(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) EP 3 865 801 A1

(12) **EUROPEAN PATENT APPLICATION**

(43) Date of publication:
18.08.2021 Bulletin 2021/33

(51) Int Cl.:
F27B 7/20 *(2006.01)*

(21) Application number: **20158040.4**

(22) Date of filing: **18.02.2020**

(84) Designated Contracting States:
AL AT BE BG CH CY CZ DE DK EE ES FI FR GB GR HR HU IE IS IT LI LT LU LV MC MK MT NL NO PL PT RO RS SE SI SK SM TR
Designated Extension States:
BA ME
Designated Validation States:
KH MA MD TN

(30) Priority: **17.02.2020 EP 20157779**

(71) Applicant: **Alite GmbH**
31535 Neustadt (DE)

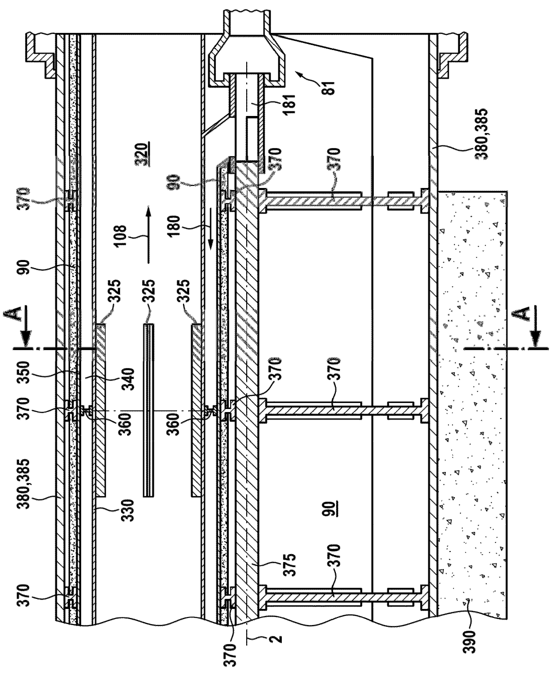
(72) Inventors:
- **Köhler, Mr. Reinhard**
  31535 Neustadt (DE)
- **Hammerich, Mr. Jörg**
  31535 Neustadt (DE)

(74) Representative: **Lohr, Jöstingmeier & Partner**
Junkersstraße 3
82178 Puchheim/München (DE)

(54) **APPARATUS AND METHOD FOR MANUFACTURING CEMENT CLINKER**

(57) A calciner 18 for receiving raw meal 102 from a preheater 20 of a cement clinker line 1, for calcining the raw meal 102 and for providing the calcined and/or pre-calcined raw meal 108 to a kiln of the cement clinker line 1 comprising at least one duct 320 configured to convey the raw meal from an inlet to an outlet, and at least one conduit 340 surrounding the duct 320 at least partially or being surrounded at least partially by the duct 320 and further having a wall 330 separating the duct 320 and the conduit 340 to thereby enable an indirect heat transfer via the wall 330 from an energy carrier fluid flowing through the conduit 340 to raw meal in the at least one duct 320, is scalable to be adapted to calcine large amounts of raw meal in a continuous process if the calciner has a bearing 380, 395 rotatably supporting the duct (320) relative to a support structure 390, and if the duct 320 is torque-transmittingly coupled to a rotational drive 395.

Fig. 2B



EP 3 865 801 A1

Printed by Jouve, 75001 PARIS (FR)

Description

Field of the invention

[0001] The invention relates to a calciner being configured to receive raw meal from a preheater of a cement clinker line and to release calcined raw meal to a kiln of the cement clinker line. The calciner has at least one raw meal duct with a raw meal inlet and a raw meal outlet. A conduit surrounds the duct at least partially or is surrounded at least partially by the duct, to thereby enable an indirect heat transfer from an energy carrier fluid in the conduit via a wall (e.g. of the duct) to raw meal in the duct. The conduit has an inlet for receiving an energy carrier fluid and an outlet for releasing the energy carrier fluid after having transferred at least a portion of its internal energy via the wall to the raw meal in the duct. A static support structure supports at least the duct relative to a base. The invention further relates to a cement clinker line and in particular to a cement clinker line including a calciner and a carbonator.

Description of the related art

[0002] About 8% of the overall man-made CO_2 emission is associated to the cement clinker manufacturing process (Olivier, Janssens-Maenhout, Muntean and Peters, Trends in global CO2 emissions: 2016 Report, The Hague: PBL Netherlands Environmental Assessment Agency, http://edgar.jrc.ec.europa.eu/news docs/irc-2016-trends-in-global-co2-emissions-2016-report-103425.pdf,accessed 22 Jan. 2020, page 65). The CO_2 emission of the cement clinker process is in part inherent to the process, as limestone ($CaCO_3$) is calcined into lime (CaO), thereby releasing CO_2. The corresponding chemical reaction is described by the formula $CaCO_3$ + heat$\rightarrow$ CaO + CO_2, and is thus an endothermal chemical reaction. This reaction is herein referred to as *calcination*). Another portion of the CO_2 is produced by burning fuel to thereby provide the thermal energy driving the above endothermic calcination, to sinter the lime with the other constituents of the raw meal to clinker and to produce the electrical power for operating the plant. Depending on the particular cement clinker line, approximately 50-60% of the released CO_2 are released in the calcination step. The other approximately 50-40% are released by burning fuel (see e.g. Johanna Lehne and Felix Preston, Making Concrete Change Innovation in Low-carbon Cement and Concrete, Chatham House Report, London 2018).

[0003] It has been suggested to capture and store the CO_2 produced in the clinker manufacturing process. A very promising approach for capturing the CO_2 is the so-called **R**egenerative **C**alcium **C**ycle (RCC). The RCC consists essentially in capturing CO_2 in flue gases by an exothermal reaction of the CO_2 with CaO to $CaCO_3$. The reaction reads CaO + CO_2 $\rightarrow$ $CaCO_3$ +heat, is thus exothermal and referred to as carbonation. Subsequently, the $CaCO_3$ is decarbonized (i.e. calcined) in a calciner, thereby releasing CO_2 and CaO, enabling to thereby obtain at least essentially pure CO_2. The CO_2 can be stored, e.g. in geological formations (commonly referred to as CO_2- sequestration), or used in other processes. In any case it is not released to the environment. The CaO can be subjected to carbonation, again.

[0004] A tail end approach for adding an RCC to a cement clinker plant has been suggested in EP 2 461 892 A1 and as well in US 2009/0255444 A: Raw meal is preheated in a preheater tower. The preheated raw meal is conveyed to a calciner and calcined by direct heat exchange with hot flue gases. The calcined raw meal is provided to a kiln configured to subsequently sinter the calcined raw meal. All CO_2 released in the process is collected and transported as a single flue gas stream through the preheater, cooled down and dedusted. Prior to releasing the flue gas to the environment, the CO_2 is removed from the flue gas by reacting the CO_2 with CaO to $CaCO_3$ in a carbonator. The $CaCO_3$ is removed from the carbonator and heated in a second reactor to invert the carbonation, i.e. to subject the $CaCO_3$ to a calcination thereby releasing essentially pure CO_2 and CaO. CaO and CO_2 are subsequently separated enabling to store the CO_2 and to return the CaO to the carbonator. The advantage of this approach is that the RCC can be retrofitted to existing cement clinker plants while not changing the core of the established clinker process. The accumulated CO_2 is simply removed from the flue gas prior to releasing the flue gas. The RCC is independent from the clinker process.

[0005] Another approach, as suggested in FR 2 921 059 A1, is the integration of an RCC into the cement clinker process, i.e. the calciner for (pre-)calcination of the raw meal is the source of the CaO being required in the carbonation step of the RCC. The $CaCO_3$ obtained in the carbonation step is subsequently provided to the calciner to obtain fresh CaO, i.e. a portion of the CaO / $CaCO_3$ circles in the process. In this approach, preheated raw meal is provided to a calciner, wherein the calciner is an indirect heat exchanger for heating the $CaCO_3$. This enables to remove almost pure CO_2 from the calciner which can be stored or used for other industrial or agricultural purposes. A first portion of the calcined raw meal is provided to the kiln to complete the transformation of the raw meal into clinker. The remaining portion of the calcined raw meal is provided to a carbonator. In the carbonator, the CaO in the calcined raw meal reacts with the CO_2 contained in the flue gases from the kiln to $CaCO_3$. The flue gases from the kiln are thus subjected to CO_2-removal. The CO_2 bound in $CaCO_3$ produced in the carbonator is added to the raw meal entering the calciner, where the CO_2 is released.

Summary of the invention

[0006] The invention is based on the observation that the conceptually appealing suggestion of integrating the

RCC in the clinker process is not practical due to a lacking possibility to calcine the raw meal throughput of modern cement clinker plants by indirect heat exchange with the calciner as sketched in FR 2 921 059 A1. The difficulty is presently that no high throughput indirect heat exchange calciners are available, which could be used in modern cement clinker plants producing in the order of 10.000t of clinker per day and more. The problem to be solved by the invention is to provide an indirect heat exchanger based calciner that enables a precise process control of the calcining process, while enabling to integrate the RCC in the clinker process. Another problem is to improve energy efficiency of a clinker process with an integrated RCC.

[0007] Solutions to the problem are described in the independent claims. The dependent claims relate to further improvements of the invention.

[0008] The suggested calciner is a reactor configured for receiving raw meal from a preheater of a cement clinker line, for calcining the raw meal and for providing the calcined and/or pre-calcined raw meal to a kiln of the cement clinker line. The calciner comprises at least one duct. The (at least one) duct provides a reactor space for calcining raw meal, i.e. at least a portion of raw meal inside the volume being defined by the duct is subjected to calcination, in case the calciner is in operation. In operation, at least a portion, preferably more than 50% (even more preferred more than 50%, e.g. more than 60%, 70%, 80%. 90% or 95%) of the $CaCO_3$ in the raw meal is decomposed into CaO and CO_2, again this endothermal decomposition is referred to as *calcination.* The duct has an inlet for receiving the raw meal, preferably from a preheater, and an outlet for providing (at least partially) calcined raw meal to a kiln, e.g. via some conveying means (typically another duct, a chute or the like). Typically, a duct is formed by a wall enclosing the volume of the duct. Ducts may be bent and do not necessarily have a constant cross section along their lengths, but vastly simplifying ducts can be considered as cylindrical objects (for the definition of a cylinder see Bronstein, Semendyayev, Musio & Muehlig Handbook of Mathematics, Springer Berlin Heidelberg, 2007, 5th ed.; Chapter 3.3.4; cylinders may have circular and non-circular direction curves and thus corresponding cross sections, herein ducts with a circular cylindrical volume are preferred).

[0009] The calciner further has at least one conduit. Generally, a conduit is essentially the same as a duct, both enable a flow of fluid from at least one inlet to at least one outlet. Thus, we could alternatively use the wording the calciner has a first duct (see above) and a second duct (the conduit). Herein, we use the terms *duct* and *conduit* to verbally distinguish between two structural elements, wherein a *duct* is a raw meal duct configured to enable a flow of raw meal (unless explicitly specified differently) and a *conduit* is an energy carrier conduit (unless explicitly specified differently). The conduit is configured to receive an energy carrier fluid via at least one inlet and to release the energy carrier fluid (or its residues) via at least one exit. As will be explained below, the energy carrier fluid may undergo chemical reactions in the fluid to thereby heat up, i.e. the energy carrier fluid entering the conduit is not necessarily chemically the same as the energy carrier fluid which is removed from the conduit via the at least one exit. For example, the energy carrier fluid may comprise fuel and oxygen. The energy carrier fluid may be a gas or a mixture of gases. It may transport fluidized particulate matter, e.g. clinker dust, raw meal, fuel, etc.

[0010] The volumes of the duct and the conduit may be separated by a wall, e.g. by a sheet metal wall. In operation, the wall enables an indirect heat exchange between the raw meal in the duct and the energy carrier fluid in the conduit, while maintaining separation of duct volume from the conduit volume. The wall may be considered as a heat sink, which may be heated by a thermal contact with the energy carrier fluid and/or radiant heat being released by the energy carrier fluid. In other words, energy being transported by the energy carrier fluid heats the wall separating the volume of the duct from the volume of the conduit.

[0011] The raw meal at the opposite side of the wall in the duct may thus be heated up by thermal contact with the wall and by radiant heat being emitted by the wall into the volume of the duct. The wall may thus be cooled by the raw meal which in turn heats up and the $CaCO_3$ in the raw meal decomposes into CaO and CO_2. Briefly summarizing, the energy transferred via the wall from the energy carrier fluid to the raw meal drives the endothermal calcination of the $CaCO_3$ in the raw meal.

[0012] For example, the at least one conduit may surround the at least one duct (hereinafter simply "duct" or "duct(s)") at least partially, or more generally surround at least one of the at least one ducts at least partially. Preferably, the conduit encloses the duct, i.e. the conduit surrounds the perimeter of the duct at least in a section of the duct's length. For example, at least a section of the conduit and the duct may be positioned coaxially. Thus, the volume of the conduit does not necessarily have the shape of a full cylinder, but can be a hollow cylinder. This configuration provides for an efficient heat exchange between the conduit and the duct via the wall. In this case, the wall may define the outer perimeter of the duct and the inner boundary of the conduit.

[0013] In another example, the conduit is at least partially surrounded by the duct. The effect is essentially the same as explained above and the previous paragraph can be read mutatis mutandis, i.e. the terms duct and conduit can simply be replaced by each other.

[0014] In both examples, the volumes of the conduit and the duct are separated by the wall, i.e. there is no fluid communication between the volume of the duct and the volume of the conduit, while enabling in operation an indirect heat transfer from the energy carrier fluid in the at least one conduit via the wall to raw meal flowing at the other side of the wall, i.e. in the duct.

[0015] The calciner comprises a static support structure. The static support structure is configured for supporting at least the duct relative to a base. The static support structure can of course support the conduit as well.

[0016] Preferably, at least one bearing rotatably supports at least the duct relative to the support structure. The bearing thus defines a rotational axis around which at least the duct, preferably at least the duct and the conduit, can rotate. The calciner may further comprise a drive being coupled (directly or indirectly) with the duct to drive a rotation of the duct relative to the static support structure. The drive may for example comprise a motor with a shaft being coupled by a transmission to the duct. In operation, the rotational motion of the duct contributes to a homogeneous energy transfer from the wall to the raw meal in the duct and thus increases the efficiency of the calciner. At the same time, by the rotational motion the exposure time of the raw meal can be controlled. Increasing the angular velocity of the duct increases the conveying speed of the raw meal and thus decreases the exposure time of the raw meal (and vice versa). So called *"dead-burnt lime"* can be avoided as well as incomplete calcination of the raw meal. The angular velocity of the duct can be adjusted in operation by simply controlling the drive, e.g. in response to variations in the flow rate of raw meal entering the duct's inlet, to variations of the thermal energy being provided by the energy carrier, etc..

[0017] In a preferred embodiment, the at least one bearing rotatably supports the duct and the conduit relative to the support structure. In other words, the at least one duct and the at least one conduit may form a rotatable (in operation rotating) heat exchanger unit.

[0018] For example, the conduit may support the duct relative to the at least one bearing. For example, the duct can be attached to the conduit and the conduit may be attached to or have a bearing surface forming part of the bearing.

[0019] The rotational axis is preferably inclined against the horizontal direction. For example, the inclination may be smaller equal 20°, smaller equal 15°, smaller equal 10°, or less. Thus, particularly preferred, the raw meal exit is (preferably slightly) lower than the raw meal inlet. In this case the raw meal transport in the duct is at least in part gravity induced, expensive spiral or screw inserts in the duct configured for conveying the raw meal uphill can be completely omitted or reduced to a minimum. Slightly lower means in this context, that the height difference h between the raw meal inlet of a duct and the raw meal outlet of the same duct is smaller equal than a fourth of the length *l* of the calciner, preferably smaller equal than an eight of the length of the calciner, particularly preferred smaller equal than a tenth of the length of the calciner or smaller (i.e. $h \leq \frac{1}{4} \cdot l,\ h \leq \frac{1}{8} \cdot l$ or $h \leq \frac{1}{10} \cdot l$). The length *l* of the calciner is the distance from its raw meal inlet to its calcined raw meal outlet. In another example, the mean slope (i.e. the inclination) α of the duct is in the order of a few %, e.g. $\alpha \leq 10\%$, preferably $10\% \leq \alpha < 0\%$, more preferred $7{,}5\% \leq \alpha < 1\%$, even more preferred $6\% \leq \alpha < 2\%$.The flow direction of the energy carrier fluid is preferably countercurrent (opposite) to the flow direction of the raw meal in the duct. Thereby, heat transfer is enhanced. The longitudinal extension of the duct can be reduced, thereby reducing construction cost.

[0020] For example, the duct and/or the conduit (each) may have a longitudinal axis and this longitudinal axis may be at least essentially parallel to the rotational axis. Essentially parallel means preferably parallel, but deviations, e.g. within ±30° (preferred: within ±15°, more preferred: ±10° or even less, e.g., ±5°, ±2.5°, ±1°, ...) are accepted. The parallel alignment simplifies the construction as will be apparent below. A definition for parallel lines is provided in the above specified *Handbook of Mathematics, Chapter* 3.5.3.4, Sec.7.

[0021] Vividly speaking, *parallel* means that the axes are parallel, if they have a constant distance along their extension. In case of non-straight (e.g., helical) ducts, parallel is to be understood in that the center of the respective duct (i.e. the duct's neutral phase) maintains an at least essentially constant distance to the rotational axis, wherein at least essentially constant means preferably constant or constant within ±25% of the mean distance, more preferred: ±10% or even less, e.g., ±5%, ±2.5%, ±1%, ...

[0022] For example, the calciner may have at least two of the ducts (e.g. three, four, five, six, seven, eight, nine or any reasonable number), preferably being arranged at least essentially in parallel (parallel within ±30°, preferred: within ±15°, more preferred: ±10° or even less, e.g., ±5°, ±2.5°, ±1°, ...) to each other. In case the ducts are not straight, this is to be understood such that they are preferably congruent and that the centers (the neutral phases) of the (e.g., three) ducts maintain an at least essentially constant distance to each other (at least essentially constant means constant within ±25%, more preferred: ±10% or even less, e.g., ±5%, ±2.5%, ±1%, ...). This arrangement has a number of advantages: For example, the ducts may be attached to each other, e.g. via a support structure (it may be considered that the duct walls in operation may heat up to about 1000°C or more). Further, having multiple ducts (at least two or more), enables to increase the accumulated cross sectional area of the ducts (and thus the amount of raw meal the calciner may process at a given point in time) while maintaining the proportion of the surface being available for a heat exchange between the energy carrier fluid and the raw meal, i.e. the capacity (in units (e.g. tons) of calcined raw material per unit of time) can be increased without increasing the time of exposure of the raw meal in the calciner (avoiding "dead-burnt" lime) and reducing the length of the calciner (measured in the direction of the rotational axis).

[0023] The (at least e.g., three) ducts may be (preferably jointly) rotatably supported by the at least one bearing and driven synchronously by the at least one drive. The center of gravity of the e.g., at least three ducts is preferably centered at least essentially on the rotational axis (at least essentially centered means centered or centered within ±25% of the mean distance of the centers of the ducts to the rotational axis, more preferred: ±10% or even less, e.g., ±5%, ±2.5%, ±1% of said mean distance). Each of these optional, but preferred features reduces construction and maintenance costs, while at the same time reducing fluctuations in the raw meal flow rate measured at the raw meal exit. It is to be noted that the number of ducts "three" is only an example of "at least two", throughout the entire application.

[0024] In one example, the (e.g., at least three) ducts are jointly positioned in a single conduit having a peripheral conduit wall. The interstices between the walls defining neighbored ducts and between the ducts and the conduit wall define the conduit volume. This example has the advantage of being particularly cost efficient, i.e. the construction and operating cost per capacity of calcined raw meal are reduced. Further, the footprint of the respective calciner is low, making this example particularly suited for retrofitting existing cement clinker lines having limited available space.

[0025] In another example, the (e.g., at least three) ducts are each positioned in a separate conduit. This example has the advantage of a more uniform heat distribution in the ducts, of reducing fatigue of the material and thus allow for a reduction of the material thickness, e.g., of the wall separating the duct's volume from the conduit's volume. This contributes to lower construction costs and better heat transfer between the conduit and the respective duct, further reducing construction cost (the wall surface can be dimensioned smaller) as well as operating costs.

[0026] Particularly preferred, the separate conduits and/or ducts are supported by at least one longitudinal beam. This enables to support the duct and the conduit using constructional elements that are not (at least less) exposed to the heat being required to initiate calcination. This provides a more stable and cheaper construction. Further, sagging of the duct(s) and the conduit(s) is reduced, reducing fatigue of the conduit wall(s) and the duct wall(s). The bearing may be attached to the at least one longitudinal beam or integrated at least in part in the longitudinal beam. For example, the longitudinal beam may enclose the conduits and the ducts. In this example the longitudinal beam is tubular and has a longitudinal axis. The longitudinal beam's longitudinal axis is preferably at least essentially parallel (parallel within ±30°, preferred: within ±15°, more preferred: ±10° or even less, e.g., ±5°, ±2.5°, ±1°, ...) to the rotational axis.

[0027] In a preferred example, the longitudinal beam is thermally insulated from the conduit and/or the duct (and vice versa). For example, thermal insulation can be obtained by positioning at least one of a layer of refractory bricks, concrete, concrete foam, thermal resistant foam, mineral wool, or the like in between of the (at least one) longitudinal beam and at least one of the conduit(s) and the duct(s). The thermal insulation not only reduces thermal losses, but as well enables to maintain the temperature of the longitudinal beam comparatively low. The latter has the positive effect of reducing the construction costs, as high-temperature resistant steel can be replaced by a cheaper material. The insulating material may be attached to the longitudinal beam, and/or to at least one of the conduit and/or duct. Thermally insulating material is any material that reduces the thermal energy flow rate from the conduit(s)/duct(s) to the at least one longitudinal beam.

[0028] Relative to the longitudinal beam, the conduits and/or the ducts are preferably radially supported by at least one carrier while preferably enabling a longitudinal displacement of the conduits and/or ducts, respectively, relative to the longitudinal axis of the longitudinal beam. For example, the carrier(s) may provide a suspension in the radial direction (radial within ±30°, preferred: within ±15°, more preferred: ±10° or even less, e.g., ±5°, ±2.5°, ±1°, ...), while enabling the conduits and/or the ducts to float relative to the longitudinal beam's longitudinal axis, e.g. by means of plain bearings. Blocks may limit the longitudinal displacement. The longitudinal displacement reduces stress of the conduit(s) and/or duct(s), e.g. due to thermal expansion and/or subsequent contraction, thereby reducing installation and maintenance costs.

[0029] The carrier(s) may extend through the optional insulating layer, but as the carrier(s) can have a small cross sectional area (referencing to the plane being orthogonal to the temperature gradient), the heat transfer via the carrier(s) is comparatively small.

[0030] For example, the carriers may be one or more discs, e.g., of sheet metal having through holes for the at least one conduit(s) and/or ducts(s). The radial end section(s) of the disc(s) may be attached to the longitudinal beam. Thus, by providing a number of discs, being spaced from each other, the conduit(s) and/or the ducts(s) may be positioned radially and in the circumferential direction. Thus, the mechanical stress on the conduit(s) and /or duct(s) can be reduced, allowing to decrease the wall thickness and thus enhance the thermal energy transport from the energy carrier fluid via the wall to the raw meal. Further, a torque can be transmitted from the longitudinal beam via the carrier(s) to the conduits and/or beam(s). Thus, coupling the longitudinal beam to a rotational drive may drive the rotation of the conduit(s) and/or duct(s). The drive may thus be attached to a cold (less hot) portion of the calciner, which again contributes to enhance longevity and to reduce construction costs.

[0031] For example, a number of carriers may be attached to each other thereby forming a carrier structure having a disc like shape. This simplifies manufacture of the disc and eases transportation of the parts to the construction site, where the calciner is installed. The carrier(s) preferably have an at least essentially congruent shape.

[0032] For example, the at least one longitudinal beam may comprise or consist of a hollow profile defining a volume. For example, the longitudinal beam may be or comprise a tube or resemble a tube. The separate conduits may be positioned in the volume of the hollow profile, e.g. in the given example, the conduits may be aligned in the tube. This has a number of advantages: The outer surface of the hollow profile may provide a bearing surface of said bearing or support a bearing ring of the bearing. Further, the hollow profile may comprise insulating material, reducing thermal losses. In addition, the components inside the hollow profile are protected from weather and mechanical impacts.

[0033] In a preferred example, the at least one duct has at least one baffle plate. The baffle plate may be of some sheet material. The baffle plate is preferably in thermal contact with said wall, thereby forming part of the heat sink, i.e. the heat transfer surface is increased, reducing the required length of the duct and the exposure time of the raw meal in the duct. Further, in operation, the baffle plate effectively mixes the raw meal in the duct due to the rotation of the duct and thus contributes to a homogeneous heat transfer to the raw meal. As apparent from the above, the at least one baffle plate preferably extends into the volume of the duct and has a longitudinal extension in the direction of raw meal transport. The baffle plate may be inclined relative to the direction of raw meal transport, i.e. the angle between the baffle plate's longitudinal axis surface and the direction of transport. Thereby a screw segment may be provided by the baffle plate, which depending on the direction of the screw segment's slope may be configured to increase or decrease the conveying speed of the raw meal at a given angular velocity of the respective duct.

[0034] As already apparent, the calciner comprises an energy carrier fluid inlet and an energy carrier fluid outlet. The energy carrier fluid inlet and/or the energy fluid carrier outlet preferably comprise(s) a pipe being at least essentially aligned and at least essentially coaxial to the rotational axis, wherein the inlet end of the pipe is connected to, or integrally forms a part of a rotary joint. This configuration eases providing and/or removing the heat carrier fluid to and/or from, respectively the rotating portion of the calciner. Downstream of the energy carrier fluid inlet, connection pipes may distribute and/or collect the heat carrier fluid to and/or from the conduit(s).

[0035] The calciner is preferably installed or configured for being installed in a cement clinker line (i.e. all other components of the cement clinker line are optional). For example, the calciner's raw meal inlet may be connected via some conveying means with a raw meal exit of a raw meal preheater. The raw meal exit of the calciner may be connected to a kiln to provide at least a (first) portion of the calcined raw meal to the kiln for further processing to clinker. Optionally, a portion of the calcined raw meal may be provided by conveying means to an optional carbonator. The calcined raw meal exit of the calciner may thus preferably be connected or at least configured to be connected, e.g. by conveying means, to a lime (as comprised in the calcined raw meal) inlet of a carbonator. The optional carbonator may be a reactor receiving flue gas (e.g. from the kiln and/or the energy carrier fluid exit of the calciner) and a (second) portion of the calcined raw meal being released by the calciner's raw meal exit. In the carbonator, the CaO of the calcined raw meal reacts with CO_2 to $CaCO_3$, thereby removing the CO_2 from the flue gases. By circling the $CaCO_3$ from the carbonator by some conveying means (e.g. via a raw meal preheater) to the raw meal inlet of the calciner, the previously captured CO_2 is released and can be further processed as explained above. Accordingly, the carbonator may have a raw meal exit being connected to the calciner's raw meal inlet.

[0036] The CO_2 being released in calciner is preferably provided from the calciner to a heat exchanger, to cool the CO_2 down. The heat thereby recuperated can be used as process heat in the clinker process, for example for preheating primary or secondary air provided to the kiln, for drying raw meal and/or for preheating raw meal. Alternatively, or in addition, the heat may be used to heat and/or generate steam. The steam may subsequently be decompressed, e.g. using a turbine to thereby obtain mechanical power, which may be converted by a generator into electrical power.

[0037] The energy carrier fluid may be or comprise flue gas (e.g., from the kiln and/or a separate combustion reactor) and/or tertiary air (e.g. which may have been heated in a clinker cooler) and/or fuel being fired directly in a conduit. Fuel is understood herein as *combustible matter,* be it fluid, gaseous, solid or a mixture of different *combustible matters.*

[0038] The optional carbonator is a reactor with a flue gas inlet and a flue gas outlet. The flue gas inlet may be connected with a flue gas source, e.g. the kiln's exhaust and/or the energy carrier outlet of the calciner. In practice, the flue gas may be mixed with calcined raw meal, e.g. using a cyclone, at the inlet of the carbonator. Alternatively, the carbonator may have a separate CaO inlet as well referred to herein as lime inlet or calcined raw meal inlet. Herein, we will not further distinguish between these alternatives and referencing to one of them shall be understood to include a reference to the other alternative, as well.

[0039] The flue gas and the lime (as part of the calcined raw meal) may be conveyed through the carbonator while carbonation takes place, thereby the lime is converted into $CaCO_3$. Thus, the calcined raw meal is converted into non-calcined raw meal (simply raw meal, herein). In this process CO_2 is removed from the flue gas, yielding CO_2-lean flue gas, hereinafter *lean gas* for short. The carbonator has at least one outlet configured to release the raw-meal and the lean gas. Preferably, the lean gas and the raw meal may be separated, e.g. using a filter and/or a precipitator, e.g., a ceramic filter and/or a cyclone and/or electrostatic precipitator and/or any other appropriate gas-dust separation apparatus.

[0040] Thus summarizing, as already apparent from the above, the invention as well relates to a method for operating a cement clinker line and to a corresponding cement clinker line. The method may comprise for example at least one of preheating a first stream of raw meal, calcining the preheated raw meal in a calciner thereby obtaining at least partially calcined raw meal by indirect transfer of thermal energy from a heat carrier fluid to the preheated raw meal. Thereby the CO_2-stream and the heat carrier fluid leave the calciner as distinct streams.

[0041] A first portion of the calcined raw meal may be sintered in a kiln to cement clinker, whereas a second portion of the calcined raw meal may be fed to the carbonator to react with flue gases from the kiln and/or from a combustion reactor for heating a heat-carrier fluid being provided to the calciner, thereby obtaining by said carbonating a CO_2-lean flue gas stream and a second stream of raw meal, as explained above.

[0042] The second stream of raw meal can be mixed with the first stream of raw meal upstream of the calciner, e.g. in the preheater. Preferably, the flue gases being provided to the carbonator are cooled prior to reacting with the second portion of the calcined raw meal. This cooling step may for example comprise splitting the CO_2-lean flue gas stream in at least two portions, wherein a first portion of the CO_2-lean flue gas is used as heat source for preheating the raw meal and a second portion is cooled down. The cooled CO_2-lean flue gas may be injected into the flue gas stream upstream to the carbonator to cool the flue gas stream prior to the carbonation step.

[0043] For example, the second portion of the of the CO_2-lean flue gas may be cooled in an indirect heat exchanger, thereby heating a fluid up. The thermal energy transferred in the indirect heat exchanger to the fluid may at least partially be converted into mechanical energy by feeding the heated fluid to a turbine. For example, the fluid may be water and the indirect heat exchanger may be a steam boiler or a stage thereof.

[0044] Preferably, at least a first portion of the lean gas portion may be provided via a connection to the hot inlet of a heat exchanger (preferably an indirect heat exchanger) and removed from the cold outlet of the heat exchanger, thereby heating a fluid up, wherein the fluid enters the heat exchanger via a cold inlet and exits the heat exchanger via a hot outlet. Summarizing, the lean gas may be cooled down, while in turn another fluid is heated up. In a preferred example, the heat exchanger is a steam boiler or a stage of a steam boiler, wherein the steam boiler may be configured to drive a turbine being coupled with a generator. As explained above, the cooled lean gas may be used to cool the flue gas stream prior to entering the carbonator. Similarly, the cooled flue gas stream may be used to cool the second portion of the calcined raw meal stream down prior to providing it to the carbonator.

[0045] In a preferred example, a fan (as a pars pro toto of pressure differential generating apparatus) may be installed downstream of the cold gas exit of the heat exchanger, sucking at least a portion of the lean gas through the heat exchanger. The optional second portion may be provided for example as energy source to a raw meal preheater.

[0046] The cold exit of the heat exchanger may be connected to the inlet of the carbonator or to a mixing chamber upstream the carbonator inlet to thereby cool the flue gas from the kiln and/or the calciner down prior to providing it to the carbonator inlet. For example, the hot flue gases can be cooled down, e.g., from typically 1000°C-800°C to, e.g., about 400 - 650°C.

[0047] Alternatively or in addition, cooling down can be obtained by a heat exchanger (e.g. a steam boiler) or by mixing the flue gas being provided to the carbonator inlet with ambient air, to thereby cool the flue gas to a temperature where carbonation takes place.

[0048] Alternatively or in addition, the flue gas may be cooled down in an indirect heat exchanger, thereby heating a fluid up. Similarly, thermal energy transferred in the indirect heat exchanger to the fluid may at least partially be converted into mechanical energy by feeding the heated fluid to a turbine. Again, for example, the fluid may be water and the indirect heat exchanger may be a steam boiler or a stage thereof.

[0049] Urea ($CO(NH_2)_2$) or another reducing chemical (e.g. ammonia (NH_3)) may be injected into the flue gas stream downstream the energy carrier outlet of the calciner and upstream the carbonator inlet. At the temperature levels present in this section of the flue gas stream (typically between 850°C and 1050°, preferably between 900°C and 1000°, even more preferred between 925°C and 975°C), the urea (as an example for reducing chemicals) reacts with nitrogen oxides (in this example) to nitrogen (N_2), CO_2 and water. This reaction is called **S**elective **N**on-**C**atalytic **R**eduction (SNCR) and reduces the NO_x in the flue gas. An SNCR at this position in the cement clinker plant has the advantage that the CO_2 being released in the SNCR process is as well subjected to removal from the flue gas stream in the carbonator and that the additional installation costs for installing and operating a catalysator enabling de-nitrification at lower temperature levels, e.g., downstream the raw meal preheater, can be omitted.

[0050] As apparent, the kiln has a flue gas exit side. Preferably, the calcined raw meal exit of the calciner is in the proximity of the flue gas exit side. Proximity means that the distance *d* between the calciner's calcined raw meal exit and the kiln's flue gas exit side is smaller equal than three times the kiln's diameter 2 . r_k, i.e. smaller equal 6 times the kiln's outer radius r_k. In other words, *d*

$\leq 6 \cdot r_k$, preferably $d \leq 4 \cdot r_k$, even more preferred $d \leq 2 \cdot r_k$, $d \leq r_k$ or even better, *e.g., $2d \leq r_k$.* In a preferred example the horizontal distance d is smaller equal 5m ($d \leq 5m$), even more preferred smaller equal 2.5 ($d \leq 2.5m$), smaller equal 1.5 ($d \leq 1.5m$) or less (e.g. $d \leq 1m$). These short distances enable to essentially directly feed a stream of precalcined raw meal from the calciner to the kiln's raw meal inlet.

[0051] This direct feed is further supported, if the vertical distance *h* between the lower edge of the calciner's raw meal outlet and the lower edge of the kiln's raw meal inlet is preferably small as well, e.g. *d* is smaller equal 6m ($h \leq 6m$), even more preferred smaller equal 3m ($h \leq 3m$), smaller equal 1.5 ($h \leq 1.5m$) or less (e.g. $h \leq 1m$).

[0052] Further, the hot flue gas from the kiln may be provided as well at least almost directly to the calciner's energy carrier fluid inlet. Thereby, construction costs are reduced. Further operating costs are reduced as well, as thermal losses can be reduced to a minimum. At least almost directly means in this context, that the kiln's flue gas exit may be connected to some hot gas dedusting means, e.g. to a cyclone, a ceramic filter or the like. The gas outlet of the gas dedusting means may be connected to the calciner's energy carrier inlet. The advantage of the optional dedusting step is that the conduit of the calciner is not exposed to abrasive dust, however, removing the dust particles as well removes the thermal energy transported with this hot particulate matter from the energy carrier stream. The removed thermal energy can thus not be used in the calciner for calcination.

[0053] For example, the calciner's rotational axis and the kiln's longitudinal axis (i.e. typically its rotations axis) may be aligned, parallel or are at least essentially parallel (parallel within $\pm 30°$, preferred: within $\pm 15°$, more preferred: $\pm 10°$ or even less, e.g., $\pm 5°$, $\pm 2.5°$, $\pm 1°$, ...). This arrangement further simplifies transportation of the calcined raw meal to the kiln.

[0054] The calciner as described above is an indirect heat exchanger, receiving a heat carrier fluid at its hot inlet and releasing the heat carrier fluid at its cold outlet. The preferably preheated but not yet calcined raw meal is provided to the cold inlet of the heat exchanger and the calcined raw meal is released via the hot outlet of the heat exchanger. The CO_2 being released, as well, leaves the calciner via the same or another hot outlet.

[0055] In another example of the invention, the heat carrier fluid can be replaced at least partially by an electrical current. The electrical current drives at least one electrical heating element(s), being in thermal contact with raw meal in the rotationally supported duct(s) of the calciner. Only to avoid any confusion, the electrical heating may provide a portion of the thermal energy required for calcination or entirely replace the energy being provided by the energy carrier fluid being described above.

[0056] The electrical heating element(s) may be integrated into a wall defining at least a portion of the contour of the duct(s). Alternatively or in addition, at least one electrical heating element may be thermally attached to the wall. In this sense, electrical heating elements can be considered as the conduit being described above or as an auxiliary conduit in case of a partial substitution of the energy carrier fluid. Accordingly, the electrical current can thus be considered the energy carrier fluid or as an auxiliary energy carrier fluid, respectively.

[0057] In case the calciner is heated at least partially electrically, at least a portion of the thermal energy of the kiln's flue gas can be used to heat steam for driving at least one steam turbine(s). Thus, the kiln's exhaust may be connected to the hot inlet of a steam boiler. The thereby produced steam may be provided to the steam turbine(s), which have a drive shaft. The drive shaft is preferably coupled to the rotor of a generator for converting kinetic energy into electric energy. Similarly, at least a portion of the heat being recuperated in the clinker cooler can be used at least in part to produce steam, driving the at least one steam turbine. For example, the socalled tertiary air stream may be dedusted (e.g. using a cyclone) and provided to the hot inlet of a steam boiler. The electrical current being produced by the generator(s) can be used for example to heat the calciner electrically, at least in part.

[0058] Above, we used the terms *connection* or *is connected* to indicated that a flow of matter (like raw meal, CO_2, fuel, clinker, etc.) is conveyed from one processing means to another. Examples of these processing means are a kiln, a calciner, a carbonator, a heat exchanger, a cyclone, a precipitator, a filter, etc.. The *connection* is as well referred to as *conveying means.* In a very simple case, the conveying means (i.e. the connection) may be a chute, a pipe or tube. But other conveying means /connections can as well be used. A tube is essentially the same as a conduit and duct. Only to verbally distinguish from the conduit and duct of the calciner described above, we use the term tube unless the conduit or duct of the calciner is referred to.

Description of Drawings

[0059] In the following the invention will be described by way of example, without limitation of the general inventive concept, on examples of embodiment with reference to the drawings.

Figure 1A shows a cement clinker plant with integrated RCC.

Figure 1B shows a simplified sectional view of a calciner 18

Figure 1C shows a preferred example of positioning a calciner 18 relative to a kiln 12.

Figure 2A shows a cross sectional view of a calciner 18.

Figure 2B shows a detail of a longitudinal sectional view of a calciner 18, very similar to the calciner in Figure 2A.

Figure 3 shows a sectional view of a calciner 18.

Figure 4 shows a detail of a calciner 18.

Figure 5 shows a detail of an another calciner 18.

[0060] In figure 1A, a preferred embodiment of a cement clinker line 1 with an integrated RCC is schematically shown: Raw meal 100 enters a preheater 20. Preheated raw meal 102 is withdrawn from the preheater 20 and provided to a raw meal inlet 185 of a calciner 18. As depicted, the calciner 18 is an indirect heat exchanger having an energy carrier fluid inlet 181 and an energy carrier fluid outlet 182 (see as well Fig. 1B).

[0061] The energy carrier fluid 180 may be a flue gas from the kiln 10 and/or an optional combustion reactor 16. The optional combustion reactor 16 burns fuel 161, e.g. using tertiary air 140 provided by an optional clinker cooler 12 via an optional tertiary air duct 14 (see Fig. 1A). The combustion reactor 16 may be integrally formed with a conduit 340 (see e.g. Fig. 1B, 2A, 2B and 3) of the calciner 18 or, as shown, upstream the hot energy carrier fluid inlet 181.

[0062] By transferring heat provided by the energy carrier fluid 180 to the preheated raw meal 102, the preheated raw meal 102 is calcined. In other words, the $CaCO_3$ in the preheated raw meal 102 as provided by the preheater 20 is decomposed, essentially into CaO and CO_2. The decomposition may be incomplete, but the calcined raw meal 108 comprises CaO (typically more than 50% of the initially available $CaCO_3$ has been decomposed, preferably more than 60%, even more preferred more than 75%, 90%, 95% of the initially available $CaCO_3$).

[0063] A gas-dust separation may provide essentially pure CO_2 which can be removed from the process via a CO_2-outlet 187. The CO_2 may potentially be diluted with vapors of constituents of the raw meal 102 which evaporate in the calciner 18 (e.g. water, mercury (Hg), chlorides, etc.). Depending of the process conditions and the subsequent designation of the CO_2, these impurities may be removed by further processing of the CO_2-stream or not. The still hot CO_2 is preferably cooled down, as indicated by an optional heat exchanger 25. The thereby recuperated heat may be used as process heat in the clinker manufacturing process and/or used to heat steam.

[0064] The calcined raw meal 108 may be withdrawn from the calciner 18 via a calcined raw meal outlet 186 and the calcined raw meal stream 108 may be separated into a first portion 108a and second portion108b (see Fig. 1A and Fig. 1B). The first portion 108a of the calcined raw meal stream 108 may be provided to the kiln 10. In the kiln 10, the calcined raw meal 108 may be sintered to cement clinker 109. The cement clinker 109 may preferably be cooled down in a clinker cooler 12 and can be subjected to further processing, e.g. milling.

[0065] As can be seen in Fig. 1A, another portion 108b of the calcined raw meal 108 may be provided via a CaO-inlet 285 to a carbonator 28. The carbonator 28 may preferably be integrated into the preheater 20 and thus be a portion of the preheater 20. As depicted, the carbonator may receive flue gas from the kiln and optionally from an optional combustion reactor 16 or as well from other CO_2-sources. The optional combustion reactor 16 may be integrated in the calciner 18.

[0066] The flue gas from the kiln 10 and optionally from the optional combustion reactor 16 may be provided from the flue gas outlet 182 of the calciner 18 to a flue gas inlet 281 of the carbonator 28 (see Fig. 1A). Preferably, a reductant 17, e.g. urea ($CO(NH_2)_2$) and/or ammonia (NH_3, e.g. aqueous NH_3) may optionally be injected into the flue gas while it flows from the calciner 18 to the carbonator 28. In other words, the injection takes place between the flue gas outlet 182 of the calciner 18 and the flue gas inlet 281 of the carbonator 28, to thereby reduce nitrogen oxides in the flue gas.

[0067] CO_2 comprised in the flue gas 111 provided to the carbonator 28 reacts in the carbonator 28 with the CaO in the second portion 108b of the calcined raw meal 108 in an exothermal reaction to $CaCO_3$. Thus, the flue gases heat up, unless the heat is directly dissipated by a housing of the carbonator (optional). The second portion 108b of the calcined raw meal 108 is thereby essentially converted back to raw meal and heated up by the exothermal reaction. Via the outlet 283 of the carbonator, the CO_2-lean flue gas (*lean gas*) and the raw meal is provided to an optional preheater cyclone 23. The raw meal may remain in the process, i.e. it may be provided back to the calciner 18 (e.g. via optional cyclone 22), while the CO_2-lean flue gas is preferably dedusted (e.g. by optional dedusting means 19) and may be subjected to further cleaning steps (e.g. desulfurization, mercury removal, NO_x-reduction, etc.) prior to being released. Optionally, a portion of the (preferably dedusted) lean gas may be branched off from the raw meal preheater 20 and provided to a hot gas inlet 61 of a heat exchanger 60. In the heat exchanger 60, the lean gas may be cooled down and the corresponding thermal energy may be transferred to a fluid which in turn heats up. The transferred thermal energy may be used as process heat in the clinker process and/or as schematically indicated feed to an optional turbine driving an optional generator.

[0068] The cooled lean gas exits the heat exchanger 60 at a cold gas outlet 62 and may be provided to the flue gas inlet 281 of the carbonator 28, thereby mixing with hot flue gas from the calciner 18, e.g. as depicted here in a cyclone 22, and cooling the flue gas down to for example about 400-650°C, i.e. to a temperature where carbonation takes place. As indicated by a number of valves, the lean gas may as well (alternatively or in addition) be cooled using water 209 or by means of mixing with ambient air or another fluid (regardless of being liquid or gaseous). Another option (as alternative or in addition), is to cool the hot flue gas as released from the calciner (and/or the kiln) using an indirect heat exchanger 65, i.e. the cold inlet of heat exchanger 65 may be connected, e.g. via some dedusting apparatus (see optional cyclone 22), to the energy carrier fluid outlet 182 of the calciner 18.

[0069] As already mentioned above, the calciner 18 has an energy carrier fluid inlet 181. Via this an energy carrier fluid inlet 181, the calciner 18 may receive via a connection hot flue gas from the kiln 10. Alternatively or in addition, the energy carrier fluid inlet 181 may receive at least a portion of preheated air (e.g. tertiary air 140) being drawn from the clinker cooler via a so called tertiary air duct 14 (optional). The tertiary air 140 may optionally be further heated by burning fuel 161 in a combustion reactor 16. Numerous of these combustion reactors 16 have been suggested in the past and we reference for simplicity only to EP 2 868 636 B1 and documents cited therein. The content of EP 2 868 636 B1 and documents cited therein shall be considered to be included herein by reference as if fully set forth. It is further noted that the optional combustion reactor 16 may be integrated into the calciner, thereby reducing heat transmission losses.

[0070] As already mentioned, an example calciner 18 is sketched in Fig. 2B. As already apparent, the calciner 18 has an energy carrier fluid inlet 181, configured to receive hot fluid, e.g. flue gas from the kiln 10 and/or from another combustion reactor 16. Via an optional rotary joint 81 the energy carrier fluid 180 may enter the calciner 18 and is provided to conduits 340. The conduits 340 each have a conduit shell 350, enclosing a wall 330 separating the conduit 340 from a raw meal duct 320. The energy carrier fluid 180 flowing from the energy carrier inlet 181 to the energy carrier outlet 182 provides heat via the wall 330 to preheated raw meal 102 in the raw meal duct 320. The raw meal 102 is thus heated up and converted to calcined raw meal, i.e. $CaCO_3$ in the preheated raw meal 102 decays into CaO and CO_2. The CO_2 leaves the calciner via a CO_2 outlet 187. The calcined raw meal 108 leaves the calciner 18 via calcined raw meal outlet 186 and may be provided to the kiln 12 and/or a carbonator 28 (see Fig. 1A). The duct 320 and the conduit 340 are preferably supported by and/or inside an optional tubular longitudinal beam 385, e.g. via carriers 370 as depicted in Fig. 2A and 2B. Another optional central longitudinal beam 375 may be provided alternatively or in addition. The ducts 320 and the conduits 340 are rotatably supported and driven to rotate around the rotational axis 2. The bearing and the drive are symbolized by the rotational axis 2.

[0071] Fig. 1C shows a preferred example of positioning a calciner 18 relative to kiln 12 (see Fig. 1A), e.g. one of the example calciners 18 discussed herein, relative to a kiln 12. The same reference numerals are used as in Fig. 1A, 1B and 2A to 3, and generally the description of Figs. 1A, 1B, 2A, 2B and 3 can be read on Fig. 1C, as well, although for simplicity not any detail is repeatedly shown. As can be seen, the calciner 18 has a rotational axis 2, and the kiln 10 has a rotational axis 3. The kiln 12 has a secondary air inlet side 101 and flue gas outlet side 103. The flue gas outlet side 103 of the kiln at least essentially faces the raw meal outlet side of the calciner 18, thereby enabling an at least almost direct raw meal feed (see arrow 108a) from the calciner's calcined raw meal outlet 186 to the kiln 10. As well, the hot flue gas may be fed at least almost directly to the energy carrier fluid inlet 181 of the calciner 18. Thus, transportation distances of the energy carrier fluid 180 as well as of the calcined raw meal 108 can be minimized. This measure reduces installation cost and at the same time enhances the cement clinker line's efficiency, because thermal losses are as well reduced by said position. In the depicted example, the rotational axes 2 and 3 are depicted almost parallel to each other. Indeed, this is a preferred example, but the technical effect is obtained by positioning the flue gas exit side 102 of the kiln 12 in the proximity of the calcined raw meal outlet 186 of the calciner 18, wherein proximity means in this context within a distance d being smaller than three times the diameter $(2 \cdot r_k)$ of the kiln $(d \leq 6 \cdot r_k)$, preferably less than twice the diameter of the kiln$(d \leq 4 \cdot r_k)$, even more preferred once the diameter of the kiln $(d \leq 2 \cdot r_k)$ or $d \leq r_k$ or even $2d \leq r_k$. In a preferred example the horizontal distance d is smaller equal 5m $(d \leq 5m)$, even more preferred smaller equal 2.5 $(d \leq 2.5m)$, smaller equal 1.5 $(d \leq 1.5m)$ or less (e.g. $d \leq 1m$). This enables to essentially directly feed a stream of precalcined raw meal from the calciner to the kiln's raw meal inlet.

[0072] The vertical distance h (not indicated in the figure) between the lower edge of the calciner's raw meal outlet and the lower edge of the kiln's raw meal inlet is preferably small as well, e.g. d is smaller equal 6m $(h \leq 6m)$, even more preferred smaller equal 3m $(h \leq 3m)$, smaller equal 1.5 $(h \leq 1.5m)$ or less (e.g. $h \leq 1m$).

[0073] The angle defined by the two axes 2, 3 can be varied, an alignment is not required, but preferred. At least one these two axes 2, 3 is, preferably both are, slightly inclined in the raw meal conveying direction, e.g. a few percent as explained above.

[0074] In this example, the energy carrier fluid 180 is dedusted as indicated by an optional cyclone (as an example for a hot gas dedusting means). In an alternative example, the flue gas exiting the kiln at 102 can be provided directly to the energy carrier inlet 181 of the calciner. Theoretically one could as well omit dedusting of the portion of the heat carrier fluid originating from the clinker cooler 12, thereby further increasing heat transfer to the calciner's ducts 320. The drawback is that the clinker dust being transported by the tertiary air is highly abrasive, i.e. maintenance costs are increased. When dedusting, the energy carrier fluid 180 upstream of the calciner's energy fluid inlet 181, it is favorable to dedust the flue gas from the kiln and the tertiary air 140 separately, thereby obtaining precalcined raw meal and clinker dust, separately from each other. The thereby obtained fraction of precalcined raw meal can be provided to the kiln and the clinker dust fraction can be provided to a clinker reservoir

[0075] Fig. 2A shows a simplified cross sectional view of an example calciner 18. Fig. 2B shows a detail of a longitudinal sectional view of a very similar example calciner 18. The two examples are not identical in any detail, but both figures show the same underlying working and constructional principles and in this regard they can be considered to be at least almost identical. The calciner 18 may be supported relative to a base (e.g. the ground) by a static support structure 390. In more detail, the static support structure 390 may for example rotatably support rollers 395. The rollers 395 may rotatably support a bearing ring 380 having a peripheral surface 382. In this example, the bearing ring 380 is integrally provided by a tubular longitudinal beam 385. At least one of the rollers 395 may be driven by a drive (motor and optional transmission) being schematically indicated by arc shaped arrows 396. Thus, the bearing ring 380 and thus the tubular longitudinal beam 385 rotates around a rotational axis 2, which defines the center of the bearing ring 380.

[0076] Inside the bearing 380 ring is at least one, are preferably two, three or even more ducts 320 for conveying raw meal. The ducts 320 each have a peripheral wall 330 separating the volume of the ducts 320 from an energy carrier fluid in the conduits 340. In the depicted example the wall 330 is fully enclosed in a peripheral shell 350 of the conduit 340. The conduit shell 350 may support the wall 330 and thus the duct 320 by at least one optional spacer 360. Depicted are eight spacers 360 (see Fig. 2A), which are preferably evenly distributed. Further, it is to be understood that the number eight is only an example for at least one. The shell 350 itself, is supported by a carrier 370 having the contour of a section of a disc, in this example of a circular disc. Multiple carriers 370, preferably, with an at least essentially congruent contour, may be assembled to provide an (e.g., circular) carrier structure being positioned inside a tubular longitudinal beam 385 and/or the bearing ring 380. The bearing ring 380 may be rotatably supported by rollers 395 relative to a static support structure 390. The rollers 395 may be rotatably supported and driven as indicated by arc shaped arrows 396. Thus, the bearing ring 380 (i.e. the longitudinal beam) and the rollers 395 are an example of a rotatable bearing of the duct 320 relative to the static support structure 390.

[0077] The ducts 320 may have at least one optional baffle plate 325, optionally being attached to the wall 330. Fig. 2B shows a lower number of baffle plates than Fig. 2A. The baffle plates 325 increase the heat transfer of the wall 330 into the duct volume 320 and in operation are cold ends of a heat sink. These baffle plates 325 further stir the raw meal in the duct, i.e. provide for a homogeneous heat distribution. Inclining (optionally) the longitudinal direction of at least one baffle plate 325 relative to a direction being parallel to the rotational axis 2, enables to increase or decrease the conveying rate of the raw meal in a wider range by altering the rotational speed of rotation of the ducts 320.

[0078] Further enhancement of heat transfer can be obtained by at least one optional heat-collector blade 345. Preferably, a number bigger than one is installed, thus below we use the plural "heat-collector blades 345", which of course means "at least one optional heat-collector blade 345". These heat-collector blades 345 may be (e.g. longitudinally extending) profiles extending into the volume of the conduit 340 (omitted in Fig. 2B) being attached to the conduit side of the wall 330. In operation, the heat collector blades 345 are thus in direct thermal contact with the heat-carrier fluid and accordingly heat up. By thermal conduction, the heat is provided to the wall 330, being in thermal contact with the heat collector blades 345. Thus, the heat collector blades 345 increase the temperature of the wall 330 and thus the heat transfer to the raw meal inside the duct 320. Further, the heat collector blades may be configured to stir the heat carrier fluid to thereby further increase heat transfer. For example, the heat-collector blades 345 may be vortex generators being attached, e.g. to the wall 330. The thereby created vortices in the heat carrier fluid reduce the radial temperature gradient in the conduit and thus increase heat transfer via the walls 330 to the raw meal in the respective duct 320.

[0079] At least one longitudinal beam 375 may be attached to at least one of the carriers 370(, preferably as depicted to all of them) and thus to the carrier structure. The longitudinal beam 375 may extend for example coaxially with the rotational axis 2. The optional beam 375 further reduces sag of the ducts 320 and the conduits 340. In this example, the carriers jointly form an optional recess through which the longitudinal beam 375 extends.

[0080] As can be seen in Fig. 2B, the calciner 18 has a heat carrier inlet 181 tube, being centered with the rotational axis. The heat carrier inlet 181 is connected by a connection tube with the conduit 340, thereby enabling a fluid flow from the heat carrier fluid inlet to the heat carrier fluid outlet 182 (see Fig. 1). A rotary joint 81 may connect the heat carrier inlet with a heat carrier source (e.g. a tertiary air duct 140, a combustion heater 16, the kiln's flue gas exit, ...).

[0081] The raw meal flow is preferable countercurrent to the energy carrier fluid's flow direction as indicated by the arrow 180 (cf. Fig. 2B and Fig. 1A). The raw meal may be released, e.g. via a chute or a bunker (see Fig. 1B). A portion 108a of the calcined raw meal 108 may be provided to the kiln's raw meal inlet (cf. Fig. 1A) another portion 108b of the calcined raw meal may be conveyed to a carbonator 28 (cf. Fig. 1A).

[0082] Fig. 3 shows a further example of a calciner 18. Similar to the calciners 18 in Fig. 2A, 2B, the calciner 18 has an (optional) static support structure with optional rollers 395 rotatably supporting a bearing ring 380. The bearing ring 380 may support a tubular longitudinal beam 385. In this example the bearing ring 380 and the tubular longitudinal beam 385 are different parts. This concept can be transferred to other examples of the calciner 18, in particular to the example as shown in Fig. 2A and 2B.

[0083] Still with reference to Fig 3, inside the tubular longitudinal beam 385 is a conduit shell 350 of a conduit 340 for conveying an energy carrier fluid 180 (compare Fig. 1) essentially along the rotational axis 2. In this example, the conduit volume 340 is delimited radially by a preferably circular cylindrical inner boundary 355 of the conduit 340. In between of the inner boundary 355 and the conduit shell 350 are a number of ducts 320, each may be defined by a cylindrical wall 330 (as example, circular cylindrical walls are shown). The space being delimited by conduit shell 350, the inner boundary 355 and the walls 330 is the conduit volume enabling an energy carrier to flow essentially parallel to the rotational axis and thereby transfers, via the walls 330 heat to preheated raw meal 102 in the ducts' volumes 320. Baffles plates 325, heat collector blades 345 and spacers 360 have been omitted in this figure for simplicity, only, but may be added independently from each other.

[0084] Another aspect of the invention is shown in Fig. 4. This aspect may be the subject matter of an independent claim or a divisional application and is related to a spacer 360 configured for supporting a wall 330 of a duct 320 relative to a conduit shell 350 and/or a conduit's inner boundary 355.

[0085] The spacer 360 may be of a piece 361 of sheet material, e.g. of a piece of sheet metal 361. The piece 361 may have a first leg 362 being configured to be firmly attached to a surface of a wall 330 facing side of a conduit shell 350 or to a surface of the conduit's inner boundary 355. Alternatively, the first leg may be configured to be firmly attached to a surface of the wall 330 facing towards the shell 350 or the conduits inner boundary 355 (see Fig. 5).

[0086] Firmly attached means herein force-transmittingly attached, i.e. the first leg 362 may not be moved relative to the conduit 340 without releasing the attachment. As depicted, the first leg 362 preferably has an attachment surface 362a configured to be tangentially attached to the conduit's or wall's surface. From the first leg 362 extends (at least one) second leg 363 being curved away from the conduit's or wall's surface, respectively. The second leg 363 provides a slider 364, being configured to slide on the wall 330 or the conduit shell 350 (or conduit inner boundary 355), respectively. The spacer 360 thus provides a radial support of the conduit 340 relative to the duct 320 (and vice versa), while enabling an axial displacement of the conduit 340 relative to the duct 320. This axial displacement enables to compensate for different thermal elongations of the duct 320 and the conduit 340. Further, elasticity of the sheet material as well enables to compensate for different thermally induced radial expansion and contraction of the duct 320 and the conduit 340, as well as to allow some sag of the duct 320 relative to the conduit 340 and/or vice versa.

List of reference numerals

[0087]

1	cement clinker line
2	rotational axis of the calciner
3	rotational axis of the kiln
10	kiln
101	secondary air inlet side
102	flue gas outlet side of the kiln
12	clinker cooler
14	tertiary air duct (optional)
140	tertiary air stream
16	combustion reactor (optional)
161	fuel
17	reductant, e.g. urea ($CO(NH_2)_2$) and/or ammonia (NH_3)
18	calciner
180	energy carrier fluid
181	energy carrier fluid inlet
182	energy carrier fluid outlet
185	raw meal inlet
186	calcined raw meal outlet
187	CO_2 outlet
19	dedusting means (e.g., precipitator, filter, ...)
20	preheater
209	water
21	first cyclone stage (optional)
22	second cyclone stage (optional)
23	third cyclone stage (optional)
24	fourth cyclone stage (optional)
25	heat exchanger
28	carbonator
281	flue gas inlet (carbonator inlet)
283	CO_2 lean flue gas outlet
285	CaO inlet (carbonator inlet)
60	heat exchanger
61	hot lean gas inlet of heat exchanger
62	cold lean gas outlet of heat exchanger
65	heat exchanger
81	rotary joint
90	insulating material
100	raw meal
101	cooler facing side of kiln / secondary air inlet
102	preheated raw meal
103	flue gas outlet side of kiln
108	calcined raw meal
108a	first portion
108b	second portion
109	cement clinker ('clinker' for short)
111	flue gas stream

320 duct, duct volume
322 duct axis / neutral phase
325 baffle plate
330 wall separating duct and conduit volumes

340 conduit, conduit volume
342 conduit axis / neutral phase
345 heat-collector blade
350 conduit shell
355 conduit inner boundary

360 spacer
361 piece of sheet material
362 first leg
363 second leg
364 slider

370 carrier
375 longitudinal beam
380 bearing ring
382 surface of bearing ring
385 longitudinal beam
390 static support structure / base
395 roller, optionally rotatably driven
396 arc shaped arrow symbolizing rotational drive

Claims

1. A calciner (18) for receiving raw meal (102) from a preheater (20) of a cement clinker line (1), for calcining the raw meal (102) and for providing the calcined and/or pre-calcined raw meal (108) to a kiln of the cement clinker line (1), wherein the calciner (18) comprises:

   - at least one duct (320), wherein the at least one duct has at least one raw meal inlet (185) and at least one raw meal outlet (186),
   - at least one conduit (340), wherein the least one conduit (340) surrounds at least one of the at least one ducts (320) at least partially or is surrounded at least partially by the at least one duct (320), wherein a wall (330) separates the at least one duct (320) and the at least one conduit (340) to thereby enable an indirect heat transfer from an energy carrier fluid (180) in the at least one conduit (340) via the wall (330) to raw meal (100, 102) in the at least one duct (340), wherein the at least one conduit (340) has at least one inlet (181) for receiving the energy carrier fluid (180) and at least one outlet (182) for releasing the energy carrier (180) fluid after having transferred at least a portion of the energy via the wall (330),
   - a static support structure (390) configured for supporting at least the at least one duct (320) and/or the at least one conduit (340) relative to a base,

   characterized in, that
   at least one bearing (380, 395) rotatably supports at least the duct (320) relative to the support structure (390), wherein the bearing (380, 395) defines a rotational axis (2) of the duct 320 and **in that** at least the duct (320) is torque-transmittingly coupled to a rotational drive (395).

2. The calciner (18) of claim 1, **characterized in that** the at least one bearing (380, 395) rotatably supports the at least one duct (320) and the at least one conduit (340) relative to the support structure (390).

3. The calciner (18) of claim 2, **characterized in that** the at least one conduit (340) supports the at least one duct (320) relative to the at least one bearing (380).

4. The calciner (18) of one of the previous claims, **characterized in that** the rotational axis (2) is inclined against the horizontal direction.

5. The calciner (18) of one of the previous claims, **characterized in that** the at least one duct (320) and/or the at least one conduit (340) have/has a longitudinal axes/axis (322, 342) and **in that** the longitudinal axes/axis (322, 342) and the rotational axis (2) are parallel within $\pm 30°$ to each other.

6. The calciner (18) of one of the previous claims, **characterized in that** the calciner (18) has at least three of said at least one duct (320), wherein the at least three ducts (320) are arranged in parallel to each other.

7. The calciner (18) of claim 6, **characterized in that** the at least three ducts (320) are jointly positioned in a single conduit (340).

8. The calciner (18) of one of claims 1 to 6, **characterized in that** the at ducts (320) are each positioned in a separate conduit (340).

9. The calciner of one of the previous claims, **characterized in that** the at least one conduits (340) and/or the at least one ducts (320) are jointly supported by at least one longitudinal beam (375).

10. The calciner (18) of claim 9, **characterized in that** the at least one longitudinal beam (375) comprises a hollow profile defining a volume, and **in that** separate conduits are positioned in the volume of the hollow profile.

11. The calciner (18) of one of the previous claims, **characterized in that** the at least one duct has at least

one baffle plate (325), wherein the at least one baffle plate (325) extends into the volume of the duct (320), wherein at least a section of the baffle plate (325) is inclined relative to the plane including the rotational axis (2) of the duct (320).

12. A cement clinker line (1) comprising the calciner (18) of one of the previous claims.

13. A method for manufacturing cement clinker comprising at least:

- preheating a first stream of raw meal (100),
- calcining preheated raw meal (102) in a calciner (18) into at least partially calcined raw meal (108) by indirect transfer of thermal energy from a heat carrier fluid to the preheated raw meal (102), thereby providing at least a CO_2-stream separate from the heat carrier fluid and an at least pre-calcined raw meal stream (108), wherein the calciner (18) is preferably the calciner (18) of any one of the previous claims 1 to 11,
- sintering a first portion (108a) of the calcined raw meal (108) in a kiln to cement clinker,
- carbonating a second portion (108b) of the calcined raw meal (108b) in a carbonator (28) with flue gases from the kiln (10) and/or with flue gases from a combustion reactor (16) for heating a heat carrier fluid being provided to the calciner (18) for heating the raw meal (102) in the calciner, thereby obtaining by said carbonating a CO_2-lean flue gas stream and a second stream of raw meal (100),
- merging the second stream of raw meal (100) into the first stream of raw meal (100) upstream of the calciner (18), thereby obtaining said preheated raw meal (102),

characterized in that
the flue gases are cooled down prior to reacting with the second portion (108b) of the calcined raw meal (108).

14. The method of claim 13, **characterized in that** cooling the flue gases comprises at least splitting the CO_2-lean flue gas in at least two portions, wherein a first portion of the CO_2-lean flue gas is used as heat source for preheating the raw meal and a second portion is cooled down and the cooled CO_2-lean flue gas is injected into the flue gas stream upstream of the carbonator (28) to cool the flue gas stream prior to the carbonation step.

15. The method of claim 14, **characterized in that** the second portion of the of the CO_2-lean flue gas is cooled in an indirect heat exchanger (60), thereby heating a fluid up; and **in that** the thermal energy transferred in the indirect heat exchanger to the fluid is at least partially converted into mechanical energy by feeding the heated fluid to a turbine.

16. The method of claim 13, **characterized in that** the flue gas is cooled down in an indirect heat exchanger (65), thereby heating a fluid up; and **in that** the thermal energy transferred in the indirect heat exchanger to the fluid is at least partially converted into mechanical energy by feeding the heated fluid to a turbine.

Fig. 1A

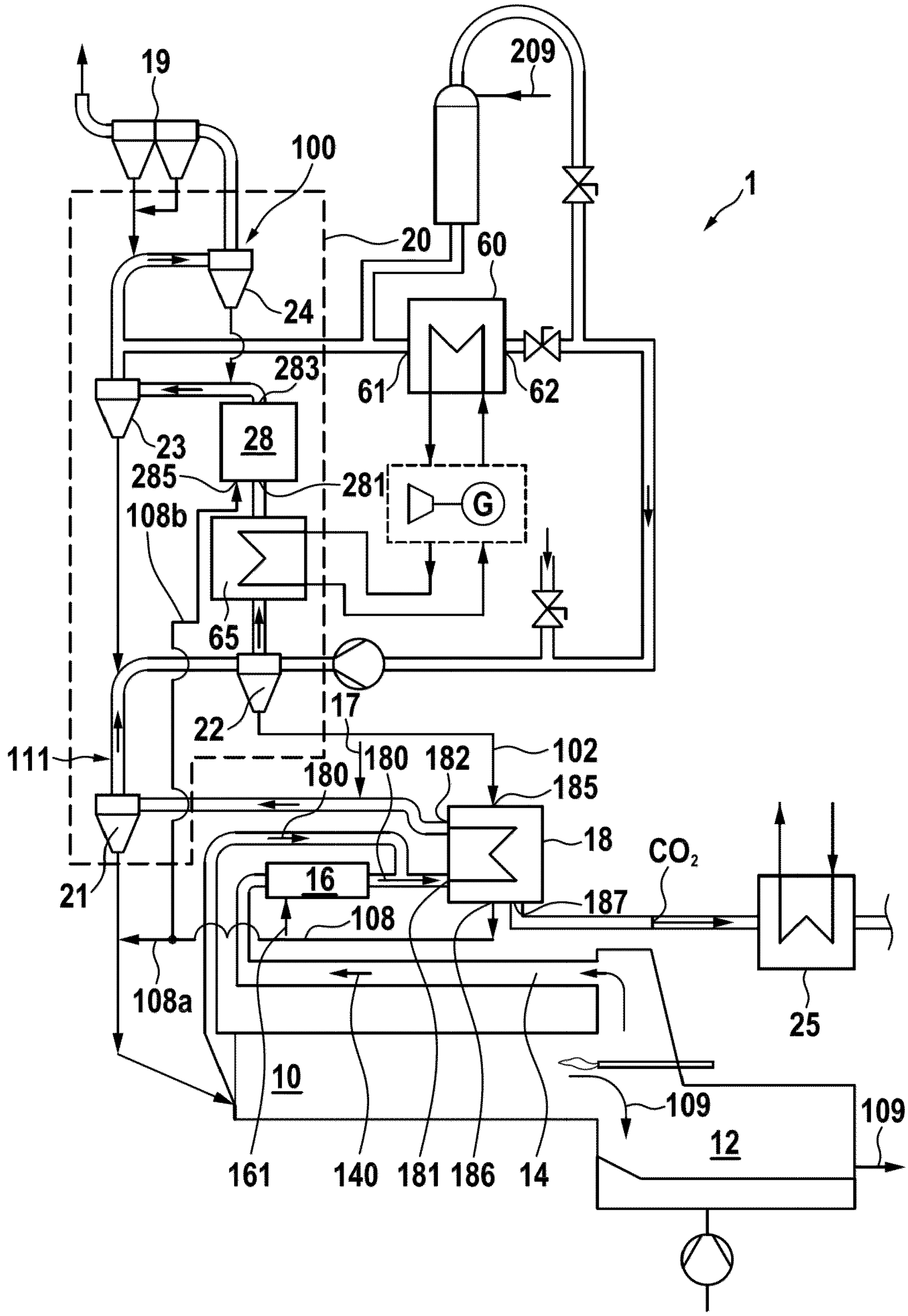

19
100
209
1
20
60
24
283
61
62
23
28
285
281
G
108b
65
17
22
111
180
180
182
102
185
21
18
CO2
16
187
108
108a
25
10
109
109
12
161
140
181
186
14

Fig. 1B

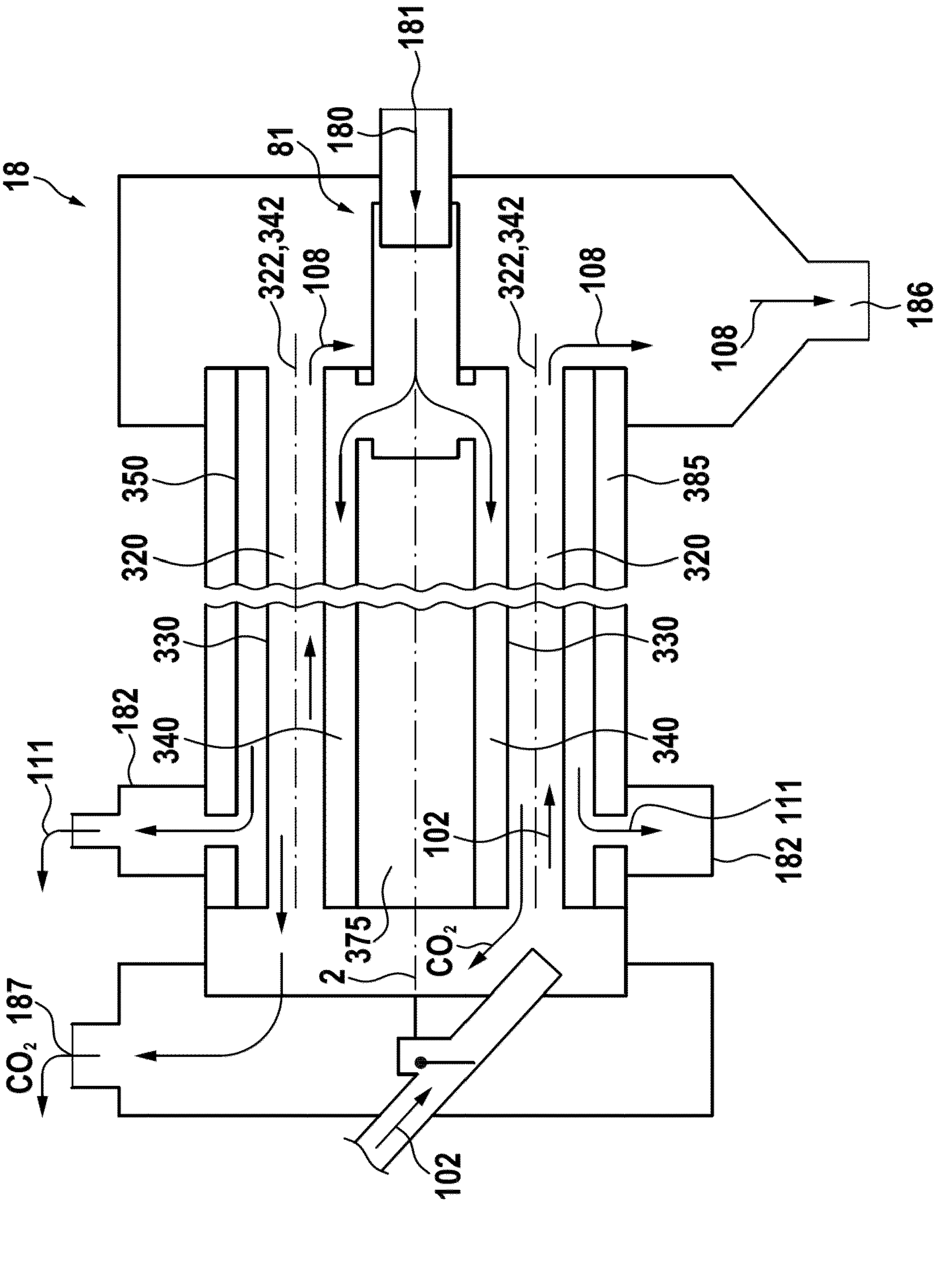

18
181
180
81
322,342
108
322,342
108
108
186
350
385
320
320
330
330
182
340
340
111
102
182 111
375
CO_2
2
CO_2 187
102

Fig. 1C

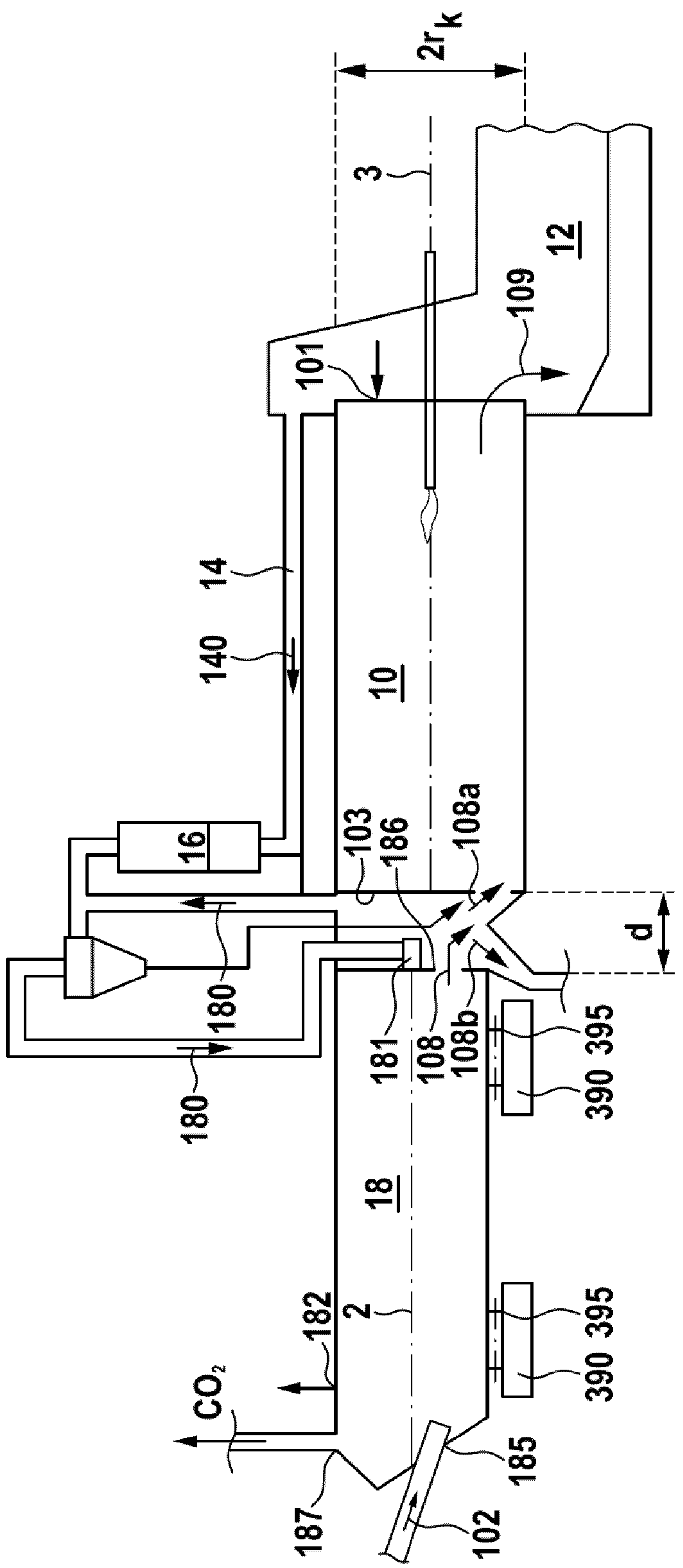

2r_k
3
12
109
101
14
140
10
16
103
186
108a
d
180
181
108
108b
395
390 395
18
2
182
CO₂
390 395
185
187
102

Fig. 2A

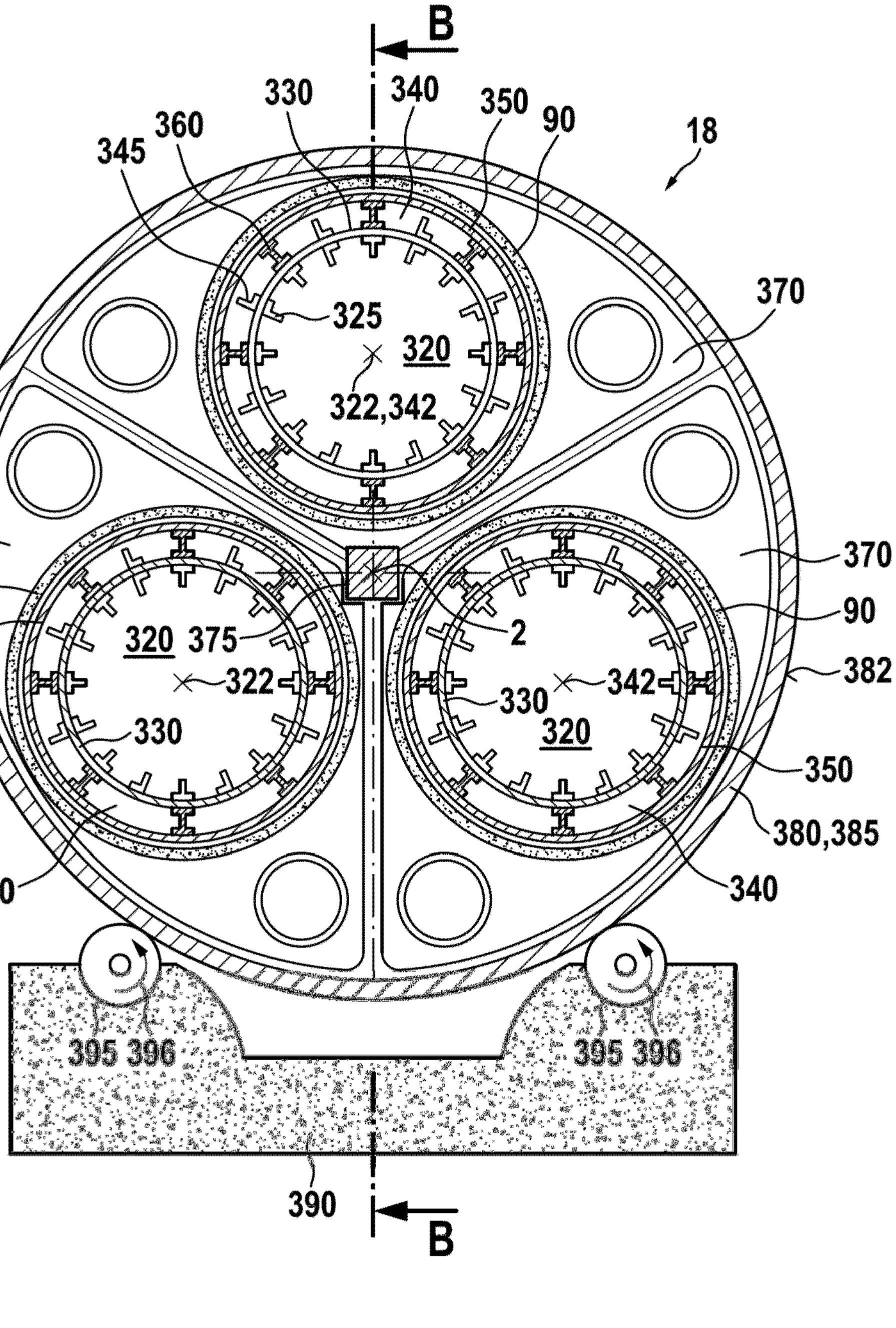

B
330
340
350
90
18
345
360
370
325
320
322,342
370
370
90
350
320
375
322
2
90
342
330
382
330
320
350
380,385
340
340
395 396
395 396
390
B

Fig. 2B

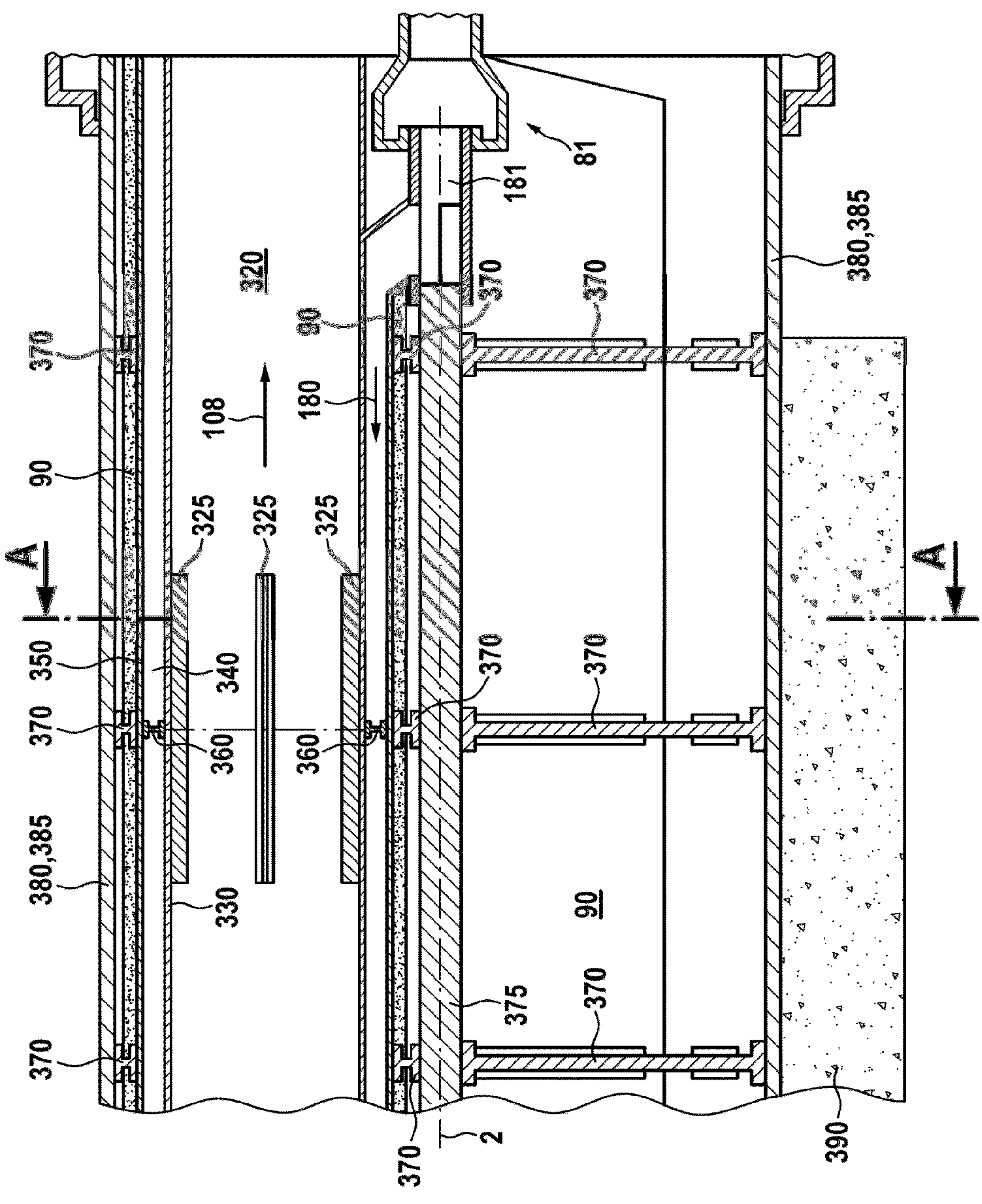


Fig. 3

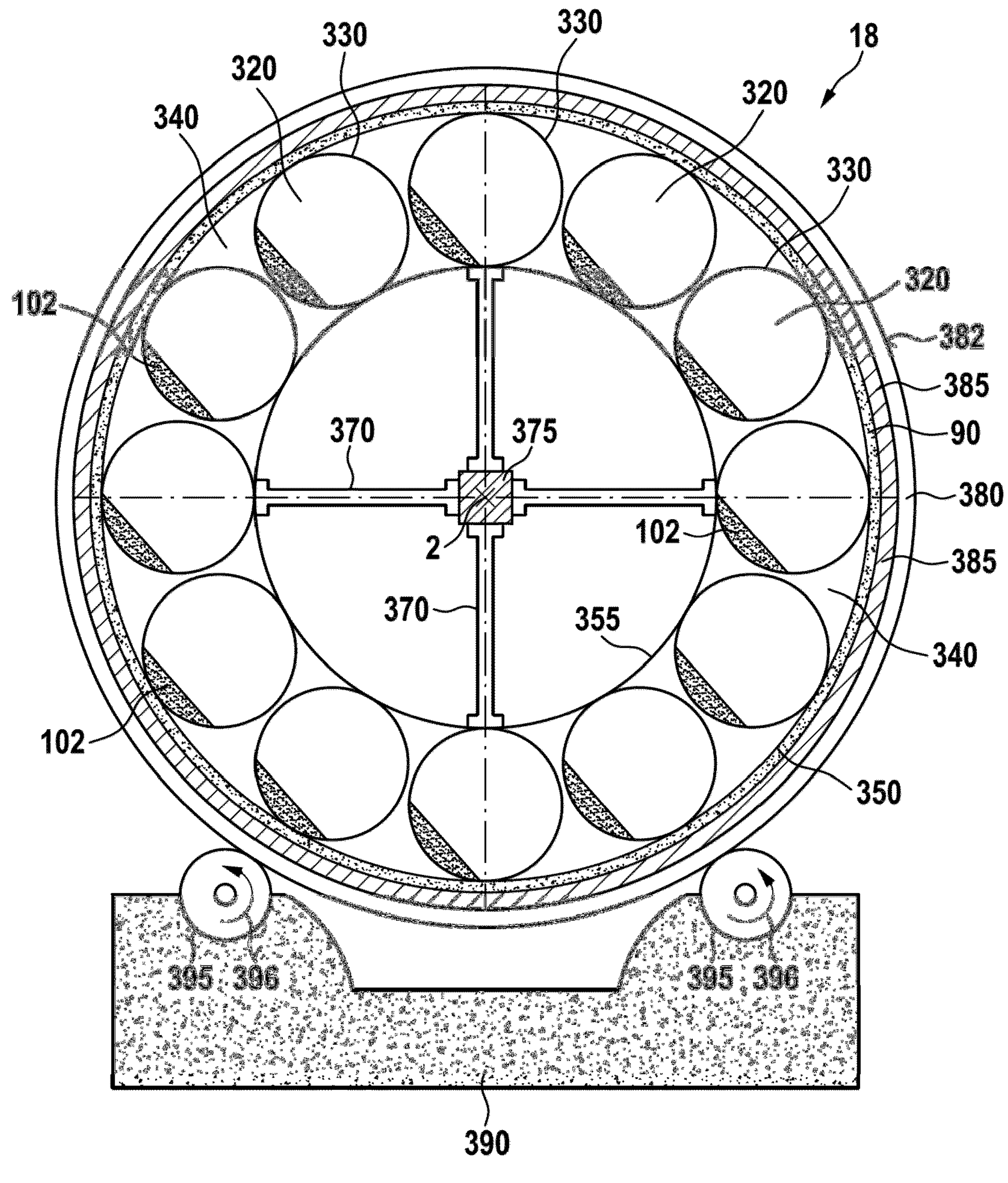

18
330
330
320
320
340
330
320
102
382
385
90
370
375
380
2
102
385
370
355
340
102
350
395
396
395
396
390

Fig. 4

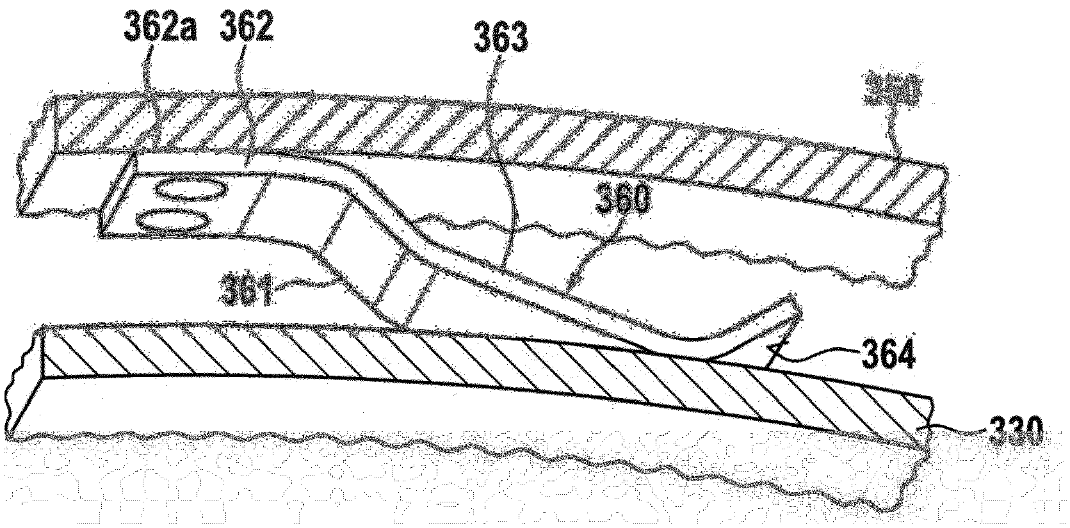
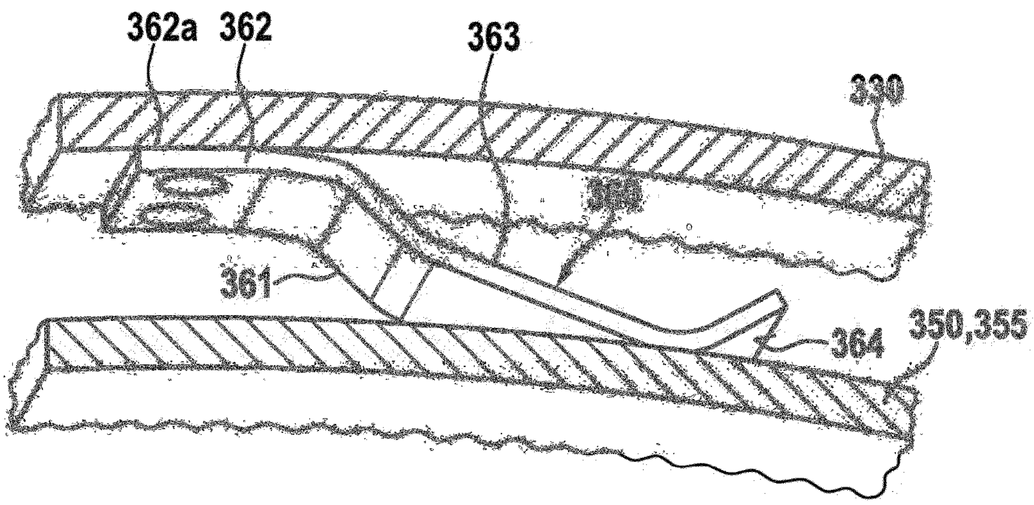

362a
362
363
350
360
361
364
330

Fig. 5


362a
362
363
330
361
364
350,355

Europäisches Patentamt
European Patent Office
Office européen des brevets

EUROPEAN SEARCH REPORT

Application Number
EP 20 15 8040

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
X	US 1 995 948 A (SHAFTER RULAND R ET AL) 26 March 1935 (1935-03-26) * figures 1-4 * * column 1, line 1 - line 32 * -----	1-12	INV. F27B7/20
X	EP 2 952 244 A1 (ALSTOM TECHNOLOGY LTD [CH]) 9 December 2015 (2015-12-09) * figures 1-4 * * paragraph [0030] - paragraph [0046] * -----	12-16	

TECHNICAL FIELDS SEARCHED (IPC)

F27B
B01D

The present search report has been drawn up for all claims

1

Place of search	Date of completion of the search	Examiner
The Hague	19 May 2020	Peis, Stefano

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
Y : particularly relevant if combined with another document of the same category
A : technological background
O : non-written disclosure
P : intermediate document

T : theory or principle underlying the invention
E : earlier patent document, but published on, or after the filing date
D : document cited in the application
L : document cited for other reasons
....
& : member of the same patent family, corresponding document

EPO FORM 1503 03.82 (P04C01)

ANNEX TO THE EUROPEAN SEARCH REPORT ON EUROPEAN PATENT APPLICATION NO. EP 20 15 8040

This annex lists the patent family members relating to the patent documents cited in the above-mentioned European search report.
The members are as contained in the European Patent Office EDP file on
The European Patent Office is in no way liable for these particulars which are merely given for the purpose of information.

19-05-2020

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 1995948 A	26-03-1935	NONE	
EP 2952244 A1	09-12-2015	AU 2015202289 A1	17-12-2015
		CA 2892062 A1	02-12-2015
		CN 105126599 A	09-12-2015
		EP 2952244 A1	09-12-2015
		US 2015343373 A1	03-12-2015
		US 2018028967 A1	01-02-2018

EPO FORM P0459

For more details about this annex : see Official Journal of the European Patent Office, No. 12/82

REFERENCES CITED IN THE DESCRIPTION

This list of references cited by the applicant is for the reader's convenience only. It does not form part of the European patent document. Even though great care has been taken in compiling the references, errors or omissions cannot be excluded and the EPO disclaims all liability in this regard.

Patent documents cited in the description

- EP 2461892 A1 **[0004]**
- US 20090255444 A **[0004]**
- FR 2921059 A1 **[0005] [0006]**
- EP 2868636 B1 **[0069]**

Non-patent literature cited in the description

- **OLIVIER ; JANSSENS-MAENHOUT ; MUNTEAN ; PETERS.** The Hague: PBL Netherlands Environmental Assessment Agency. *Trends in global CO2 emissions: 2016 Report,* 22 January 2020, 65, http://edgar.jrc.ec.europa.eu/news docs/irc-2016-trends-in-global-co2-emissions-2016-report-103425.pdf,accessed **[0002]**
- **JOHANNA LEHNE ; FELIX PRESTON.** Making Concrete Change Innovation in Low-carbon Cement and Concrete. *Chatham House Report,* 2018 **[0002]**
- **BRONSTEIN ; SEMENDYAYEV ; MUSIO ; MUEHLIG.** Handbook of Mathematics. Springer, 2007 **[0008]**