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An apparatus for conducting physical, chemical, or biological interaction between gases and solid particles

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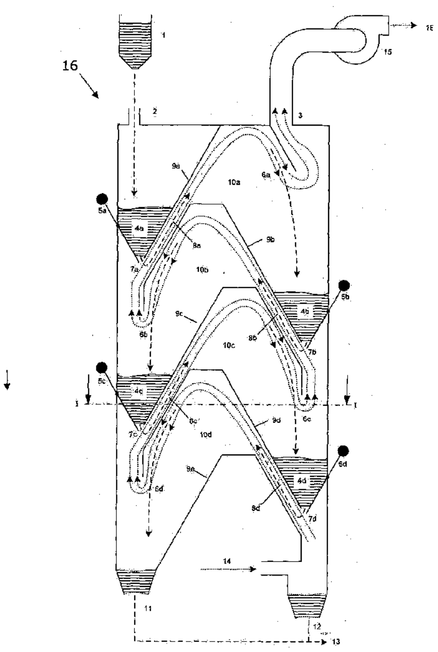

Fig. 1

(57) Abstract: The invention provides an apparatus for conducting interaction between gases and solid particles. The apparatus has a vertical hollow shaft with a vertical row of constrictions formed internally and defining a series of intercommunicating chambers in the shaft for guiding the gas and particles e.g. in counter current to effect interaction there between, e.g. for transferring thermal energy. To enable redesign of the apparatus and to enable an improved match between need for capacity and size of the apparatus, the invention provides an apparatus where the shaft comprises a stack of separate modules arranged vertically above each other or side-by-side whereby the apparatus becomes modular.

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AN APPARATUS FOR CONDUCTING PHYSICAL, CHEMICAL, OR BIOLOGICAL INTERACTION BETWEEN GASES AND SOLID PARTICLES

INTRODUCTION

The invention relates to an apparatus for conducting interaction between gases and solids or between different solid particles, e.g. for conducting physical and/or chemical and/or biological reactions between gases and solid particles, e.g. for exchanging thermal energy and/or performing reactions between gas and solid particles. More particularly, the invention relates to an apparatus comprising a vertical hollow shaft comprising a vertical row of constrictions formed internally and defining a series of intercommunicating chambers in the shaft. The chambers are interconnected by gas conduits and by solids conduits. The apparatus further comprises means for introducing and removing the solid particles and gas into and out of the shaft in one or more vertically offset levels.

BACKGROUND OF THE INVENTION

Exchange of thermal energy between gas and solid particles is a challenge in numerous industrial processes, due to the poor thermal conductivity in bulk powders as well as the non-floating properties of solid particles and thereby the need for mechanical or pneumatic forces to transport or agitate the solid particles.

The purposes of the heat exchange process can be several, however often it is desired to obtain a high efficiency in the heat transfer, i.e. obtain the highest particle outlet temperature for heat exchange of a hot gas with cold particles, or to obtain a controlled heating profile and specific outlet temperatures, i.e. in the production of food, foodtech, biotech, or pharmaceutical components.

Heat exchangers for exchanging thermal energy between gas and solid particles exist in different variants. One way of obtaining an efficient heat exchange is to bring particles in direct contact with gas while moving gas and particles in opposite directions. This heat exchange principle is referred to as counter-current heat exchange. Typically, it is convenient to introduce the particles in top of a chamber and to establish an upwardly directed current of gas in the chamber. During decent of the particles against the current of the gas under influence of gravity, thermal energy is transferred between gas and particles, depending on the temperature difference and other system specific parameters.

In practise, it is difficult to achieve counter-current heat exchange since the gravimetric settling velocity of fine particles relative to the gas velocity is low. Therefore, in traditional gas and solid heat exchange systems, particles are typically suspended and transported with the gas. Once the suspended particles and the gas obtain a uniform temperature, the particles are separated from the gas to retrieve the particles. The particles are now, depending on the purpose of the process, either colder or hotter, than the particles fed to the process. The opposite applies for the gas. This mixing, transport, and separation process constitutes a stage in a gas/solid heat exchange process. Arranging several stages in a series, the heat exchange process obtains an overall counter-current-like pattern with increased thermal performance as a result, compared to the performance of a single stage. The actual performance will, among other things, depend on the number of stages in the series.

Typically, various chemical processes may result in transformation of substance during the process, and often, it is required to combine the thermal exchange process with other processes, e.g. for removing unwanted substances, to promote reactions of certain kinds, or to condition particles by e.g. grinding, agglomeration, or coating.

In bulk-industry, efficient thermal exchange processes are typically very important for the overall thermal efficiency of the plant and, depending on the specific purpose, also expensive to construct. In cement manufacturing, taken as an example, solid particles of different composition, e.g. fine calcium carbonate particles mixed with clay and other materials are typically heated in a pre-heater tower to near the calcination temperature before entering the calciner and the rotary kiln. The particulate material is today heat exchanged in a cyclone based heat exchanger arranged in a kind of counter-current pattern with waste gas from the calcination and/or kiln processes.

The heat exchange is typically carried out in discrete steps whereby carbon or sulphur containing components may evaporate and/or partly oxidize forming unwanted gases which may be emitted from the process. Furthermore, the very large heat exchangers are custom made and offer little flexibility with regards to the amount of material which is processed. Furthermore, the heat exchangers and the support structure are expensive to construct.

Heat exchangers are described in various publications including GB1039470, AU2109870, US 4,188,184, and GB1038965.

GB1039470 discloses a heat-exchange apparatus with a zig-zag shaft the bottom of which forms both an inlet for gas and an outlet for particles. Particles are feed to the upper part of the shaft and falls under gravity in the gas while heat is exchanged between the gas and the particles.

AU 2109870 discloses an apparatus for conducting heat between gases and fine-grained solids. The apparatus consists of several separating chambers connected with each other by a gas channel such that material in one chamber can reach the chamber situated beneath via a material outlet. The material outlet opens into the connecting channel leading gas from the chamber situated beneath. The disclosed apparatus is not very easy to scale up and down in size depending on the needed capacity, and typically, a device of the disclosed kind will be made in a "standard-size" which may not be suitable with a specific production in mind. This apparatus also does not enable different modules combined, e.g. combustion sections etc. It is solely a heat exchanger for fine powders.

GB1038965 discloses a method of and apparatus for exchanging heat between solid particles and gases, GB1297185 discloses an apparatus for contacting a finely divided material with a hot gas, and US2888096 discloses a horizontal centrifuge separator.

US 4,188,184 discloses a container with deflectors.

DESCRIPTION OF THE INVENTION

The invention emanates from the existing heat exchangers, e.g. as described in AU2109870. It is an object of embodiments of the invention to overcome the disadvantages detailed above, particularly with regard to the size, cost, and lack of flexibility by use of the existing heat exchangers and to have an easily scaleable system.

Accordingly, the invention, in a first aspect, provides an apparatus as defined in claim 1.

According to the invention, at least the constrictions, or alternatively both the constrictions and the hollow shaft are modular whereby the apparatus can be configured and reconfigured with different numbers, sizes or shapes of constrictions or reconfigured with different distances between adjacent constrictions.

Herein "*modular*" refers to the feature that the apparatus comprises a number of predefined constrictions and/or shaft modules. The modules may be physical modules arranged against each other and being assembled rigidly to form an apparatus, or the modules may be design modules, i.e. virtual modules available for the designer of an apparatus. Accordingly, the apparatus can be designed based on a number of predefined parameters, e.g. based on a width, height, or depth of the shaft or based on a number of chambers and thereby a number of constrictions or based on the distance between adjacent constrictions. In the following, this will be referred to as parametric design of the apparatus.

Herein, "*width*" refers to a dimension in a horizontal plane, "*height*" refers to a dimension in a vertical plane and "*depth*" refers to a dimension in a horizontal plane and being perpendicular to the width. I.e. the terms are defined by the direction of gravity in a normal use situation for the apparatus.

Particularly, the modules may be detachably fixed to adjacent modules to enable reconfiguration of the apparatus.

The predefined modules may particularly have predefined interfaces determining the connectivity and/or the detachability between the module and adjacent modules. As an example, the predefined interfaces may determine the way two adjacent modules are joined, it may determine a capability obtained by joining two predefined modules, it may determine a necessary resource required for assembling the modules, it may determine an expected duration for assembling the modules etc.

The predefined interface may e.g. comprise a horizontal interface adapted for joining the module with horizontally or at least substantially horizontally adjacent modules. Such an interface enables configuration and reconfiguration of an apparatus by changing its width and/or depth for a particular purpose.

The predefined interfaces may also comprise a vertical interface adapted for joining the module with vertically adjacent modules. Such an interface enables stacking of the modules on top of each other and thereby enables configuration and/or reconfiguration of an apparatus by changing the height of the apparatus.

The vertical interface may e.g. include a specification of a capability of a module to carry a load, e.g. specified in an amount of modules of a specific kind which can be carried by the module. Additionally, it may specify the weight of the module and thereby the load which a lower module is charged with.

The apparatus may comprise blinding elements adapted to blind an interface of a module at locations where no adjacent modules are foreseen. As an example, it may be desired to make an apparatus from a vertical row of modules. In this case, all horizontal interfaces are blinded by blinding elements.

In one embodiment, the entire apparatus is made from prefabricated modules which can be moved by a truck and assembled on the location where the apparatus is to be used. The prefabricated modules could e.g. be detachably fixed to each other such that the apparatus can be disassembled after use, moved to a new location and assembled again, either in an identical configuration and size or in different configuration and size.

Particularly, the hollow shaft may be assembled from wall elements or panels which are detachably joined. In that way, the total height, width, or depth of the apparatus may be amended based on a specifically required capacity. Several assembled panels may form an outer part of the apparatus, i.e. panels may form a boundary to the surrounding space. Particularly, such panels may be assembled in such a way that single panels or groups of panels can be removed to thereby provide access to an inner space within the apparatus, e.g. for maintenance purpose or for replacing single elements, e.g. for replacing the constrictions etc.

Additionally, several assembled panels may form an inner part of the apparatus.

As an example, an apparatus can be completely defined by a number of constrictions, say e.g. 5 constrictions arranged in a standard shaft with a homogeneous or gradually changing distance between each constriction due to thermal expansion of the gases. Should another task require a larger capacity, a new apparatus can be defined by a higher number of constrictions, or a higher height, width or depth of the shaft, i.e. the number of constrictions, the size of the constrictions, and/or the distance between the constrictions can change.

According to the invention, each module or each constriction may be selected based on a desired process. As an example, a number of modules may be for gas/solid heat exchange and other modules and constrictions may be for combustion, gasification or other reactions. The predefined module may therefore have a predefined purpose. The apparatus may e.g. include fluidized modules e.g. including heat transfer tubes. A bottom of the apparatus could e.g. be constituted by a fluid bed combustion reactor, or a calcinator.

To improve flexibility with regards to configuration and reconfiguration and to make scaling easy, the constriction may particularly have a 2-dimensional shape.

By definition, the 2-dimensional shape means that the shape of the constriction is defined in a 2-dimensional plane and that the last, third, dimension in space is defined merely by shifting the two dimensional shape along a vector extending in the third dimension e.g. perpendicular to the before mentioned plane.

If each constriction has a particular shape, e.g. the shape of a V or the shape of an L, e.g. in a plane in the X-Y directions of a Cartesian space, then this shape is maintained along the Z-direction in this space. Particularly, the 2-dimensional shape may be a shape in a vertical plane such that the Z-direction becomes out of the vertical plane, e.g. in a horizontal plane.

This feature is hereafter termed a 2-dimensional shape, and it enables easy scaling in the previously mentioned vertical Z-direction. Accordingly, the feature enables an easier reconfiguration of the apparatus either in the design phase or in the construction phase.

To further improve the scalability by use of constrictions with a 2-dimensional shape, the shaft may have a quadrangular or rectangular shape in a cross section perpendicular to a vertical axis. In this way, the constrictions may e.g. have straight edges and/or the constrictions may have a 2-dimensional shape.

Due to the 2-dimensional shape, it is possible to expand the constrictions in the third dimension and thereby to increase the capacity of the apparatus without expanding the constrictions in the first and second dimension or without changing the shape of the constrictions.

Accordingly, it becomes easy to match a specific need for capacity and/or size of the apparatus. The 2-dimensional shape is closely related to the aforementioned horizontal interface since it enables modification of the width and/or the depth of the apparatus depending on the actual need.

Particularly, it may be an advantage if all constrictions have identical shape and size. In that case, the production rate of the apparatus may be obtained by selection of a specific number of constrictions or by selection of a specific distance between the constrictions in the shaft. In this way, an apparatus can be made by selecting constrictions from a library and using any number sufficient for a specific purpose. Also the attachment of the constrictions in the shaft may be standardised such that attachment of the constrictions in the shaft becomes easy. Again, this is facilitated by the modularity – i.e. the apparatus may include a plurality of identical modules assembled by standardised interfaces.

The identical constrictions may e.g. be arranged in two groups such that every second constriction is in identical orientation and every other second constriction is in identical orientation being rotated by 180 degrees about a vertical axis relative to the constrictions of the other group of constrictions. This provides a mirrored configuration where one group of constrictions corresponds essentially to the other group being mirrored in a central, vertical plane of symmetry.

The apparatus may e.g. comprise a top module, three heat exchange modules and a bottom module. All modules could be designed for heat exchange of raw meal with hot process gas. In this example, the three heat exchange modules could include a number of identical and 2-dimensional constrictions. The top and bottom modules may be different from the modules with the identical constrictions, and the top and bottom modules may e.g. have a larger capacity for separation of particles from the gas. This apparatus may easily be scaled by insertion of removal of constrictions and/or by changing the size of the constrictions in the third direction. The capacity may also be changed by amending the distance between the constrictions.

The 2-dimensional constrictions could be assembled e.g. from planar plates or from plates which are shaped or curved only in the mentioned 2-dimensions, i.e. not double curved.

Generally, the apparatus may be for any kind of reaction or interaction between gas and solid particles or even between solids particles and other solid particles, e.g. reduction of ore with coke, clinker formation reactions etc.

Examples of physical interaction include transfer of thermal energy between the gas and particles, adsorption of gas species on particles, volatilization of liquid or solid material from the particles during heating i.e. drying of particles.

Examples of chemical interaction include: Combustion, gasification, pyrolysis, catalytic reactions, e.g. to reduce unwanted emissions.

Examples of biological interaction between gases and solid particles include gas phase enzymatic catalysis, sterilization and protein denaturation and degeneration

The apparatus can be used e.g. for the following purposes:

— Preheating of raw meal;

— Calcination of raw meal and other minerals;

— Formation of cement clinker;

— Heating of raw meal with insertion of $Ca(OH)_2$ or CaO at optimal temperatures for absorption of sulphur compounds;

— Steam production in exterior or interior walls and horizontal constrictions for utilization for e.g. power production. Note that the steam can also be heat exchanged in counter current relative to the gas to thereby achieve the best possible effect;

— Heating of raw meal with insertion of combustible compounds, e.g. waste materials or fossil fuels;

— Removal of moist from particles, i.e. drying of grain;

— Heterogeneous catalytic processes, e.g. catalytic cracking , catalytic oxidation and catalytic reduction;

— Homogeneous gas phase reactions, e.g. selective non-catalytic reduction (SNCR) of NO by NH_3;

— Gas cleaning by heterogeneous reactions, e.g. sulphur absorption and HCl absorption processes;

— Heat treatment of solids, e.g. controlled sintering or sterilization;

— Coating of particles;

By the arrangement of the separate modules above each other in the vertical direction, also the chambers become vertically arranged above each other.

The gas and solids conduits extend between the chambers and thereby facilitate transport of the gas and solid particles between the chambers, i.e. the solids conduit extends from the particle bed of one chamber to an adjacent chamber.

During use of the apparatus, the particles and gas are introduced into the shaft. Typically the gas is introduced at the bottom or lower end of the shaft from where the gas flows from chamber to chamber via the gas conduits. The particles are introduced at the top or upper end of the shaft into a first chamber in the vertical downward array of chambers.

Typically a stage in the process will consist of two chambers, each facilitating a mixing and a separation process, respectively. The particles are introduced into the first chamber and thereafter transported through the first chamber by the stream of gas and during this step, the gas and particles can interact e.g. by transferring thermal energy from the gas to the particles. During this step, the constrictions will guide the gas and particles.

In the second chamber, the particles are separated from the gas and they are transferred via the particle conduit to the second chamber located below the first chamber. For this purpose, the chambers may e.g. form a particle bed with a certain solid storage capacity. The particle bed thereby acts as a guard against short-circuiting gas streams. If needed, the conduction of particles from chamber to chamber may be facilitated by mechanic or acoustic vibration or by application of pneumatic forces. Such means may be included in selected or in each of the modules, i.e. the modules may have predefined mechanical actuation means for conducting the transport of particles.

In the consecutive stages, the process is repeated; the particles decent down into the first chamber and are transported to the second chamber with the stream of gas moving upwards in the chamber.

Each constriction could be a standard module designed to perform a specific task, and the stack of modules can thereby be designed for specific process purposes by mixing constriction modules of different kind and size.

As an example, the individual constrictions could be adapted to constitute a stage in gas/solid heat exchange process consisting of a mixing and a separation process, a combustion chamber, a gas/solid reactor, or a catalytic reactor. The constrictions may also be adapted to match different classes or types of particles, e.g. classes as defined by Geldart [D. Geldart, Types for Gas Fluidisation, *Powder Technology*, 7 (1973)] .

The solid particles and the gas may additionally be introduced and removed at different levels between the upper end of the shaft and the lower end of the shaft depending on the process, temperature etc. Thus depending on the actual process conditions several gas and particle inlets and outlets can be used to optimize the process thermally or chemically. In some cases it can also be advantageous to design the system such that the internal gas and particle streams in the apparatus bypass one or more stages.

Internal valve means may be arranged relative to the constrictions and inner wall of the shaft such that flow of the solid particles between adjacent chambers can be controlled, i.e. valves, loop seals or local fluidization may control the flow in the particle conduits.

The valve means may form part of the shaft or they may form part of the constrictions. Particularly, the internal valve means may be comprised in each separate module.

Depending on the desired interaction, the apparatus may comprise modules with different internal structure, e.g. relating to different processes selected from the group consisting of particle/gas heat exchange, drying, clinker formation, reactions including oxidation and reduction reactions, combustion, gasification, steam production, melting, granulation, condensation, absorption, adsorption, desorption, calcination, pyrolysis, sterilization, heat treatment or other processes of similar kind and combinations thereof.

The planar design of the constrictions and walls enables steam production or process cooling using simple planar heat transfer surfaces incorporated in the constrictions or wall of the apparatus.

To ensure an even distribution of both gas and particles over the entire available cross sectional area inside the apparatus, each module can be fitted with devices or guiding aids to ensure that the gas and particle streams are directed in the optimal direction. Thus the risk of gas and particles short circuiting a stage is minimized. This also makes it possible to operate only a part of the apparatus, as gas and particle streams are confined to the active area.

Particularly, it is an object to enable easy scaling of the apparatus. For that purpose, the apparatus may be delivered in the form of an assembly kit with components, e.g. planar panels, which can be assembled by use of pre-defined assembly elements to form a modular apparatus according to the invention.

In a second aspect, the invention provides an assembly kit for making an apparatus of the kind described above. The assembly kit comprises a plurality of modules adapted for being assembled with adjacent modules to form the apparatus.

In a third aspect, the invention provides the use of an apparatus according to any of the preceding claims for manufacturing cement or minerals.

In a fourth aspect, the invention provides a method of designing or making an apparatus of the kind described above. The method comprises the steps of:

- providing a number of predefined modules each having a predefined configuration, the configuration including a predefined shape, size, and purpose in the assembled apparatus;
- selecting a number of modules;
- selecting a position of each module relative to adjacent modules;
- assembling the modules to form a vertical hollow shaft with a vertical row of constrictions formed internally and defining a series of intercommunicating chambers in the shaft,
- providing at least one gas conduit and at least one solids conduit connecting adjacent chambers,
- providing means for introducing and removing the solid particles and gas into and out of the shaft,

Each of the predefined modules may be assigned an expected capacity contribution of that module when assembled to other modules, and an expected total capacity could be calculated from the expected capacity contribution of each module.

The method may further comprise the step of determining a desired total capacity for the apparatus and selecting predefined modules for the apparatus until the expected total capacity corresponds to the desired capacity.

The method may further comprise the step of providing predefined modules with different configuration.

The method may comprise the step of providing a predefined interface between the modules and adjacent modules.

Particularly, the modules may include any of the features mentioned relative to the first aspect of the invention, e.g. the 2-dimensinally shaped constrictions and the mirrored arrangement of identical constrictions etc.

The process conditions may be of such kind, that the introduced particles will melt during the physical and/or chemical interactions with the gas and/or a second a type of introduced particles. Thus the bottom stages can be designed to handle a liquid outlet.

The apparatus may contain access points, e.g. inspection manholes for access to the interior of the apparatus for cleaning, removal of deposits, repairs or inspection.

The method may comprise the step of introducing the solid particles into the particle inlet and introducing a gas which is hot relative to the solid particles into the gas inlet and providing interaction between the solid particles and gas within the chambers, e.g. such that the solid particles are melted during a physical and/or a chemical interaction with the gas and/or a second type particles which are introduced into the shaft.

BRIEF DESCRIPTION OF THE DRAWINGS

The invention will now be described by way of an example with reference to following figures in which:

Figs. 1 and 2 illustrate an apparatus according to the invention;

Fig. 3 illustrates a section along line II in Fig. 1;

Figs. 4 and 5 illustrate details of modular designs, particularly with regards to extension of the apparatus in the Z-direction due to the 2-dimensional shape of the constrictions;

Fig. 6 Illustrates a combustion and gasification module between two heat exchange modules;

Figs 7-12 illustrates different configurations of the apparatus and different shapes of the constrictions; and

Figs. 13-15 illustrate different valves for controlling flow out of the particle beds.

DETAILED DESCRIPTION OF EMBODIMENTS

Further scope of applicability of the present invention will become apparent from the following detailed description and specific examples. However, it should be understood that the detailed description and specific examples, while indicating preferred embodiments of the invention, are given by way of illustration only, since various changes and modifications within the scope of the invention will become apparent to those skilled in the art from this detailed description.

The module based process design approach also provides option for easy expansion of a existing module based process, as a new stack of modules similar to the existing can be constructed adjacent to the existing, thus reducing complexity of expansion process, reducing the time of refurbishing the existing process and reducing the overall complexity of the equipment, compared to expansions performed in the chemical industry today, where a new process is often designed and constructed independently from the existing design. Furthermore it is possible to stock different types of modules that can be combined for application in different kinds of systems.

Referring now to Figs. 1 and 2, an apparatus according to the invention comprises a vertical hollow shaft 16 with a vertical row of constrictions 9a, 9b, 9c, 9e formed internally and defining a series of intercommunicating chambers

10a, 10b, 10c, 10d in the shaft. The chambers are connected by gas conduits 8a, 8b, 8c, 8d each conducting a mix of gas and particles from one chamber to an adjacent chamber. The chambers are also connected by solids conduits 7a, 7b 7c, 7d which conduct solid particles from a particle bed 4a, 4b, 4c, 4d in one chamber to a chamber located below that particle bed.

The constrictions 9a, 9b, 9c′, 9e each have a shape which is defined in the illustrated 2-dimensinal plane drawing of Fig. 2. This means that the third dimension is merely a height of the illustrated constrictions without changing the shape. Herein this is termed a 2-dimensional shape. As illustrated, the 2-dimensional shape of all constrictions 9a, 9b, 9c′, 9e are defined in a vertical plane.

During use, cold particles are fed from a feed tank 1 or fed from a preceding process in a continuous process facility. The particles enter the shaft through the inlet means 2 which facilitate introduction of the solid particles into the shaft. From the inlet means 2, the particles move to a top particle bed 4a at the top stage. Hot process gas is introduced at the bottom of the system via the inlet 14 which constitutes the means for introducing the gas into the shaft.

The particles from the bottom of particle bed 4a are released via the solids conduit 7a and mixed with gas which flows in the chamber 10b located below the particle bed 4a. At the exit of the solids conduit 7a, the particles are caught and form a combined gas and particle flow in the gas conduit 8a. At this location, the gas and particles flow in the same direction.

The rate of the particles leaving the particle bed 4a is controlled by an internal valve means 5a which thereby forms a particle rate control device.

The process repeats it self from the top toward the bottom. In this process, the solid particles are transported from particle bed to particle bed in descending direction.

I.e. The heat exchange between the hot gas and the cold particles takes place in the gas conduits 8a, 8b, 8c, 8d. Each chamber comprises a particle separation section 6a, 6b, 6c, 6d. At this point, the particles are separated from the gas and at the top of the shaft, the gas exits the through the outlet means 3 supported by the fan 15. The particles separated from the gas falls to one of the particle beds 4a, 4b, 4c, 4d and via a particle bed, the particles are reintroduced into the gas stream below that particle bed.

The above described is taking place in all intermediate stages/modules.

At the bottom, two particles outlets 11 and 12 are located. The particles separated from the gas at 6d ends at the particle outlet 11 and is joined with the material from the secondary particle outlet 12 and transported to the calciner (not shown but indicated by numeral 13). The secondary particle outlet leads out all particles not caught by the gas at 7d.

As the particles are fed though the particle inlet 2 are cold and the process gas introduced at the gas inlet 14 is hot, gradual heating of the particles and cooling of the gas takes places as the particles travels down through the process.

Additional separation systems, e.g. comprising a cyclone, an electrostatic filter etc. can be applied on the gas outlet 3 before the fan 15 to thereby obtain a particle free gas. Such a cyclone or filter would be suitable if the gas that leaves the system contains too high load of particles for the induced draft fan 15.

Fig. 2 illustrates schematically the apparatus in a perspective view. In this view, it is illustrated that the outer walls of the shaft are made of modular panels 17. In the illustration only the two side walls 18, 19 are shown. The apparatus also comprises front and rear walls 20, 21 such that the shaft becomes closed between the top and bottom. The panels are essentially identical and they are assembled based on a need for a specific height, width or depth. By use of the panels, not only the constrictions but also the shaft becomes modular.

According to the invention, the constrictions are modular. That means that the number of constrictions, the size of the constrictions, and/or the distance between the constrictions can change but the constrictions have the same shape. Fig. 2 also illustrates how the size of the constrictions can be changeable by making the constrictions from panels 22, 23.

Fig. 3 illustrates that a section along line I-I in Fig. 1. In this view it is clear that the constriction can be scaled in the Z direction indicated by the arrow. Since the constrictions are 2-dimensional, the shape does not change when making this scaling, and the apparatus can be designed parametrically by specifying merely the length in the Z-direction.

Fig. 4 illustrates that the apparatus can be made from modules n-1, n, n+1 where each module comprises a number of wall panels 17 and a number of constrictions 24 which again could be made from a number of separate panels as illustrated in Fig. 2. In Fig. 5 it is illustrated how the modules can be arranged side-by-side to form different sizes of the apparatus in the depth, i.e. in the Z-direction. Again, due to the 2-dimensional shape, the Z-dimension does not change the shape of the constrictions and the scaling of the apparatus in the Z-dimension becomes easy to manage.

Fig. 6 illustrates details of a process where fuel and/or combustion air is injected through an inlet 25 in one of the wall panels. Generally, any one of the mentioned modules, panels or constrictions may comprise process relevant features not mentioned specifically herein, including injection or rejection openings for feeding or removing substances from the shaft, structures for providing a homogenous flow or for enhancing the interaction between the particles and gas. Level indicated with 26 is gas/solid heat exchange modules. And level indicated with 27 is a combustion/gasification module. Combustion takes place in chamber 28 and gasification takes place in the particle bed 29. The arrow 30 illustrates a fuel particle trajectory.

Figs. 7a, 7b, and 7c illustrate examples of different kinds of combustion modules incorporated in the bottom stage. Level indicated with 31 is gas/solid heat exchange modules. Heat exchange gas is provided in the inlet 32, Fluidisat ion air is provided in the inlet 33. A fluid bed module 34 with an air outlet 35 is formed in the bottom. A distribution ion plate 36 is provided in the bottom. The apparatus further comprises an overflow 37.

Referring to Fig. 7b, solid fuel and combustion air is provided at the inlet 38, particle outlet is provided at the outlet 39 and ash is removed from the bottom at 40. 41 is a grate firing module and grate firing takes place in the grate firing chamber 42. Heat exchange gas is provided at 43.

Numbering in Fig. 7b also applies in Fig. 7c. Herein 44 is a suspension firing module and suspension firing takes place in chamber 45.

Fig. 8a illustrates an apparatus with an intermediate gas inlet and outlet configuration. Fig. 8b illustrates an apparatus with several inlets for higher particle outlet temperature. Fig. 8c illustrates one way of configuring particle inlets and outlets.

In Figs. 8a, 8b and 8c, the following numbers apply. 46 is a particle inlet, 47 is a gas outlet, 48 is a gas inlet and 49 is a particle outlet.

Figs. 9-12 illustrate different shapes for horizontal constrictions. Numbers from Figs. 8a-8c apply.

Figs. 13-15 illustrate different internal valve structures for controlling a particle flow rate. Fig. 13 illustrates a loop seal-like control valve where 50 is an air supply for particle flow rate control. Fig. 14 illustrates a local fluidization control device, and Fig. 15 illustrates the same device with a mechanical control structure 51 which rotates about its centre of rotation 52.

EMBODIMENTS

Any of the below mentioned embodiments may apply:

Embodiment 1. An apparatus for conducting physical and/or chemical and/or biological interaction between gases and solid particles, the apparatus comprising a vertical hollow shaft having at least one gas inlet for introducing the gas into the shaft, at least one particle inlet for introducing the solid particles into the shaft, at least one gas outlet for removing the gas from the shaft, and at least one particle outlet for removing the solid particles from the shaft, the shaft forming inside a series of intercommunicating chambers separated by a plurality of constrictions such that at least one gas conduit and at least one solids conduit connect adjacent chambers, wherein the constrictions are modular.

I.e. the invention may generally relate to an apparatus which is modular, i.e. constructed and assembled from predefined modules

Embodiment 2. An apparatus according to embodiment 1, comprising constriction with a 2-dimensional shape.

Embodiment 3. An apparatus according to embodiment 1 or 2, comprising a plurality of identical constrictions.

Embodiment 4. An apparatus according to embodiment 3, where constrictions of a first series corresponds to constrictions of a second series being mirrored in a vertical plane extending centrally through the shaft.

Embodiment 5. An apparatus according to embodiment 4, wherein the constrictions of the first series are arranged between constrictions of the second series.

Embodiment 6. An apparatus according to any of the preceding embodiments, wherein the constrictions are releasably attached in a vertical row of modules in the shaft.

Embodiment 7. An apparatus according to any of the preceding embodiments, wherein the shaft has a quadrangular cross section perpendicular to a vertical axis.

Embodiment 8. An apparatus according to any of the preceding embodiments, wherein the means for introducing the solid particles into the shaft is adapted for introduction of the particles in an upper end of the shaft and the means for introducing the gas into the shaft is adapted for introduction in a lower end of the shaft.

Embodiment 9. An apparatus according to embodiment 8, wherein at least one of the means for introducing the solid particles and the gas into the shaft is adapted for introduction of the particles or gas in different levels between the upper end of the shaft and the lower end of the shaft.

Embodiment 10. An apparatus according to any of the preceding embodiments, where each chamber forms a particle bed in which the solid particles will accumulate as a result of flow conditions in the chamber, and where the chamber is designed such that the particle bed acts as a guard against short-circuiting gas streams.

Embodiment 11. An apparatus according to embodiment 10, wherein each solids conduit extends from the particle bed of one chamber to an adjacent chamber.

Embodiment 12. An apparatus according to any of embodiments 10-11, where each particle bed and corresponding solids conduit is shaped such that transport of particles from each particle bed to the adjacent chamber is facilitated and controlled by mechanic means, acoustic vibration or by application of pneumatic forces or a combination thereof.

Embodiment 13. An apparatus according to any of the preceding embodiments, where the constrictions and the hollow shaft are formed by individual components to enable reconfiguration with different numbers, sizes or shapes of constrictions or reconfiguration with different distances between adjacent constrictions.

ADDITIONAL EMBODIMENTS

The invention may further provide embodiments with any of the below numbered features or combinations thereof.

1. An apparatus comprising internal valve means arranged relative to the constrictions to control a flow of fine-grained solids between adjacent chambers.

2. An apparatus wherein the internal valve means is comprised in each separate module.

3. An apparatus comprising modules with different internal structure.

4. An apparatus wherein the difference in structure relates to different processes selected from the group consisting of particle/gas heat exchange, drying, clinker formation, reactions including oxidation and reduction reactions, combustion, gasification, steam production, melting, granulation, condensation, absorption, adsorption, desorption, calcination, pyrolysis, sterilization, heat treatment and combinations thereof.

5. An apparatus wherein the constrictions are constituted by planar plates or plates curved in only one plane.

6. An apparatus further comprising at least one additional stack of separate modules arranged vertically above each other whereby each module forms one chamber of the series of intercommunicating chambers or at least forms a part of one chamber of the series of intercommunicating chambers.

7. An apparatus further comprising wall elements comprising heat transfer surfaces which can be used for process cooling or steam production.

8. An apparatus further comprising particle distribution structures arranged internally in the shaft or arranged external to the shaft, the particle distribution structures improving particle distribution within the apparatus.

9. An apparatus where the hollow shaft is formed with at least one opening of a size allowing a person to enter into at least one of the chambers.

CLAIMS

1. An apparatus for conducting physical and/or chemical and/or biological interaction between gases and solid particles, the apparatus comprising a vertical hollow shaft having at least one gas inlet for introducing the gas into the shaft, at least one particle inlet for introducing the solid particles into the shaft, at least one gas outlet for removing the gas from the shaft, and at least one particle outlet for removing the solid particles from the shaft, the shaft forming inside a series of intercommunicating chambers separated by a plurality of constrictions such that at least one gas conduit and at least one solids conduit connect adjacent chambers, wherein at least one of the constrictions and the shaft comprises a number of predefined modules.

2. An apparatus according to claim 1, wherein modules are detachably fixed to adjacent modules.

3. An apparatus according to claim 1 or 2, wherein each predefined module has a predefined interface specifying connectivity to adjacent modules.

4. An apparatus according to claim 3, where the predefined interface comprises a horizontal interface adapted for joining the module with horizontally adjacent modules.

5. An apparatus according to claim 3 or 4, where the predefined interface comprises a vertical interface adapted for joining the module with vertically adjacent modules.

6. An apparatus according to any of the preceding claims, comprising blinding elements adapted to blind an interface of a module at locations where no adjacent modules are foreseen.

7. An apparatus according to any of the preceding claims, wherein each predefined module has a predefined shape, size and purpose.

8. An apparatus according to any of the preceding claims, comprising constriction with a 2-dimensional shape.

9. An apparatus according to any of the preceding claims, where constrictions of a first series corresponds to constrictions of a second series being mirrored in a vertical plane extending centrally through the shaft.

10. An apparatus according to claim 9, wherein the constrictions of the first series are arranged between constrictions of the second series.

11. An apparatus according to any of the preceding claims, where each chamber forms a particle bed in which the solid particles will accumulate as a result of flow conditions in the chamber, and where the chamber is designed such that the particle bed acts as a guard against short-circuiting gas streams.

12. An apparatus according to claim 11, where each particle bed and corresponding solids conduit are shaped such that transport of particles from each particle bed to the adjacent chamber is facilitated and controlled by mechanic means, acoustic vibration or by application of pneumatic forces or a combination thereof, the controlled mechanic means forming part of at least one of the modules.

13. An assembly kit for making an apparatus according to any of claims 1-12, the assembly kit comprising a plurality of modules adapted for being assembled with adjacent modules to form the apparatus.

14. Use of an apparatus according to any of the preceding claims in manufacturing of cement or minerals.

15. A method of designing or making an apparatus according to any of claim 12 comprising the steps of:

- providing a number of predefined modules each having a predefined configuration, the configuration including a predefined shape, size, and purpose in the assembled apparatus;

- selecting a number of modules;

- selecting a position of each module relative to adjacent modules;

- assembling the modules to form a vertical hollow shaft with a vertical row of constrictions formed internally and defining a series of intercommunicating chambers in the shaft;

- providing at least one gas conduit and at least one solids conduit connecting adjacent chambers; and

- providing means for introducing and removing the solid particles and gas into and out of the shaft.

16. A method according to claim 15, comprising the steps of:

- assigning to each of the predefined modules, an expected capacity contribution of that module when assembled to other modules;

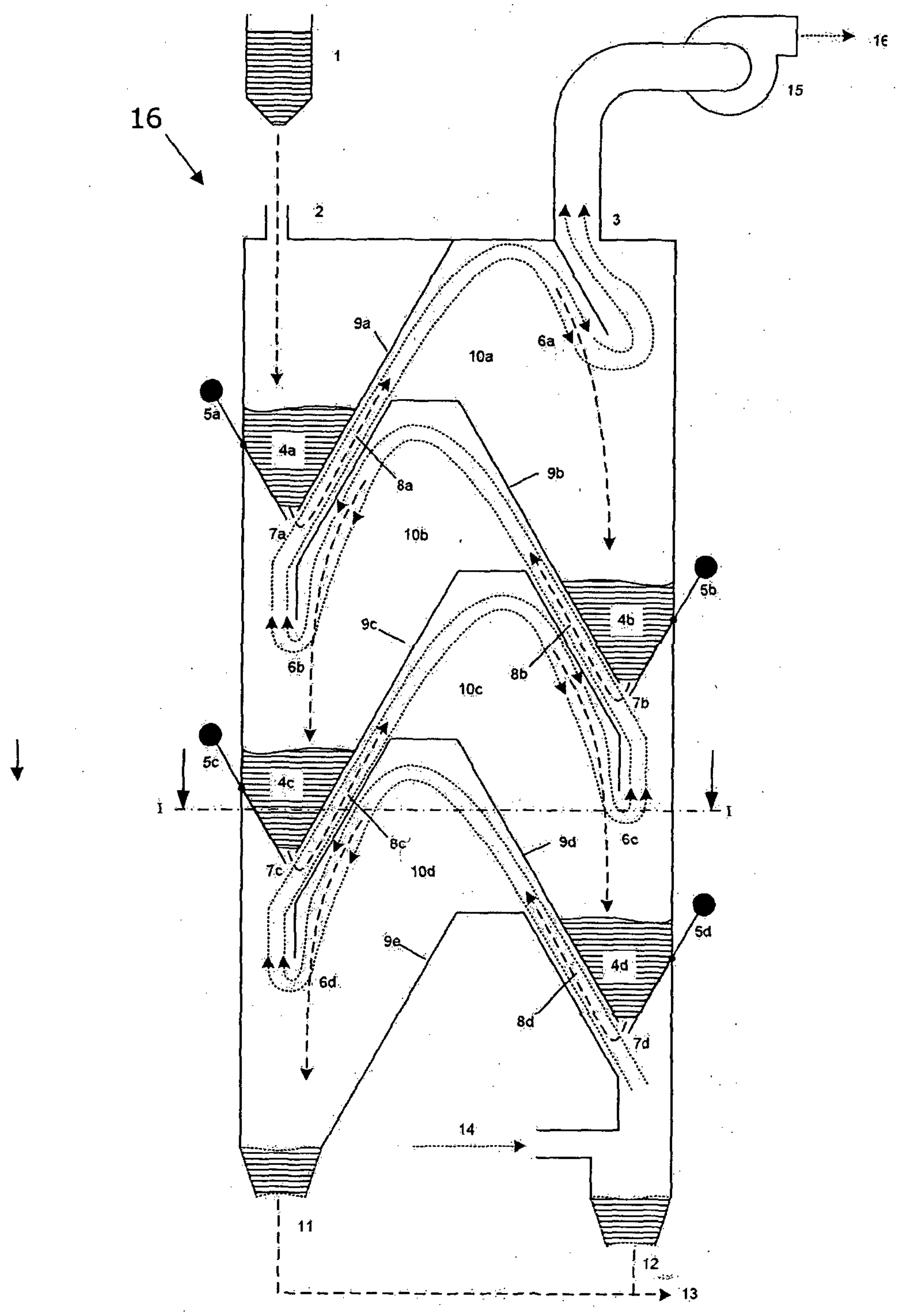
- calculating an expected total capacity from the expected capacity contribution of each module.

17. A method according to claim 16, comprising the step of determining a desired total capacity for the apparatus and selecting predefined modules for the apparatus until the expected total capacity corresponds to the desired capacity.

18. A method according to any of claims 15-17, where the step of providing predefined modules comprises providing modules with different configuration.

19. A method according to any of claims 15-18, where the step of providing predefined modules comprises providing a predefined interface between the modules and adjacent modules.

20. A method according to claim 19, where predefined interfaces are defined for a vertical configuration where the modules are positioned vertically over or under adjacent modules and/or for horizontal configuration where the modules are positioned horizontally next to adjacent modules.


16
1
2
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9a
6a
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6b
10c
8b
7b
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I
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8c
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12
13

Fig. 1

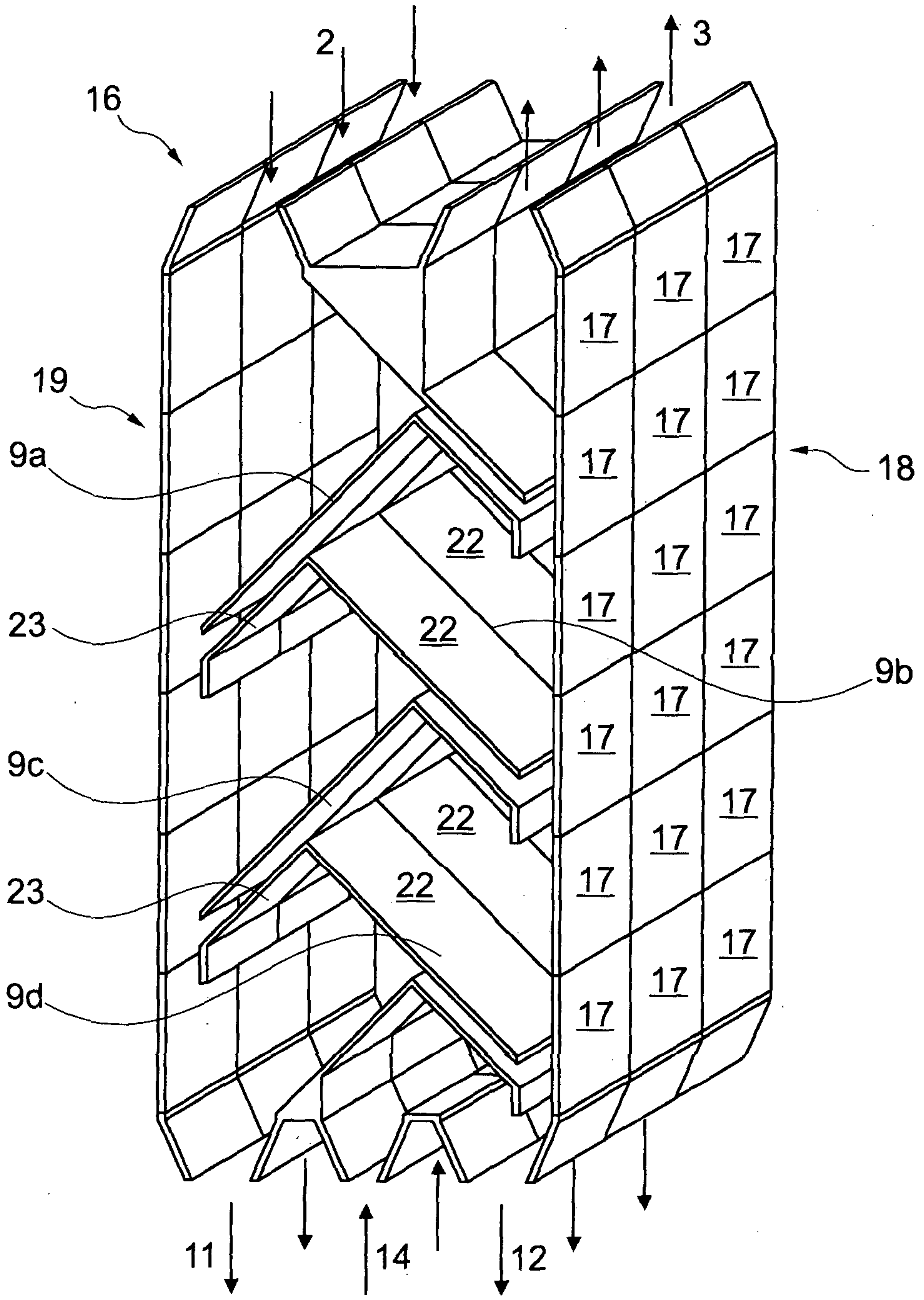

Fig. 2

Section I-I

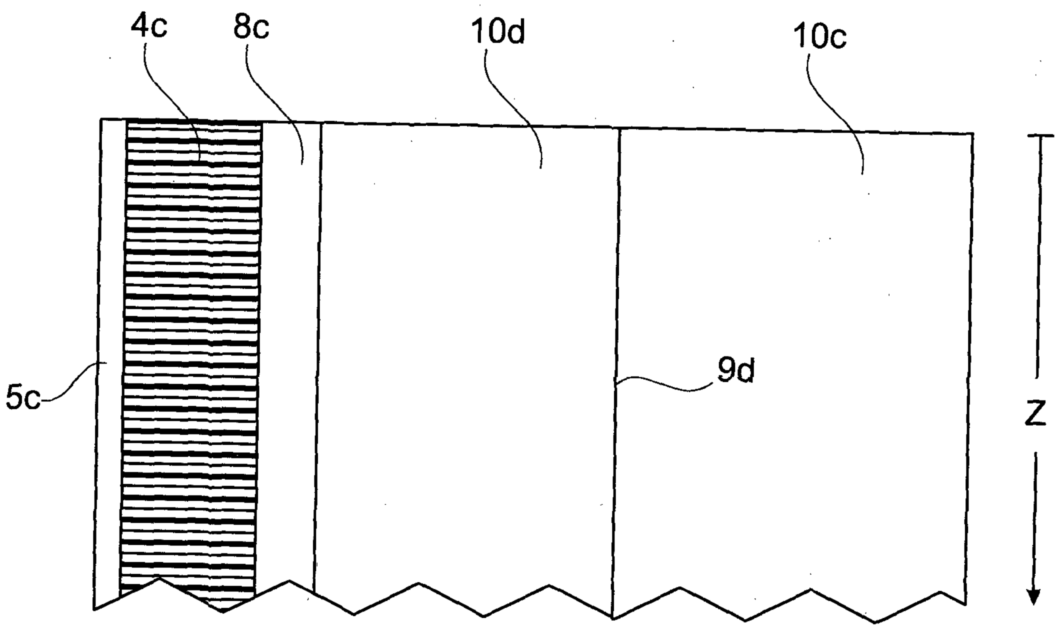

Fig. 3

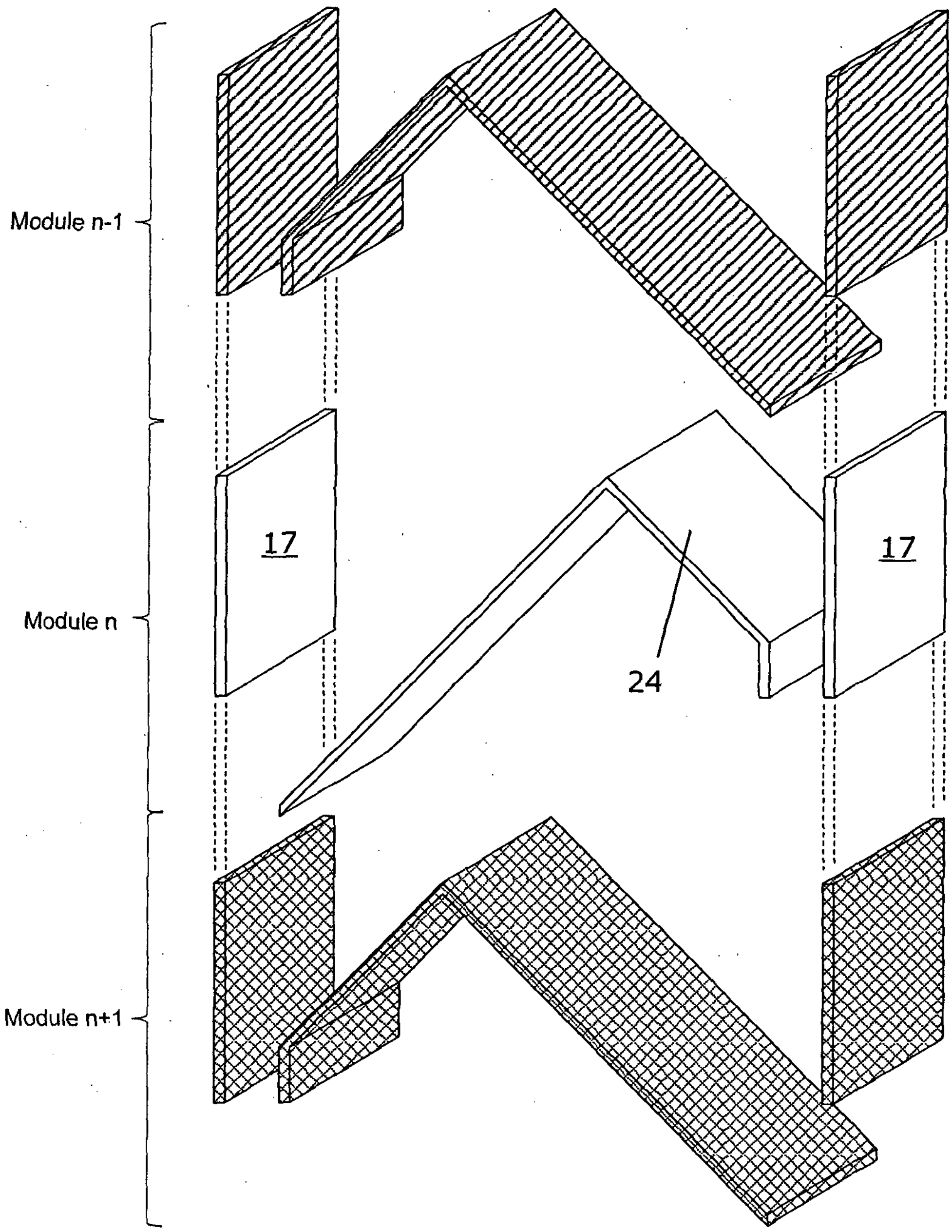

Fig. 4

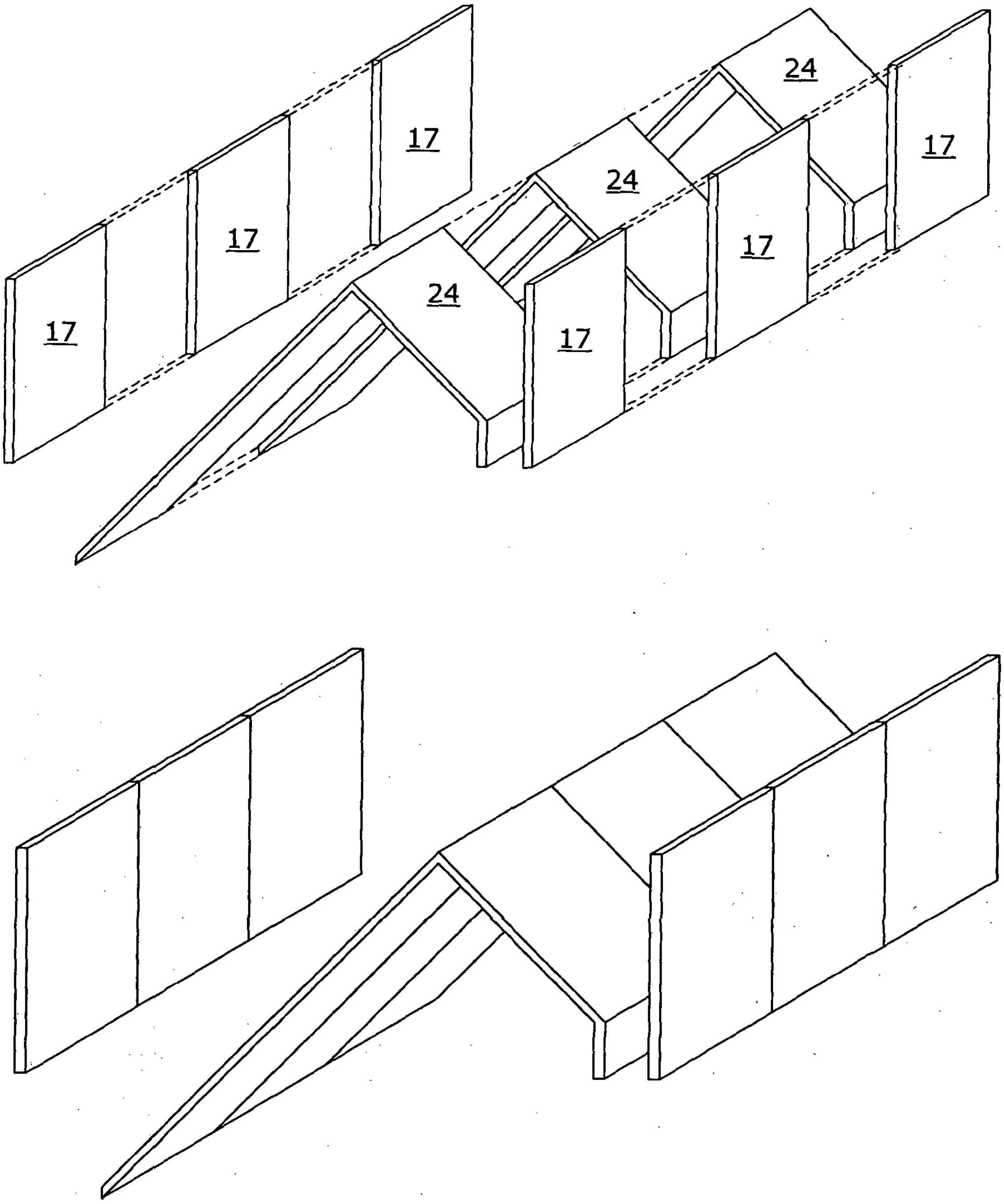

Fig. 5

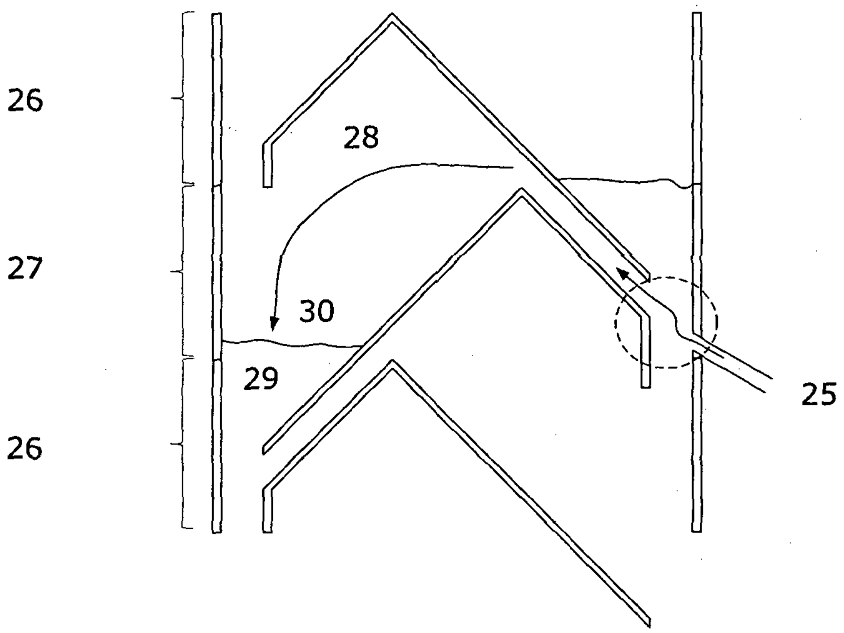

Fig. 6

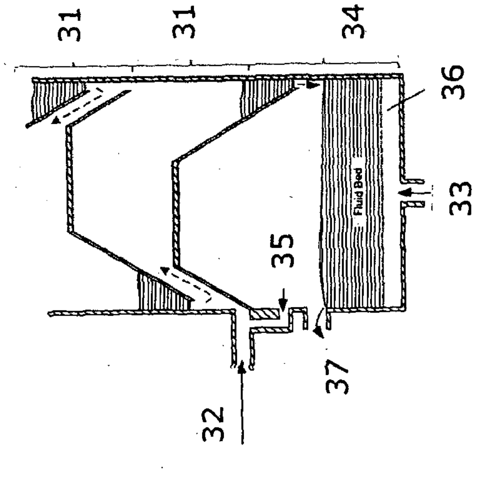

Fig. 7a

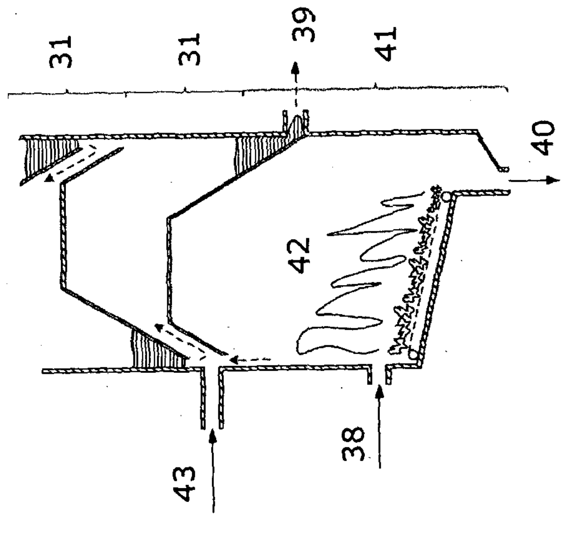

Fig. 7b

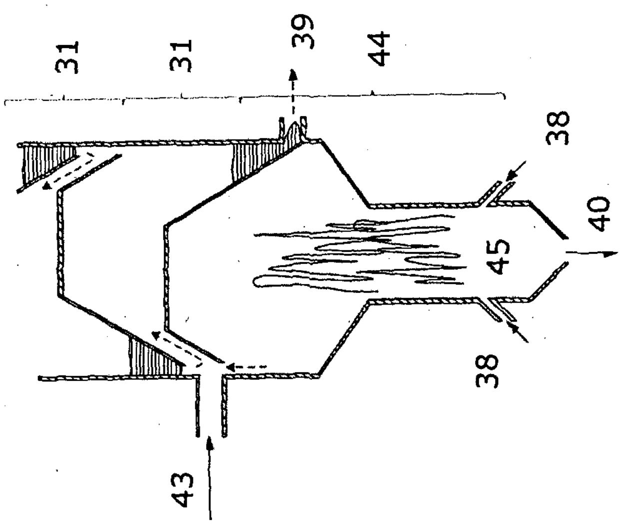

Fig. 7c

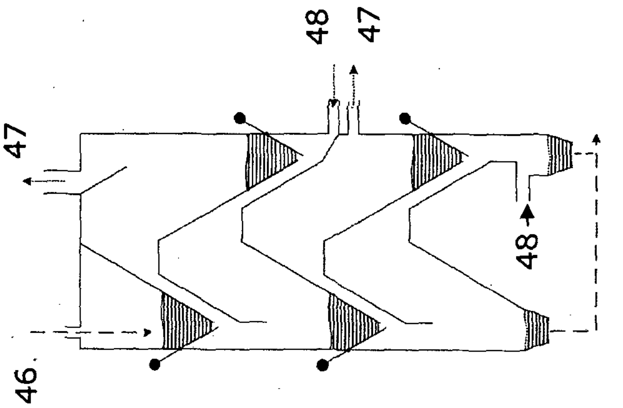

Fig. 8a

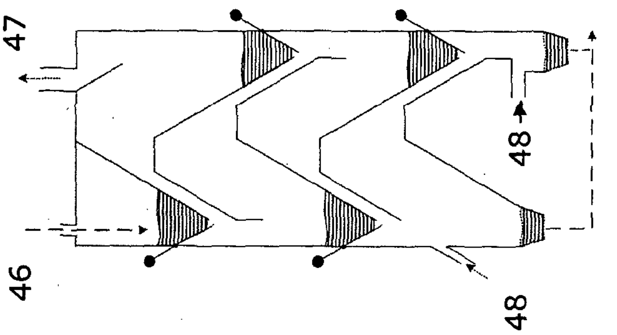

Fig. 8b

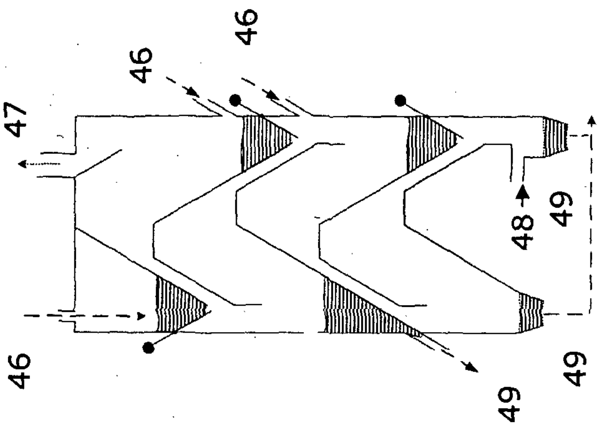

Fig. 8c

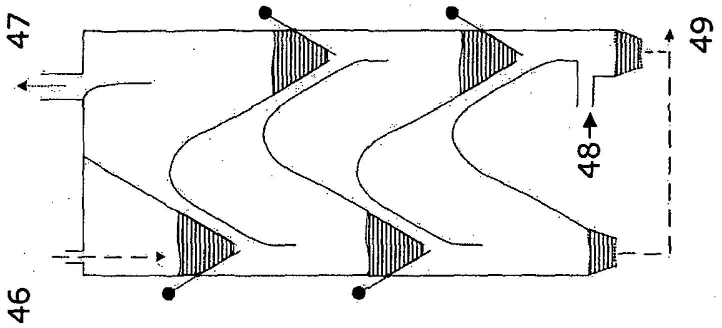

Fig. 12

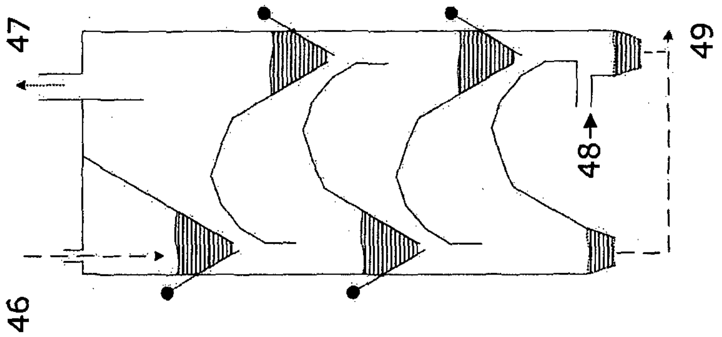

Fig. 11

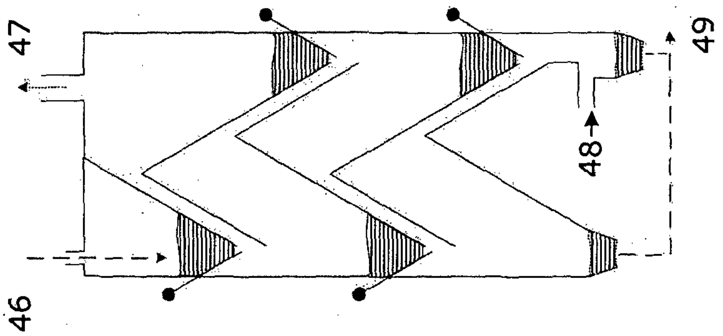

Fig. 10

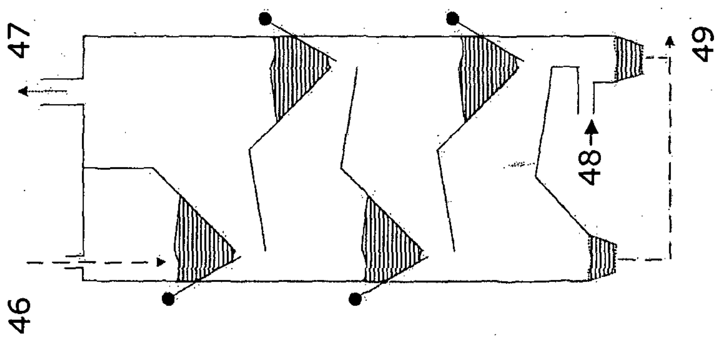

Fig. 9

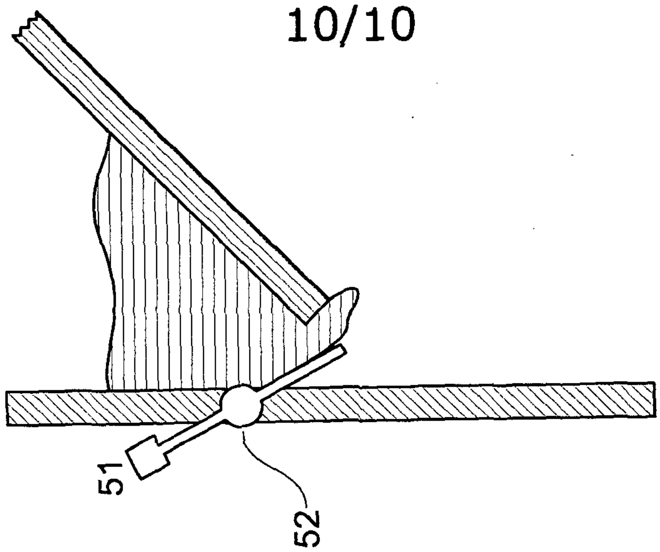

Fig. 15

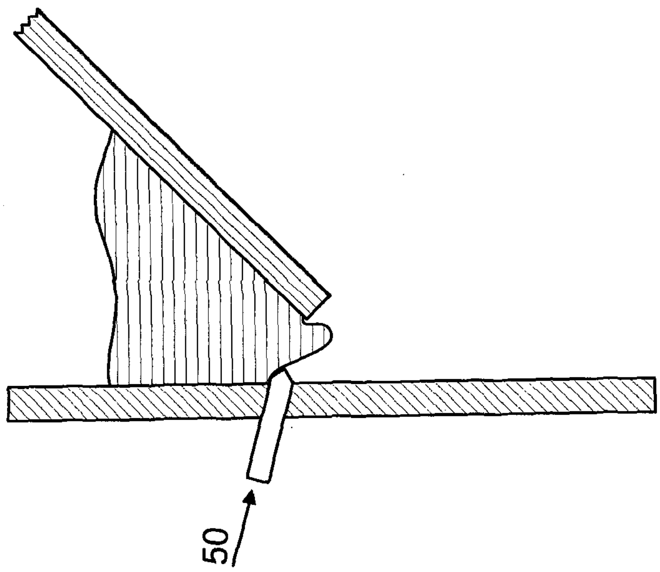

Fig. 14

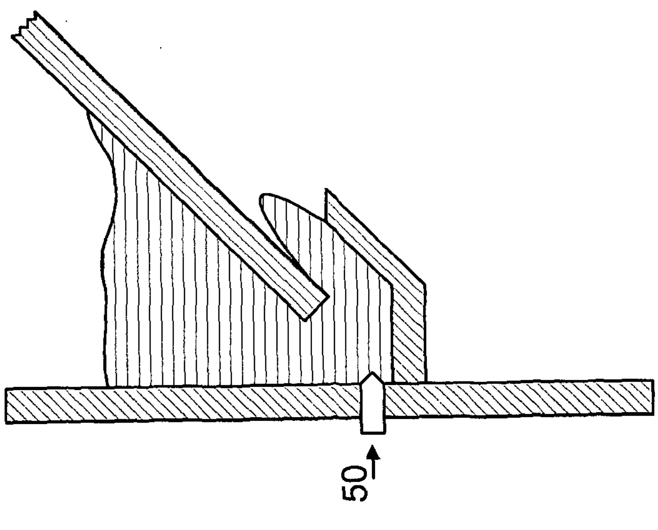

Fig. 13

INTERNATIONAL SEARCH REPORT

International application No.
PCT/EP2012/070262

Box No. II Observations where certain claims were found unsearchable (Continuation of item 2 of first sheet)

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. [X] Claims Nos.: 1-20(partially)
because they relate to subject matter not required to be searched by this Authority, namely:

see FURTHER INFORMATION sheet PCT/ISA/210

2. [ ] Claims Nos.:
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:

3. [ ] Claims Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box No. III Observations where unity of invention is lacking (Continuation of item 3 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

1. [ ] As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.

2. [ ] As all searchable claims could be searched without effort justifying an additional fees, this Authority did not invite payment of additional fees.

3. [ ] As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:

4. [ ] No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

Remark on Protest

[ ] The additional search fees were accompanied by the applicant's protest and, where applicable, the payment of a protest fee.

[ ] The additional search fees were accompanied by the applicant's protest but the applicable protest fee was not paid within the time limit specified in the invitation.

[ ] No protest accompanied the payment of additional search fees.

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2012/070262

A. CLASSIFICATION OF SUBJECT MATTER
INV. B01J8/12 F27B1/00 F27B7/20
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)
B01J F27B C04B

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

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 4 188 184 A (FORNONI LUIGI [BR]) 12 February 1980 (1980-02-12) column 3, line 61 - column 5, line 2; claims 15,20; figures 7,8,11	1-20
A	US 3 049 343 A (HERMANN HELMING BERND) 14 August 1962 (1962-08-14) column 2, line 35 - line 71; figure 1	1-20
A	US 4 547 151 A (TAKEDA HIRRO [JP]) 15 October 1985 (1985-10-15) column 3, line 31 - column 5, line 11; figure 1	1,15
A	FR 1 363 939 A (SMIDTH & CO AS F L) 19 June 1964 (1964-06-19) the whole document	1

☐ Further documents are listed in the continuation of Box C.

☒ See patent family annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
14 December 2012	02/01/2013

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Vlassis, Maria

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/EP2012/070262

Patent document cited in search report		Publication date	Patent family member(s)			Publication date
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			BR	7702321	A	24-10-1978
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			DE	2749605	A1	19-10-1978
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			JP	3080538	B	25-12-1991
			JP	59160531	A	11-09-1984
			US	4547151	A	15-10-1985
FR 1363939	A	19-06-1964	NONE			

FURTHER INFORMATION CONTINUED FROM PCT/ISA/ 210

Continuation of Box II.1

Claims Nos.: 1-20(partially)

The terms "module" appears in all independent claims and forms an essential technical feature of the invention. Its definition, as well as the definition of the closely related term "modular" are given on page 4, lines 15-19 of the description and reads as follows: " Herein "modular" refers to the feature that the apparatus comprises a number of predefined constrictions and/or shaft modules. The modules may be physical modules arranged against each other and being assembled rigidly to form an apparatus,or the modules may be design modules, i.e. virtual modules available for the designer of an apparatus . " (emphasis added) What becomes thus clear from this definition is that the term "module" also refers to something virtual which is thus a purely mental act. Since, no search is required under Art. 17(2)(a)(i) PCT in combination with Rule 39.1(iii) PCT for applications containing subject matter relating to the performance of purely mental acts, claims 1-20 were searched only in part, namely interpreting the "modules" to refer to a physical entity.