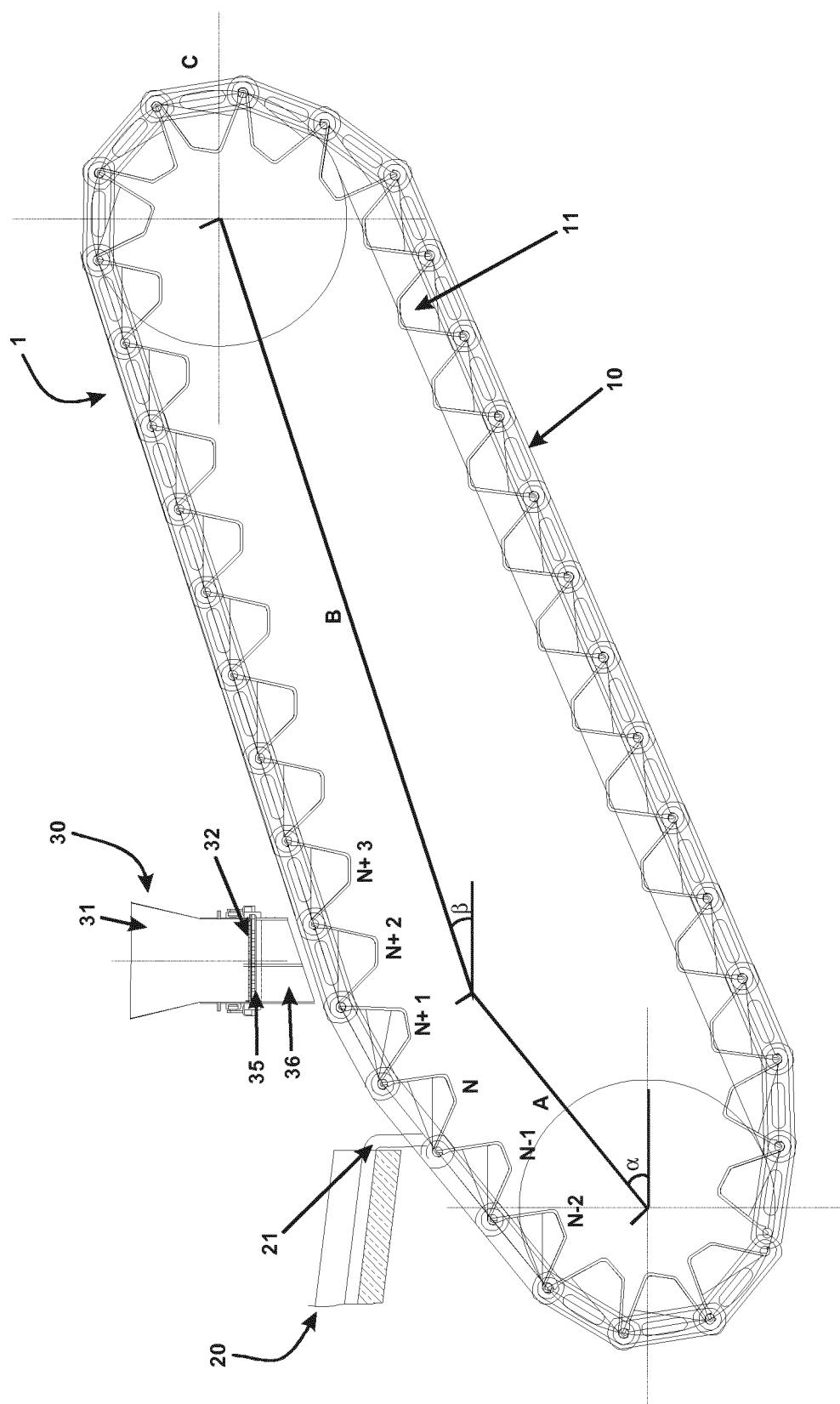


Fig. 2

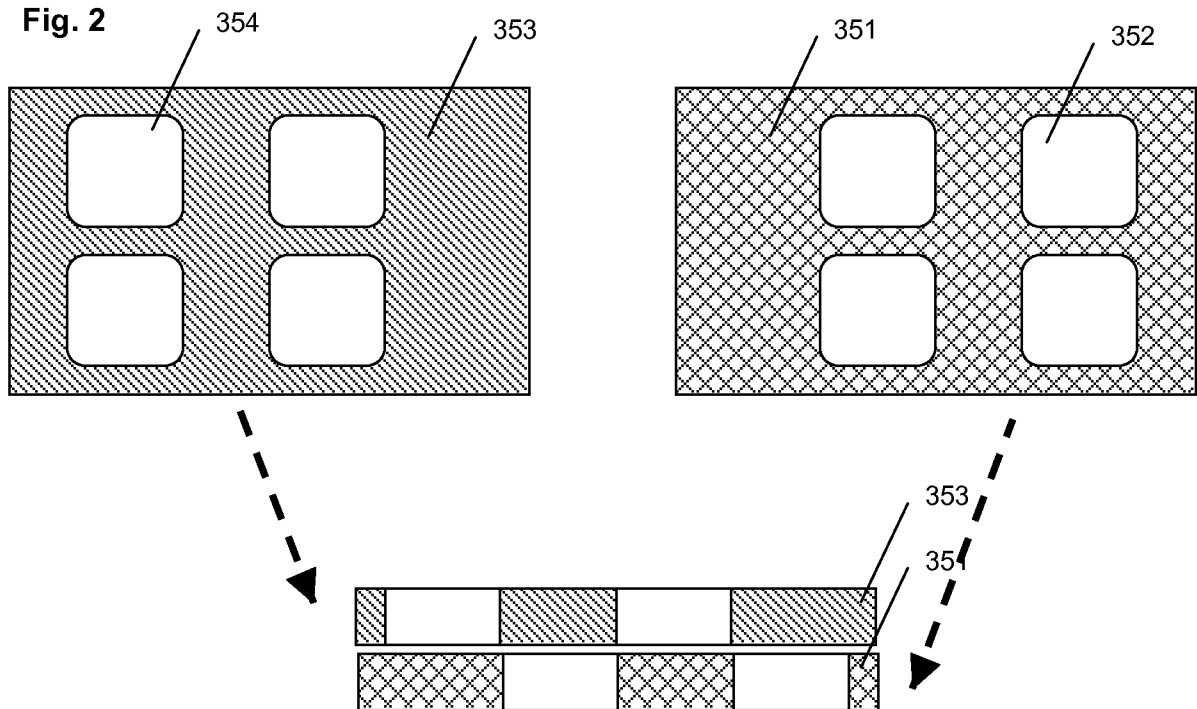


Fig. 3

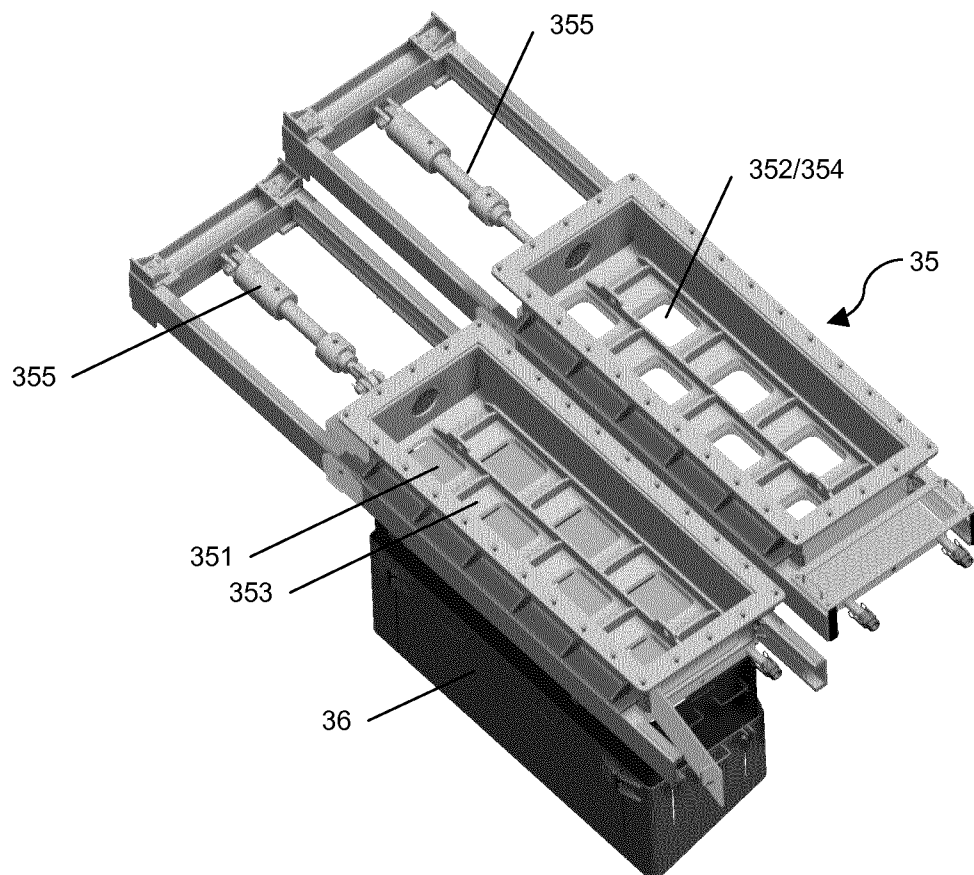


Fig. 4

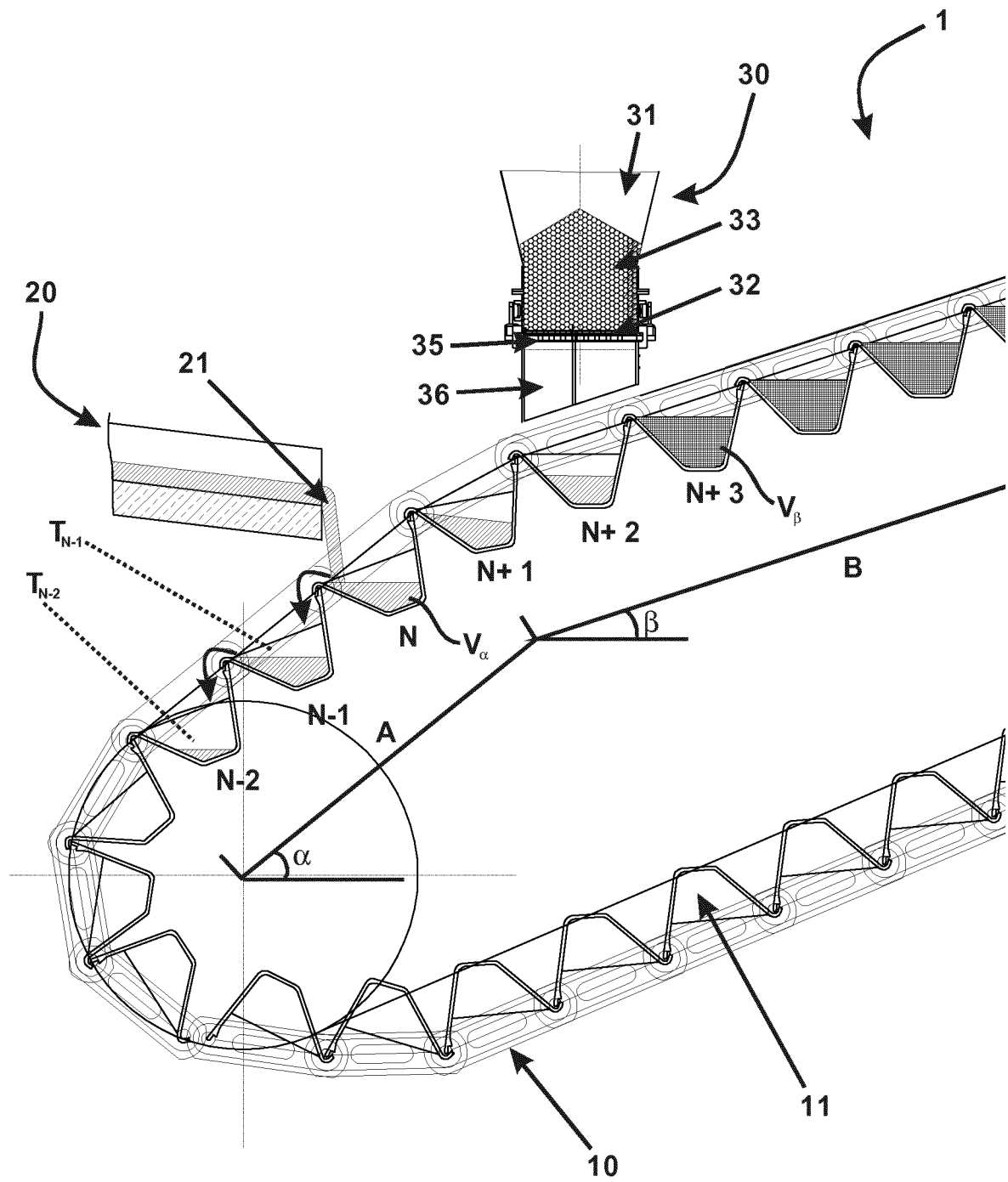


Fig. 5

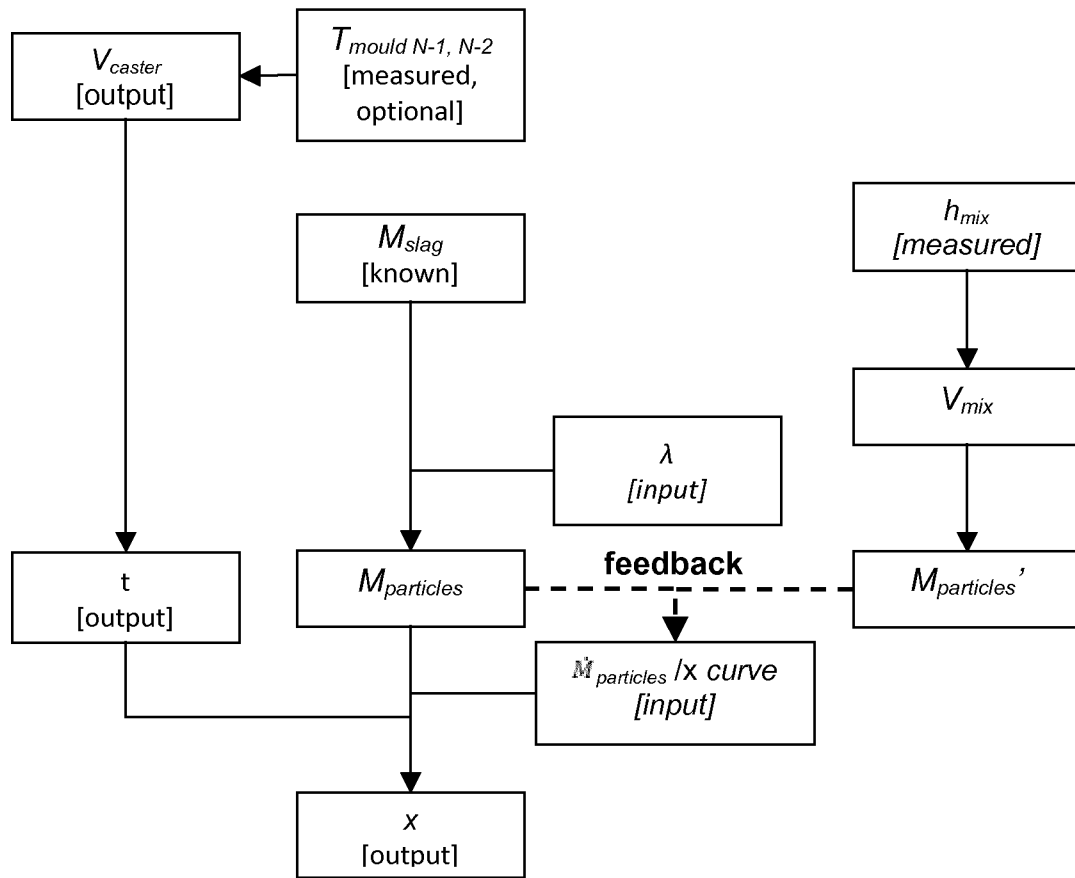
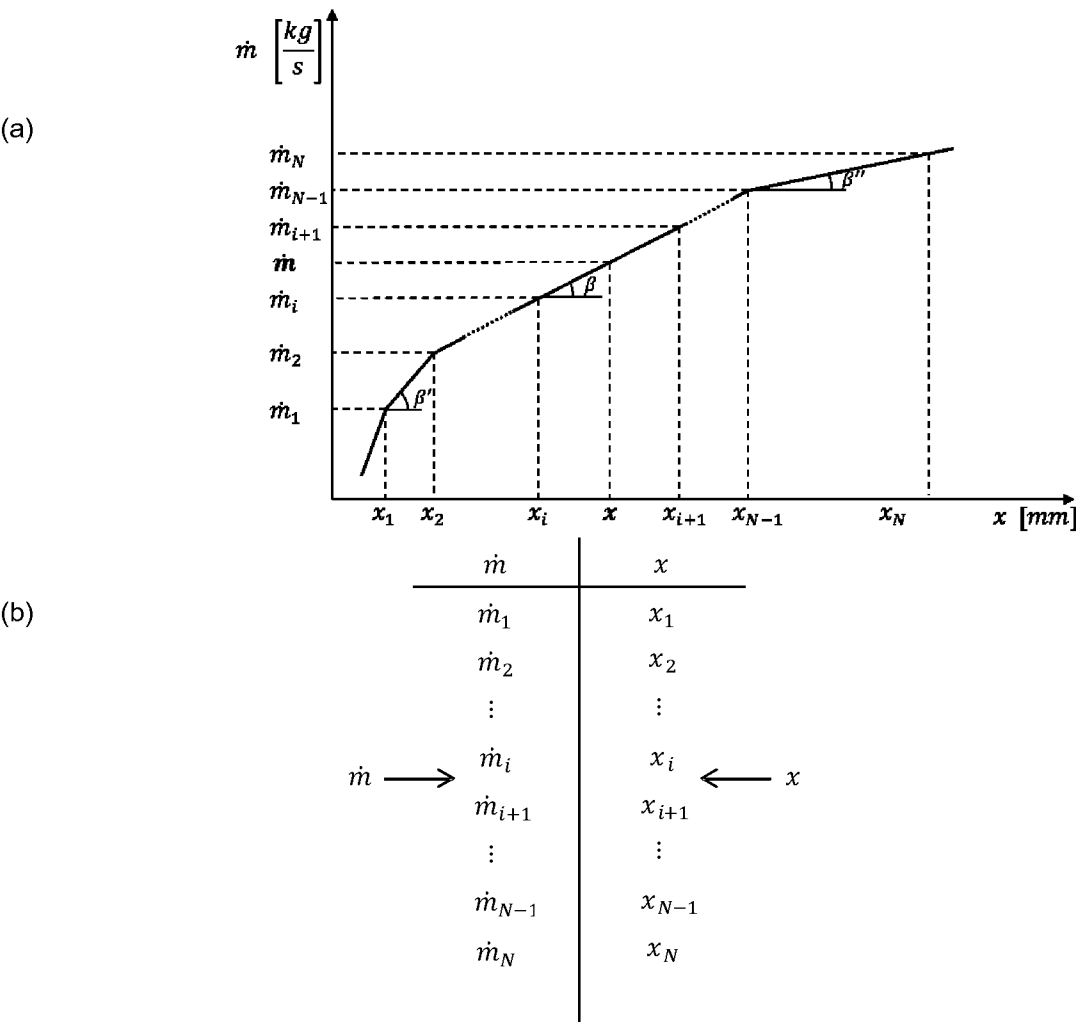


Fig. 6



INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2014/059882

A. CLASSIFICATION OF SUBJECT MATTER

INV. C21B3/08 B65G17/12 B65G17/36 B65G21/00
ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

C21B B65G

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

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A	figure 1 abstract paragraph [0002] - paragraph [0008] paragraph [0014] - paragraph [0034] -----	1-12, 19, 20
Y	WO 2012/034897 A2 (WURTH PAUL SA [LU]; SOLVI MARC [LU]; GREIVELDINGER BOB [LU]; FRIEDERIC) 22 March 2012 (2012-03-22) cited in the application	13-18
A	figure 1 figure 3 abstract paragraph [0010] - paragraph [0032] ----- -/-	1-12, 19, 20



Further documents are listed in the continuation of Box C.



See patent family annex.

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Date of the actual completion of the international search

18 June 2014

Date of mailing of the international search report

26/06/2014

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INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2014/059882

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
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Information on patent family members

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