Title: CIRCULATING BED REACTOR

Abstract: A circulating fluidized bed reactor comprising a riser channel having a separation unit (5 - 9), arranged at its upper part, for separating solid matter from fluidizing gas. The separation unit consists of a multi-inlet cyclone, which comprises a set of control vanes (5) for directing the gas against the wall of a separation chamber to pre-separate the solid matter and to provide a rotating flow, a separation chamber (6) to separate any particles that remain in the gas after the pre-separation by means of a centrifugal force, a discharge assembly (7) to remove the gas and solid matter of the recycling channel (9), which is connected to the separation chamber, from the cyclone chamber (6). According to the invention, the set of control vanes (5), the return channel (9) and the gas discharge assembly (7) of the multi-inlet cyclone are arranged symmetrically around the riser channel (4), and the cyclone chamber (6) and the discharge assembly (7) are placed coaxially above the set of control vanes (5). The invention provides a symmetrical structure, wherein any stresses caused by horizontal thermal expansion are minimized and wherein the riser channel is allowed to freely expand in the vertical direction differently from the jacket.
— before the expiration of the time limit for amending the claims and to be republished in the event of receipt of amendments.

For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.
CIRCULATING BED REACTOR

The present invention relates to a circulating fluidized bed reactor according to the preamble of Claim 1.

Generally, such a reactor comprises an elongated riser channel that has at least an essentially vertical central axis. The riser channel comprises a lower part, to which the feed assemblies and discharge assemblies of gas and solid matter are connected, through which the solid matter and fluidizing gas can be fed into and removed from the riser channel. The upper part of the riser channel, in turn, comprises a separation unit for separating solids from the fluidizing gas. In that case, the separation unit consists of a multi-inlet cyclone that comprises a separation chamber and a set of control vanes for directing solids-containing gas against the wall of the separation chamber and for imparting a rotary motion thereto. The gas, which is at least essentially free of solids and which is obtained from the separation chamber, is discharged from the cyclone through a discharge channel and the separated solids, in turn, are discharged through a return channel.

The type of a reactor described above, known as a circulating fluidized bed reactor (also referred to as a CFB reactor below) can be used both as a combustion reactor, gasifier, chemical reactor, wherein a solid catalyst circulates, and as a dryer. As an example of a commercial implementation, the so-called CYMIC boiler of Tampella should be mentioned. The said structure is characterized in that a cooled multi-inlet cyclone and the return channel are fitted inside coaxially with the riser channel. The problems with this structure include that the cyclone is narrow with respect to its flow technology and, furthermore, it disturbs the flow and the mixing in the riser channel. Furthermore, the structure is fairly expensive, when cooled. The cone that connects the cyclone chamber and the return leg is difficult to manufacture, in particular, if it must be made as a cooled structure.

Finnish Patent No. 106242 discloses an improved CFB reactor structure, wherein a multi-inlet cyclone and a return channel are fitted annularly around the riser channel. The most important advantages of this known solution, compared with all types of CFB reactors known so far is that it eliminates the previous limitation, according to which the relation of height to diameter, in practice, should be essentially higher than 1. In the device according
to Patent 106242, the said ratio can be 1 or lower, even as low as 0.5 – 0.95. The structure presented in Patent 106242 is well-suited for use at low temperatures in particular.

However, the said structure has some disadvantages regarding its use in applications requiring high temperatures and a high separating efficiency in particular. These disadvantages are mainly due to the discharge assembly of the cyclone being fitted annularly around the riser channel. Implementing, as a cooled structure, the discharge channel that is built around the riser channel will inevitably result in a complex and expensive structure. Because of wear, the cooled central tube should be protected, whereby the structure would be heavy, space-consuming and expensive. Especially in small units the discharge assemblies of cyclones that are cooled will be very clumsy because of the thick walls. The repair of such a structure in the event of a failure is difficult and expensive. Clogging of the complex set of channels can also constitute a problem. In large devices, gas removal from the annular central duct requires several discharge assemblies, after which the gas flows should be recombined to form one flow. To avoid problems with thermal expansion, these assemblies should also be realized as cooled structures, whereby their structure will also be expensive, clumsy and difficult to repair. Furthermore, the diameter of the discharge channel fitted around the riser channel becomes too large, which considerably limits the separating efficiency of the separator.

The purpose of the present invention is to overcome the above problems and to provide quite a new kind of a circulating fluidized bed reactor, which is more suitable for implementation also as a cooled structure, which is simpler in construction and better in performance.

The invention is based on an improvement of the structure disclosed in Patent No. 106242, so that the annular cyclone that is fitted around the riser channel is replaced by a cylindrical cyclone, which is located above the inflow vane unit. In the structure according to the invention, the vertical axis of the cyclone is thus inverted, compared with the one presented in Patent 106242.

More specifically, the reactor according to the invention is mainly characterized by what is stated in the characterizing part of Claim 1.
The use according to the invention is characterized by what is stated in Claim 9.

The invention provides considerable advantages in terms of its structure and performance. Regarding the thermal expansion, the structure according to the invention is an essential improvement over the invention of Patent 106242, because the riser channel is allowed to freely expand through heat in the vertical direction. This is of great importance in combustion or gasification reactors, for example, as the thermal expansion of the riser channel and the jacket, generally, is then different. In addition, the vane unit can be made easy to replace, because its connection with the riser channel does not need to be gas-tight. As the vane unit is the part of the device that wears the most, its easy replacing is a considerable advantage. Generally, in the structure of Patent 106242, even in fairly small units, it is necessary to discharge the gas from the central tube through several assemblies and again recombine the gas flows into one flow. In the structure according to the invention, gas removal from the cyclone is carried out in as simple a manner as possible.

In addition to the above-mentioned structural advantages, the structure according to the invention provides an essential improvement in the cyclone's separating efficiency with respect to the invention of Patent 106242, as the diameter of the discharge channel can be made small and the flow disturbances, which are characteristic to thick suspension flows, can't penetrate into the discharge channel. In rotating flows, the circumferential velocity increases with the radius of gyration decreasing, whereby the centrifugal acceleration in a low-frictional flow grows inversely proportionally to the third power of the radius of gyration. In the structure according to the invention, the said fluid dynamic phenomena can be fully exploited, but in the solution of Patent 106242 to a minor degree only.

Another significant functional advantage, compared with the solution according to Patent 106242, is that the flow disturbances, which are characteristic to flows with high particle-content, can't convey the particles into the discharge channel to reduce the separating efficiency. For the above-mentioned reasons, the separating efficiency of the cyclone of the structure according to the invention grows considerably, compared with that of the cyclone of Patent 106242. The pressure drop of the gas in the cyclone according to the invention is also lower than in the cyclone according to Patent 106242 due to the simpler gas discharge channel, among others.
Compared with the CYMIC reactor of Tampella, for example, the structure according to the present invention offers a better separation of gas and solids, as the flow into the cyclone chamber in the structure according to the invention takes place in the radial direction, whereby as much as 98% of the solids are separated already as the gas and the particles impinge on the wall of the cyclone chamber, and fall as a return flow into the annular return channel outside the riser. After an effective pre-separation, the dust content of the gas that must be cleaned in the actual cyclone is minor, enhancing the cyclone performance and reducing its wear. In the CYMIC solution, the inflow of gas and the circulating agent takes place from the wall of the cyclone towards the centre, whereby no pre-separation takes place. Other disadvantages of the CYMIC solution include the fact that the cyclone that is fitted inside the riser channel is narrow; it is subject to erosion and corrosion and impedes the mixing of gas that is of importance for the combustion. The ratio of the diameter of the inflow vane unit to the central tube diameter in CYMIC remains small; therefore, the separation efficiency of the cyclone is insufficient for many purposes. Compared with CYMIC, one advantage of the structure presented in this invention is also the fact that the up-flow in the return channel, which disturbs the separation efficiency, is reduced and the upward flows in the return channel can't convey particles into the gas outlet.

For the above reasons, the structure presented herein provides essential functional and structural improvements over the structure presented in the Finnish Patent 106242, as well as over the CYMIC solution patented by Tampella. The functional advantages both in cooled and uncooled structures are considerable. The structural improvements are especially considerable in applications that require cooling but, also in any uncooled structures, the structure according to the invention provides a simpler, cheaper structure that requires less maintenance and is easier to repair.

It should be emphasized that, since the discharge assembly is placed coaxially above the control vanes, the diameter of the discharge assembly can have an optimal dimension for the ratio of separation, and no unwanted flows of the return channel can penetrate to the discharge assembly. Furthermore, the cyclone’s pressure drop loads the return channel as little as possible.
The circulating fluidized bed reactor according to the invention can be used, among others, in a way known per se as a combustion reactor, gasifier or chemical reactor, wherein a fixed catalyst circulates, or as a dryer. It is used as a cooled structure in particular.

In the following, the invention is examined by means of a detailed specification with reference to the appended drawing.

Fig. 1 is a vertical cross section of the structure in principle of the CFB reactor according to the invention, and

Fig. 2 shows a horizontal section of the reactor according to Fig. 1 along the plane A-A. The CFB reactor according to the invention mainly consists of three parts I – III, namely

I. An elongated riser channel or a riser 4, its central axis being arranged essentially in the vertical direction,

II. Feeding equipment 1, 2, 3 and 11 of gas and solids at the lower end of the riser channel, and

III. Separation equipment 5 – 10 of solids and gas at the upper end of the riser channel, respectively.

The device can further be provided with

IV. Feeding and discharge equipment 12, 13 of the cooling fluid, which is needed to cool the riser channel.

The basic structure of the device is shown in Fig. 1, wherein the reference number 1 refers to an inlet assembly of fluidizing gas, which is connected to a distribution chamber 2, which is used to distribute the flow evenly over the cross section of the riser 4 to provide an upward flow. In that case, solid matter can be fed into the flow of fluidizing gas through a feeding assembly 11. The feeding assembly of solid matter is suitably arranged on the wall of the pipe that defines the riser so that it opens inside the riser channel slightly above the distribution chamber 2.

The riser 4 can have a desired cross section perpendicularly to its longitudinal axis. It may have a circular or polygonal cross section. Polygons, such as quadrangle, pentagon, hexagon, heptagon and octagon, in particular, should be mentioned. The advantage of the polygonal cross sections over the circular is that they can be manufactured of plane panels.
The riser can also consist of several pipes with round or polygonal cross sections, which are placed side by side. The riser channel is preferably arranged coaxially inside the reactor housing, whereby a return channel 9 for solid matter is formed between the outer jacket of the riser channel and the inner jacket of the reactor housing.

Fig. 2 shows the cross section of the riser channel along the plane A-A. In this case, the riser channel has a cross section of a hexagonal shape. As shown in Figs. 1 and 2, a multi-inlet cyclone 5 – 10 is arranged in connection with the upper end of the riser, its structure being symmetric in the direction of the plane of the central axis of the riser.

The cyclone has inlet assemblies 5, which are arranged on the wall of the riser channel in a completely symmetric fashion. The section A-A shows an embodiment of the inlet assemblies of the cyclone, wherein there is one inlet assembly of the cyclone fitted on each plane surface of the hexagonal riser channel. Such a structure is advantageous, when the riser is also to be cooled. Un-cooled structures are preferably implemented as round plate structures.

The wall of the cyclone chamber 6 forms the upper part 14 of the reactor housing, which is connected to the recycling channel 9 by a collar portion 8. The cyclone chamber 6 extends from the level of the inlet assemblies 5 in the direction of the longitudinal axis of the riser upwards and past the upper end of the riser channel. The cross section of the cyclone chamber 6 is preferably shaped as a circle also in a case where the recycling channel 9 is a polygon because of its manufacturing technology. The ratio of the distance between the lower edge of the cyclone’s central duct 7 and the upper end of the riser channel to the diameter of the central duct is at least 0.2, preferably over 1.0 (e.g., about 1.1 – 10). At the upper end of the cyclone chamber, at least essentially coaxially with the central axis of the riser channel, there is a gas discharge assembly 7, which is connected to a discharge duct (not shown). The extension of the collar portion 8 at the lower part of the cyclone chamber constitutes the lower part of the wall of the return channel 9. At the discharge end of the recycling channel, there is a return assembly 10 of solid matter, through which the separated solids can be returned to the riser. Generally, the return assembly 10 is located on a higher level than the feeding assembly 11 in the direction of the longitudinal axis of the riser channel.
According to the invention, the inlet assemblies 5 of the cyclone are preferably placed fully symmetrically with respect to the gas discharge assembly, which is fitted in the middle next to the axis of the riser, respectively. In this way, as disturbance-free a circulating motion as possible is achieved in the cyclone chamber between gas and solids.

To cool it, the riser 4 can be provided with an inlet assembly 12 for a cooling flow and a discharge assembly 13 for the cooling flow according to Fig. 1. According to a preferred application, the cooling medium can be directed symmetrically to the walls of the riser channel and out of the walls of the cyclone chamber through a discharge assembly that is arranged symmetrically.

According to the invention, fluidizing gas, such as air, is fed into the distribution chamber 2 through the inlet assembly 1. From the distribution chamber, the fluidizing gas is taken to the lower part of the riser channel 4, wherein the gas and the fluidized particles mix. Along with the gas, a major part of the fluidized particles drifts to the riser channel 4 and further to the inlet assemblies 5 that are fitted on the periphery of the upper part of the riser channel. The inlet assemblies 5 direct the flow so that the gas and the particles move in a rotary motion towards the wall of the cyclone chamber 6, the major part of the particles separating upon impinging on the wall. The centrifugal acceleration induced by the turbulence drives any particles, which are still left in the gas after the collision, to the wall of the cyclone chamber 6, from where they fall into the collar portion 8 under the influence of gravitation, while the gas continues to the central tube 7 that is preferably fitted above the riser channel 4 coaxially. From the collar portion 8, the particles fall into the recycling channel 9 and are returned from the lower part thereof through the assemblies 10 to the lower part of the riser channel 4. The part of solids, which does not rise with the gas, is removed through the assembly 3.

When the control vanes (5) direct the gas towards the wall of the separation chamber, pre-separation of solid matter takes place and a rotating flow is generated. In the separation chamber (6), in turn, the particles that were left after the pre-separation of gas are separated by means of centrifugal force.

The invention provides the following functional advantages, among others.
1. The separation efficiency of the cyclone can be maximized, as the centrifugal acceleration exerted on the particles almost inversely proportionally grows to the third power of the diameter of the central tube.

2. A sufficient separation power is achieved by lower inlet velocity than in the Finnish Patent 105242, whereby the wear of the structures decreases.

3. The rising flows in the recycling channel 9 cannot advance up to the discharge assembly 7 of the cyclone, as the return channel and the discharge assembly of the cyclone are located on different sides of the inlet assemblies 5 of the cyclone.

4. The ratio of the diameter of the inflow vanes and the discharge tube can be made large without increasing the pressure difference across the recycling channel that increases the upward flows in the return channel.

The said functional advantages have been verified both by calculated examinations and model tests. In the comparing tests that were carried out using corresponding performance characteristics and main measurements, the solid matter loss of the discharge gas of the new structure was 7 g/h only, while in an otherwise perfectly similar test conditions with the equipment according the FI Patent 106242, it was 350 g/h. The effect of the diameter of the central tube on the penetration was verified by means of larger testing equipment; wherein, when the diameter of the central duct was changed from 168 mm to 100 mm, the loss of sand was reduced from 1670 g/h to 3.9 g/h. In both tests, the solid matter used was sand with a particle size of within a range of 0.1 – 0.5mm. A higher concentration of fine fractions in the reactor often results in several considerable advantages, of which the following examples should be mentioned:

1. Finer-grained fluidized material can be used, whereby the wear of the structures is reduced.

2. As the suspension of particles and the circulation of solid matter can be maintained at a lower gas velocity, the turndown ratio of the plant increases.

3. In many cases, the cyclone of the circulation gas line can be avoided.

4. Power consumption is reduced in applications, wherein the fluidizing gas flow is defined by the minimum fluidization.

5. In the combustion of solids, the combustion efficiency increases, because unburned carbon is more effectively recycled to the riser.

6. The use of powder sorbents and catalysts is enhanced.
7. Dust flow from the reactor is reduced, whereby the need for dust removal from the heat surfaces of a boiler and the particulate load of the dust separator decrease.

As a summary, it can be stated that using the modification of this invention, minor as such, significant functional and structural advantages are obtained, compared with the solution, which is known from the Finnish Patent 106242.
Claims:

1. A circulating fluidized bed reactor, comprising
   – an elongated riser channel (4) having at least essentially vertical central axis and a
     lower part and an upper part, whereby solid matter and fluidizing gas can be fed
     into the riser channel through the lower part, and
   – a separation unit (5 – 9) arranged in the upper part of the riser channel for separating
     the solid matter from the fluidizing gas, the separation unit consisting of a
     multi-inlet cyclone that comprises
     - a set of control vanes (5),
     - a separation chamber (6) in connection with the control vanes, and
     - a recycling channel (9) connected to the separation chamber for recycling
       the solid matter, and a discharge assembly (7) for removing the gases from
       the separation chamber,
   characterized in that
     - the multi-inlet set of control vanes (5), the recycling channel (9) and the gas
       discharge assembly (7) are arranged symmetrically around the riser channel,
     and
     - the cyclone chamber (6) and the gas discharge assembly (7) are located
       above the set of control vanes (5).

2. A circulating fluidized bed reactor according to Claim 1, characterized in that the discharge assembly (7) is arranged coaxially with the riser chamber.

3. A circulating fluidized bed reactor according to Claim 1 or 2, characterized in that a feeding assembly (12) and a discharge assembly (13) for the cooling medium are arranged in the riser channel.

4. A circulating fluidized bed reactor according to Claim 3, characterized in that the walls of the riser channel (4), the recycling channel (9) and the cyclone chamber (6) consist of planar, cooled tubular panels.

5. A circulating fluidized bed reactor according to any of the preceding claims,
characterized in that the return channel (9) of the multi-inlet cyclone is connected, at its lower end, through the return assembly (10) of solid matter, to the riser channel (4) to recycle the solid matter.

6. A circulating fluidized bed reactor according to Claim 5, characterized in that the recycling channel (9) of solid matter consists of several parallel channels.

7. A circulating fluidized bed reactor according to Claim 6, characterized in that some of the parallel channels of the return channel (9) contain heat transfer surfaces.

8. A circulating fluidized bed reactor according to any of the preceding claims, characterized in a cylindrical cyclone (6), which is at least mainly located above the set of control vanes (5).

9. The use of the circulating fluidized bed reactor according to any of the preceding claims as a steam boiler, gasifier, chemical reactor, wherein a solid catalyst circulates, or as a dryer.

10. The use according to Claim 9, characterized in that the reactor is used as a cooled structure.
INTERNATIONAL SEARCH REPORT

A. CLASSIFICATION OF SUBJECT MATTER

IPC7: B01J 8/18, B01J 8/38
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)

IPC7: B01J

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

SE, DK, FI, NO classes as above

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

EPO-INTERNAL, WPI DATA, PAJ

C. DOCUMENTS CONSIDERED TO BE RELEVANT

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[X] Further documents are listed in the continuation of Box C.  [X] See patent family annex.

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Date of the actual completion of the international search: 18 March 2005

Date of mailing of the international search report: 21-03-2005

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