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Topsøes Alle 1, DK-2800 Kgs. Lyngby (DK).(72) Inventor: ZAKKAM, Vinod Arun Kumar; Buddinge
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(54) Title: A PSEUDO-ISOTHERMAL REACTOR

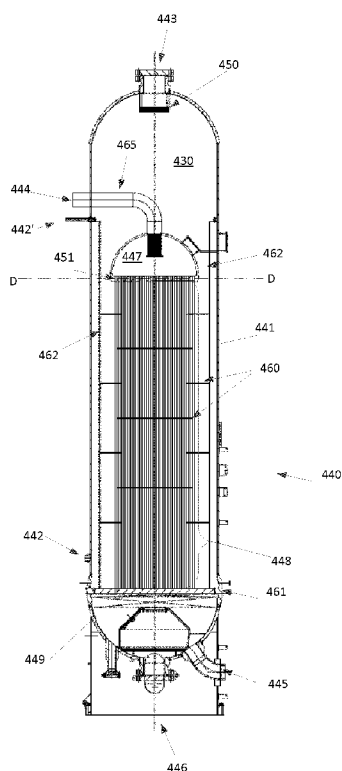


Fig. 5a

(57) Abstract: The invention relates to a pseudo-isothermal reactor for an exothermal reaction. The reactor comprises a reactor shell having at least one cooling medium inlet and at least one cooling medium outlet and the reactor shell is arranged to hold a cooling medium under pressure. The reactor shell comprises a reactant inlet and a product outlet, and the pseudo-isothermal reactor further comprises a reaction enclosure embedded within said reactor shell, the reaction enclosure comprising a reaction zone comprising a plurality of reaction tubes, an inlet manifold extending between said reactant inlet and said reaction zone, and an outlet manifold extending between said reaction zone and said product outlet. The reactor further comprises a first tube sheet between the reaction zone and the outlet manifold. The cooling medium is arranged to flow around the reaction enclosure along the part of said reaction enclosure extending from said reactant inlet to said first tube sheet, so that this part is in thermal contact with the cooling medium through walls of the reaction enclosure between said reactant inlet and the first tube sheet.



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Title: A pseudo-isothermal reactor

FIELD OF THE INVENTION

5 Embodiments of the invention generally relate to a pseudo-isothermal reactor for an exothermal reaction or to an exothermal process in a pseudo-isothermal reactor.

BACKGROUND

10

In exothermal processes a pseudo-isothermal reactor is often a relevant option, since such a reactor may have the benefit of providing optimal reaction conditions by providing a substantially constant cooling medium temperature.

15

This is favorable where the process is limited by an exothermal equilibrium reaction in which equilibrium favors products at low temperature.

20

The typical design of a pseudo-isothermal reactor involves a multitude of tubes inside a reactor shell. A confined part of the reactor shell is filled with a cooling medium under pressure. Often water is used as cooling medium, but other cooling media than water may also be used if the boiling point is appropriate. The pressure of the confined part of the reactor shell controls the boiling point of the cooling medium, which then, if operating at the boiling point, may act as a heat sink with substantially constant temperature, to the extent that liquid cooling medium is present in the reactor. The cooling medium is provided to the reactor shell from an external cooling medium container, such as e.g. a steam drum.

30

Pseudo-isothermal reactors are relatively complex and expensive pieces of equipment, due to the need for materials and work related to providing an external cooling medium container, piping or tubes between the cooling medium container and the reactor, multiple inlets and outlets and relatively large exterior surfaces, as well as the operation of the cooling medium at elevated pressure.

Common chemical processes where pseudo-isothermal reactors are of interest include methane, methanol and formaldehyde production from synthesis gas, i.e. a gas comprising hydrogen and carbon oxides and possibly other constituents. The synthesis gas may originate from a variety of sources, including gasification of carbonaceous materials, such as coal, (typically heavy) hydrocarbons, solid waste and biomass, from reforming of hydrocarbons, from coke oven waste gas, from biogas or from combination of streams rich in carbon oxides and hydrogen - e.g. of electrolytic origin. Methane and methanol production are limited by an equilibrium involving a condensable component and for formaldehyde production it is desired to maintain the methanol concentration low due to considerations of explosion limits and catalyst stability, a.o.

In the following, a fluid (e.g. a fluid reactant or a fluid product) shall be construed as comprising both gases and liquids.

In the following, the term isothermal reactor shall be construed as covering a cooled reactor with substantially constant cooling medium temperature considering the reactor length and time, but with some variation on the process

side. The term is interchanged with pseudo isothermal reactor, a boiling liquid cooled reactor or a boiling water reactor, even though the practical implementation in the form of boiling liquid reactor may not be fully and ideally isothermal with a constant temperature throughout the reactor at all times. However the cooling with boiling liquid provides a significant reduction in temperature variation as a function of time and position, compared to adiabatic reactors or reactors with interbed steam cooling.

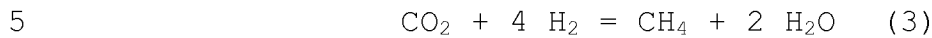
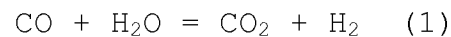
In the following, a section of the reactor is called reaction enclosure. However this shall not necessarily be construed as implying that a reaction takes place, since a reaction enclosure may simply have the function of a heat exchanger.

In the following, tubes shall be construed as enclosures of any circumferential shape, only characterized by being longer than the cross sectional distance. Typically tubes are cylindrical, but they may also have non-circular cross sectional shapes and varying cross sectional shape over the tube length.

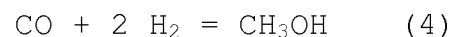
In the following reference is made to specific reactions without further definition. These reactions are well known to the person skilled in the art, but for an overview a short definition is given below.

In the following methanation reaction or methanation process shall be construed a process in which a feed comprising hydrogen and at least one carbon oxide such as carbon

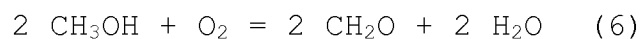
monoxide or carbon dioxide reacts according to equations (1) to (3) forming a gas rich in methane:



In the following methanol synthesis shall be construed a process in which a feed comprising hydrogen and at least one carbon oxide such as carbon monoxide or carbon dioxide
10 reacts according to equation (4) and (5) (and possibly the shift reaction (1)) forming a gas rich in methanol:



15 In the following formaldehyde synthesis shall be construed a process in which a feed comprising methanol and oxygen reacts according to equation (6) forming a gas rich in formaldehyde:



20

SUMMARY OF THE INVENTION

Embodiments of the invention generally relate to a pseudo-isothermal reactor for an exothermal reaction. The reactor
25 comprises a reactor shell having a reactor shell volume, the reactor shell volume comprising at least one cooling medium inlet and at least one cooling medium outlet. The reactor shell volume is arranged to hold a cooling medium under pressure. The reactor shell comprises a reactant inlet and a product outlet. The pseudo-isothermal reactor
30 further comprising a reaction enclosure embedded within the reactor shell volume. The reaction enclosure comprises a

reaction zone with a plurality of reaction tubes, an inlet manifold extending between the reactant inlet and the reaction zone, and an outlet manifold extending between the reaction zone and the product outlet. The cooling medium is arranged to flow between the cooling medium inlet and the cooling medium outlet, around the reaction tubes, so that the reaction tubes are in thermal contact with the cooling medium. The reactor shell volume is dimensioned so as to allow separation of a gas phase from a liquid phase of the cooling medium within the reactor shell volume, such that, during operation of the reactor, cooling medium outlet through at least one cooling medium outlet is substantially in gas phase.

The reactor shell volume of the reactor is arranged to separate gas and liquid phase of the cooling medium. This is due to the fact that the reactor shell volume is arranged to hold the cooling medium under pressure and it is dimensioned so as to allow separation of a gas phase from a liquid phase of the cooling medium within the reactor shell volume. Thus, during operation of the reactor, any cooling medium which is outlet through at least one cooling medium outlet is substantially in gas phase. The reactor shell volume thus operates as a separation chamber, and no external separation chamber on the cooling medium side is necessary. Instead the separation chamber of the cooling medium is integrated within the reactor. This provides a much cheaper reactor in that an external cooling medium container, such as a steam drum, and tubes or piping in the form of risers and down comers between the external cooling medium container and the reactor are avoided. It should be noted that the liquid phase of the cooling medium should

cover substantially the entire reaction zone. When in operation, at least one cooling medium inlet is located near the lower side of the reaction zone and at least one cooling medium outlet is located above the reaction zone. Moreover, the amount of cooling medium and the pressure of the reactor should be controlled so as to ensure that the transition between liquid and gas phase within the reaction volume is positioned between the upper side of the reaction zone and the position of the cooling medium outlet.

10

The reaction enclosure may comprise between 1000 and 6000 reaction tubes, preferably between 3000 and 5000 reaction tubes.

15 In general, temperature of the cooling medium is controlled by control of its pressure, and the cooling medium is typically kept at a temperature proximate to the boiling point of the cooling medium.

20 The term "reactor shell" shall be construed as covering the casing or the walls of the reactor, whilst the term "reactor shell volume" is to be construed as covering the room or space within the reactor.

25 In an embodiment, the reactor is a boiling water reactor. Thus, the cooling medium is water, which is a cheap and abundant cooling medium.

30 In an embodiment, the inlet manifold comprises a unit in thermal contact with the cooling medium. The unit may for example be a channel in the form of one or more tubes, piping or pipes extending from the reactant inlet to the reac-

tion zone. Alternatively, the unit may be or comprise a heat exchange unit. Hereby, a heat recovery zone is created so that a reactant fluid inlet through the reactant inlet exchanges heat with the cooling medium within prior to reaching the reaction zone. In the case of exothermal reactions, the reactant fluid is typically heated by the cooling medium prior to reaching the reaction zone.

The channel may be in the form of one or more tubes or piping extending from the reactant inlet to the reaction zone.

In an embodiment, the outlet manifold comprises flow equilibrating means. The flow equilibrating means are arranged to even out the flow of gas from the reaction zone towards the product outlet. In an embodiment, the flow equilibrating means comprises inert material. In an embodiment, the outlet manifold comprises a mesh arranged to delimit the inert material from the product outlet.

In an embodiment, the reactor comprises a demister upstream of the at least one cooling medium outlet. The demister is arranged to separate liquid droplets from the cooling medium in gas phase and to recirculate the liquid droplets within the reaction shell volume. The demister is also arranged to allow the cooling medium in gas phase to pass so that it may exit the reactor through the cooling medium outlet. In a case, where more than one cooling medium outlet exists, a demister may be provided at each cooling medium outlet in order to ensure recirculation of cooling medium within the reactor, to the extent possible.

In an embodiment, the reactor comprises a first tube sheet between the reaction zone and the outlet manifold and a second tube sheet between the inlet manifold and the reaction zone. A tube sheet is a sheet of sufficient thickness and of an appropriate material, such as for example stainless steel. The tube sheet has holes for the reaction tubes to be inserted and rolled. An inlet end of each reaction tube may be bell-mouthed for a streamlined entry of reactant fluid. This is to avoid eddies at the inlet of each tube giving rise to erosion, and to reduce flow friction. Some makers also recommend plastic inserts at the entry of tubes to avoid eddies eroding the inlet end. In smaller units some manufacturers use ferrules to seal the tube ends instead of rolling.

In an embodiment, the reactor further comprises a fastening piece arranged to fasten the reaction enclosure to an inside of the reactor shell. The fastening means may be in the form of a plate or struts.

In an embodiment, the fastening piece comprises cooling medium passages in order to let cooling medium pass between the reaction enclosure and the inside of the reactor shell, along at least part of the inlet manifold and the reaction zone.

The fastening piece may be in the form of a tubular sheet having cooling medium passages in the form of through-holes.

In an embodiment, the second tube sheet and the fastening piece are in substantially one plane. In this case, the

second tube sheet and the fastening piece may be made as a single sheet, where the fastening piece is placed between the inside of the reactor shell and the outside of the reaction zone, whilst the second tube sheet is positioned inside the reaction zone.

In an embodiment, the second tube sheet is positioned further downstream compared to the position of the fastening piece.

In an embodiment, an outer circumference of the second tube sheet is distanced from the reactor shell, at least over a majority of the outer circumference.

In an embodiment, the second tube sheet is fastened to the reactor shell by an expansion joint. The expansion joint comprise one or more springs or rollers. The springs may e.g. be wave springs or helical springs. The expansion joint is arranged to handle a length wise expansion of reaction tubes by allowing the second tube sheet to move longitudinally within the reaction shell. In smaller units some sag is given to the tubes to take care of tube expansion with both the first and second tube sheet fixed rigidly to the shell.

Alternatively, the second tube sheet may be spaced apart from the reaction shell so that cooling fluid may pass between the outside of the second tube sheet and the inside of the reactor shell.

In an embodiment, the reactor comprises one or more cooling medium flow assisting devices for assisting circulation

and/or recirculation of cooling medium around and/or along the reaction tubes. The cooling medium flow assisting devices may for example be plates, baffles, or struts. Moreover, means for assuring passage of the cooling medium between the second tube sheet and the inner wall of the reactor shell are also cooling medium flow assisting devices.

In an embodiment, the reaction tubes comprise catalyst material.

BRIEF DESCRIPTION OF THE DRAWINGS

Embodiments of the present invention are explained, by way of example, and with reference to the accompanying drawings. It is to be noted that the appended drawings illustrate only examples of embodiments of this invention and are therefore not to be considered limiting of its scope, for the invention may admit to other equally effective embodiments.

Figure 1 is an overview of an example of a known methanol process;

Figure 2a illustrates a pseudo-isothermal reactor according to the invention, and figure 2b illustrates a tube sheet used in the pseudo-isothermal reactor of figure 2a.

Figure 3a illustrates another pseudo-isothermal reactor according to the invention, and figure 3b illustrates a fastening piece used in the pseudo-isothermal reactor of figure 3a.

Figure 4a illustrates another pseudo-isothermal reactor according to the invention, and figure 4b illustrates a tube sheet used in the pseudo-isothermal reactor of figure 4a.

5 Figure 5a illustrates another pseudo-isothermal reactor according to the invention, and figure 5b illustrates a tube sheet used in the pseudo-isothermal reactor of figure 5a.

10 Figure 6a illustrates another pseudo-isothermal reactor according to the invention, figure 6b illustrates a second tube sheet and figure 6c illustrates a cross-section of a unit of the inlet manifold in the form of a helical or spiral pipe.

15 Figure 7a illustrates another pseudo-isothermal reactor according to the invention, and figure 7b illustrates a second tube sheet.

20 Figure 8 is a schematic drawing of an embodiment resembling the embodiment of figure 7a-7b.

DETAILED DESCRIPTION

25 A common concept for a pseudo-isothermal reactor is the so-called boiling liquid cooled reactor (often called a boiling water reactor), in which the cooling medium is a liquid - typically water, but it may also be e.g. oil or salt - in thermal contact with one or more reaction enclosures, such as tubes. The liquid is pressurized, and the pressure controls the boiling point of the cooling medium, which thus
30 is kept at a substantial constant temperature close to the boiling point of the liquid, with excess energy being re-

5 moved as vaporization enthalpy e.g. by evaporation of liquid water into steam. In this way the process side of the reaction enclosures is in thermal contact with a cooling medium having substantially the same temperature along the length of the reactor, and substantially the same temperature over time (as long as the pressure is not modified). This significantly reduces the variation of temperature on the process side, even though hot spots may exist where very rapid exothermal reactions take place.

10

The preheating of reactants during reactor start up is a further benefit of a pseudo-isothermal reactor. During start up the cooling medium may in such a reactor have the function of a heating medium, and be heated to an appropriate temperature externally, with the associated benefit of providing activation energy for the reaction.

15

With respect to catalytically active material three general types of catalytically active material can be considered; catalytically active pellets, catalytically active monoliths and catalyzed hardware. The nature of the catalytically active material may be the same or different between the individual reaction enclosures and/or the individual reaction tubes.

20

25

Catalytically active pellets (which may be produced by many methods, including extrusion or pelleting) are the most common form of industrial catalyst, and it is often used in processes where there is a risk of catalyst deactivation, which may require occasional or regular replacement of the catalyst.

30

When using a pseudo-isothermal reactor compared to an adiabatic reactor the desired effects are mainly related to three aspects. One aspect is the possibility of influencing the equilibrium in exothermal reactions where an elevated
5 temperature favors reactants. A second aspect is the possibility to ensure that the catalyst and/or products are kept below critical temperatures, such that thermal damage of the catalyst is avoided. A third aspect that at low temperatures reactions forming side products or consuming products
10 are often reduced.

In the following, reference is made to embodiments of the invention. However, it should be understood that the invention is not limited to specific described embodiments. Instead,
15 any combination of the following features and elements, whether related to different embodiments or not, is contemplated to implement and practice the invention. In particular, it should be stressed, that even though the embodiments of the present invention illustrated in the figures
20 relate to boiling-water reactors, the invention is not limited to boiling-water reactors, but relate to pseudo-isothermal reactors in general. Furthermore, in various embodiments the invention provides numerous advantages over the prior art. However, although embodiments of the invention
25 may achieve advantages over other possible solutions and/or over the prior art, whether or not a particular advantage is achieved by a given embodiment is not limiting of the invention. Thus, the following aspects, features, embodiments and advantages are merely illustrative and are
30 not considered elements or limitations of the appended claims except where explicitly recited in a claim(s). Likewise, reference to "the invention" shall not be construed

as a generalization of any inventive subject matter disclosed herein and shall not be considered to be an element or limitation of the appended claims except where explicitly recited in a claim(s).

5

Figure 1 is an overview of an example of a known methanol process 1. The methanol process includes the following main process steps:

- Feed preparation;
- 10 - Reforming;
- Methanol synthesis; and
- Distillation.

The feed preparation or feed purification takes place in a hydrogenator 21 and sulphur removal unit 22 in order to remove elements that could poison catalyst material.

The reforming taking place in a steam reformer 20 and a pre-reformer 23. In general, the reforming technology is chosen between advanced tubular reforming, two-step oxygen-fired reforming, auto-thermal reforming and heat exchange reforming. The composition of a feedstock gas 10 determines the composition of the synthesis gas obtainable with a one-step reformer. The process of figure 1 includes a secondary oxygen-fired reformer 25. In addition to oxygen 12 led to the secondary reformer 25 steam 11 is provided in order to protect the secondary reformer 25.

The methanol synthesis takes place in an adiabatic reactor or boiling water reactor 40. From fig. 1 it is seen that water is led to the boiling water reactor 40 from a steam drum 41.

The distillation takes place in distillation unit 60. The distillation may be of a single, two- or three-column design.

5

The process 1 further includes relevant heat exchange steps 27, 28, 51, 52 and compression steps 29, 30. The heat exchange step 27 produces steam which is taken out of the system or used as a part of the steam 11 for the secondary reformer 25.

10

The pseudo-isothermal reactor of the invention is a single unit arranged to carry out the functionality of the boiling water reactor 40 together with the steam drum 41, as indicated by the dashed line in figure 1. Due to the pseudo-isothermal reactor being a single unit, where a cooling medium reservoir in the form of steam drum is integrated within the reactor, the overall costs are reduced.

15

In the following examples shown in figure 2a-8, the pseudo-isothermal reactor is exemplified as boiling water reactors using water as cooling media. However, it should be stressed that the invention is not limited to boiling water reactors, but could be any pseudo-isothermal reactor using appropriate cooling media, such as oil or salt.

20

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Figure 2a illustrates a pseudo-isothermal reactor 140 for an exothermal reaction according to the invention. The pseudo-isothermal reactor 140 is a boiling water reactor.

30

In figure 2a, the vertical line in the centre of the reactor and along a longitudinal direction thereof indicates an axis of symmetry of the main components of the reactor.

The boiling water reactor 140 comprises a reactor shell 141 having one or more cooling medium inlets 142 in the form of water inlets and one or more cooling medium outlets 143 in the form of water and/or steam outlets. The reactor shell 141 encloses or surrounds a reactor shell volume 130. The reactor shell volume 130 is arranged to hold water under pressure. The reactor shell 141 moreover comprises a reactant inlet 144 and a product outlet 145.

The boiling water reactor 140 further comprises a reaction enclosure 146 embedded within the reactor shell 141. The reaction enclosure 146 comprises a reaction zone 148, an inlet manifold 147 extending between the reactant inlet 144 and the reaction zone 148, and an outlet manifold 149 extending between the reaction zone 148 and the product outlet 145. The reaction zone 148 comprises a multitude of reaction tubes, e.g. about 2000, about 3000, about 4000 or about 5000, having walls and being at least partly filled with catalyst material, where the walls of the reaction tubes constitute walls of the reaction zone.

A first tube sheet 161 is positioned at the part of the reaction zone facing the outlet manifold. When the reactor is positioned as seen in figure 2a, the first tube sheet 161 is a lower tube sheet. The lower tube sheet 161 is a plate or sheet of sufficient thickness and of an appropriate material, such as for example stainless steel. The first tube sheet 161 has a number of holes corresponding to the number of reaction tubes in the reaction zone, so that each reaction tube is inserted into a hole in the lower tube sheet 161. The first tube sheet 161 extends to the inside of the

reactor shell and thus forms a barrier between the part of the reactor shell arranged to hold cooling medium and the outlet manifold 149.

5 The cooling medium is arranged to flow around the reaction enclosure along the part of the reaction enclosure extending from the reactant inlet 144 to first tube sheet 161, as well as the reaction zone 148. Thus, the reaction zone 148 and at least part of the inlet manifold 147 are in thermal
10 contact with the cooling medium through walls of the reaction enclosure, viz. through the walls of the reaction tubes of the reaction zone 148 and through the walls of the inlet manifold 147.

15 Within the outlet manifold, flow equilibrating means are positioned in order to even out the flow of gas from the reaction zone towards the product outlet. The flow equilibrating means may comprise inert material. Moreover, the outlet manifold 149 may comprise a mesh or other particle
20 withholding element arranged to delimit such inert material from the product outlet 145 and/or for fixation of catalytically active material within the reaction tubes, especially when such material is catalytically active pellets.

25 It should be noted that the liquid phase of the cooling medium covers substantially the entire reaction zone. When in operation, at least one cooling medium inlet is located near the lower side of the reaction zone 148 and at least one cooling medium outlet 143 is located above the reaction
30 zone 148. Moreover, the amount of cooling medium and the pressure of the reactor are to be controlled so as to ensure that the transition between liquid and gas phase with-

in the reaction volume is positioned between the upper side of the reaction zone 148 and the position of the cooling medium outlet 143.

5 It may be seen from figure 2a that no external steam drum is present. This is due to the fact that the steam drum functionality, viz. the separation between water and steam, is integrated within the reactor of the invention. Since the reactor of the invention includes a reactor shell 141
10 being arranged to hold a cooling medium under pressure and an embedded reaction enclosure, where the cooling medium is arranged to fill substantially any part of the reactor shell not taken up by the reaction enclosure or other units within the shell, the functionality of an external steam
15 drum is integrated within the reactor of the invention.

The reactor of the invention may optionally include a demister; this is illustrated by reference number 150 in figure 2a. Moreover, the reactor includes a number of cooling
20 medium flow assisting devices 160, 160', 162 for assisting circulation and/or recirculation of cooling medium around and/or along the reaction tubes. The cooling medium flow assisting devices includes horizontal baffles 160, 160' and a vertical tube or vertical plates 162.

25

The reactor 140 moreover comprises a plate 152 comprising a second tube sheet 151 and a fastening piece 156 (see figure 2a). When the reactor is positioned as seen in figure 2a, the second tube sheet 151 is an upper tube sheet.

30

Figure 2b illustrates that the plate 152 has an inner part constituting the second tube sheet 151 and an outer part

constituting a fastening piece 156. Figure 2b is a cross-section through the boiling water reactor along the dashed line A-A. Figure 2b shows an inner dark area 151 corresponding to the second tube sheet 151 having a number of
5 holes corresponding to the number of reaction tubes of the reaction zone 148 (figure 2a), in order to let the reaction tubes be inserted into the second tube sheet 151. The second tube sheet 151 is arranged to form a transition between the reaction tubes and the inlet manifold 147. The fastening piece 156 of the plate 152 moreover comprises a section having through-holes 153 and another section having further through-holes 154. The through-holes 153, 154 are
10 arranged to let water and/or steam pass through the fastening piece 156. Thus, when the boiling water reactor 140 is in use, cooling medium in the form of water and/or steam is arranged to flow from a cooling medium inlet 142 along and between the reaction tubes 148, directed by the baffles 160 for optimal flow, and through the holes 153 and 154 in the fastening piece 156. The holes 153, 154 are thus water
15 down comer holes and steam riser holes.

The outer circumference of the fastening piece 156 is arranged to be fastened to the inside of the reactor shell 141. The fastening of the reactor enclosure 146 to the inside of the reactor shell 141 is advantageous due to stability. In the embodiment shown in figure 2a, the second tube sheet and the fastening piece a plane plate; however, this needs not be the case, as described in connection with figures 3a and 3b.

30

The cooling medium flows between the reaction tubes of the reaction zone 148 and along the inlet manifold 147. In op-

eration, water is inlet at the cooling medium inlet 142 and is heated by the reaction tubes of the reaction zone and flows upwards in a zigzag-motion due to the baffles 160. The cooling medium, as a combination of water and steam, passes through holes 153 of the fastening piece 156 (see figure 2b) and flows upwards in a zigzag motion due to the baffles 160'.

The boiling water reactor of figure 2a also comprises a heat recovery unit 163 arranged to recover heat from the steam generated within the boiling water reactor and thereby allow at least some of the steam to be condensed for subsequent recirculation within the boiling water reactor. The vertical tube or plates 162 are arranged to direct this recirculated water along the inner surface of the reactor shell 141. The recirculated water passes through the holes 153 of the second tube sheet 151. When the water between the reaction tubes of the reaction zone 148 is heated to the boiling point, determined by the pressure within the reaction shell, steam is created. The steam follows a path determined by the baffles 160 and may pass through the through-holes 152 of the second tube sheet 151. The steam may be condensed in the heat recovery unit 163 or may be demisted in the demister, in which case the recovered mist is recirculated within the reactor shell and the demistified steam is outlet through the cooling medium outlet 143.

Figure 3a illustrates another pseudo-isothermal reactor according to the invention, and figure 3b illustrates a fastening piece 252 used in the pseudo-isothermal reactor of figure 3a as indicated by the dashed line B-B in figure 3a.

The pseudo-isothermal reactor 240 is a boiling water reactor and comprises a reactor shell 241 having one or more cooling medium inlets 242 in the form of water inlets and one or more cooling medium outlets 243 in the form of water and/or steam outlets. The reactor shell 241 encloses or surrounds a reactor shell volume 230. The reactor shell volume 230 is arranged to hold water under pressure. The reactor shell 241 moreover comprises a reactant inlet 244 and a product outlet 245.

Embedded within the boiling water reactor 240 is a reaction enclosure 246. The reaction enclosure 246 comprises a reaction zone 248, an inlet manifold 247 extending between the reactant inlet 244 and the reaction zone 248, and an outlet manifold 249 extending between the reaction zone 248 and the product outlet 245. The reaction zone 248 comprises a multitude of reaction tubes, e.g. about 2000, about 3000, about 4000 or about 5000, having walls and being at least partly filled with catalyst material, where the walls of the reaction tubes constitute walls of the reaction zone.

A first tube sheet 261 is positioned at the part of the reaction zone facing the outlet manifold 245. When the reactor is positioned as seen in figure 3a, the first tube sheet 261 is a lower tube sheet. The first tube sheet 261 has a number of holes corresponding to the number of reaction tubes in the reaction zone, so that each reaction tube is inserted into a hole in the lower tube sheet 261. The first tube sheet 261 extends to the inside of the reactor shell and thus forms a barrier between the part of the re-

actor shell arranged to hold cooling medium and the outlet manifold 249.

5 The cooling medium is arranged to flow around the reaction enclosure along the part of the reaction enclosure extending from the reactant inlet 244 to first tube sheet 261, and the reaction zone 248. Thus, the reaction zone 248 and at least part of the inlet manifold 247 are in thermal contact with the cooling medium through walls of the reaction enclosure, viz. through the walls of the reaction tubes of
10 the reaction zone 248 and through the walls of the inlet manifold 247.

15 Within the outlet manifold 249, flow equilibrating means are positioned in order to even out the flow of gas from the reaction zone towards the product outlet.

The reactor 240 includes a demister 250. Moreover, the reactor 240 includes a number of baffles 260 in order to ensure an optimal flow of the cooling medium within the reactor shell. The cooling medium thus flows between the reaction tubes of the reaction zone 248 and along the inlet manifold 247. In operation, water is inlet at the cooling medium inlet 242 and is heated by the reaction tubes of the
20 reaction zone and flows upwards in a zigzag-motion due to the baffles 260. The cooling medium, as a combination of water and steam, passes through holes 253 of the fastening piece 256 (see figure 3b) and flows upwards along the outer surface of the inlet manifold 247 due to the cooling medium
25 flow assisting means 262 in the form of a vertical tube or plates 262.
30

The reactor 240 moreover comprises a second tube sheet 251. When the reactor is positioned as seen in figure 3a, the second tube sheet 251 is an upper tube sheet.

5 Figure 3b illustrates a cross-section through the reactor as indicated by the dashed line B-B in figure 3a. It should be noted that the cross-section shown does not include the second tube sheet 251, but a fastening piece 252 arranged to fasten the reaction enclosure 246 to the inside of the
10 reactor shell 241. In the embodiment shown in figure 3a, the second tube sheet 251 is thus positioned downstream along the reaction enclosure compared to the position of the fastening piece 252. In the position of the reactor 240 as shown in figure 3a, the second tube sheet 251 is placed
15 below the fastening piece 252.

Figure 3b shows the fastening piece 252 having a central part with six struts 255 and an outer, annular fastening part 256 with through-holes 253 and 254. The outer diameter
20 of the annular fastening part 256 is arranged to be fastened to the inside of the reactor shell, whilst the inner diameter of the annular fastening part 256 is arranged to be snug against the outside of the inlet manifold 247. The through-holes 253, 254 are arranged to let water and/or
25 steam pass through the fastening piece 252. In figure 3b, the through-holes 253 are shown as smaller than the through-holes 254; alternatively, the through-holes 254 could be larger than the through-holes 253; they could be of equal size or varying sizes.

30

The outer circumference of the fastening piece 252 arranged to be fastened to the inside of the reactor shell 241.

The boiling water reactor 240 of figure 3a also comprises a heat recovery unit 263 arranged to recover heat from the steam generated within the boiling water reactor and thereby allow at least some of the steam to be condensed for subsequent recirculation within the boiling water reactor. The baffles 260 located above the second tube sheet 251 are arranged to direct this recirculated water along the inner surface of the reactor shell. The recirculated water passes through the holes 253 of the fastening piece 252. When the water between the reaction tubes of the reaction zone 248 is heated to the boiling point, determined by the pressure within the reaction shell, steam is created. The steam follows a path determined by the baffles 260 and may pass through the through-holes 254 of the fastening piece 252. The steam may be condensed in the heat recovery unit 263 or may be demisted in the demister, in which case the recovered mist is recirculated within the reactor shell and the demistified steam is outlet through the cooling medium outlet 243.

Figure 4a illustrates another pseudo-isothermal reactor 340 according to the invention, and figure 3b illustrates a combined fastening piece and second tube sheet 352 used in the pseudo-isothermal reactor 340, as indicated by the dashed line C-C in figure 4a.

The pseudo-isothermal reactor 340 is a boiling water reactor. The boiling water reactor 340 comprises a reactor shell 341 having one or more cooling medium inlets 342 in the form of water inlets and one or more cooling medium outlets 343 in the form of water and/or steam outlets. The

reactor shell 341 encloses or surrounds a reactor shell volume 330. The reactor shell volume 330 is arranged to hold water under pressure. The reactor shell 341 moreover comprises a reactant inlet 344 and a product outlet 345.

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Embedded within the boiling water reactor 340 is a reaction enclosure 346. The reaction enclosure 346 comprises a reaction zone 348, an inlet manifold 347 extending between the reactant inlet 344 and the reaction zone 348, and an outlet manifold 349 extending between the reaction zone 348 and the product outlet 345. The reaction zone 348 comprises a multitude of reaction tubes, e.g. about 2000, about 3000, about 4000 or about 5000 tubes, having walls and being at least partly filled with catalyst material, where the walls of the reaction tubes constitute walls of the reaction zone.

A first tube sheet 361 is positioned at the part of the reaction zone facing the outlet manifold 345. When the reactor is positioned as seen in figure 4a, the first tube sheet 361 is a lower tube sheet. The first tube sheet 361 has a number of holes corresponding to the number of reaction tubes in the reaction zone, so that each reaction tube is inserted into a hole in the lower tube sheet 361. The first tube sheet 361 extends to the inside of the reactor shell and thus forms a part of a barrier between the part of the reactor shell arranged to hold cooling medium and the reaction enclosure 346.

The cooling medium is arranged to flow around the reaction enclosure along the part of the reaction enclosure extending from the reactant inlet 344 to first tube sheet 361 as

well as the reaction zone 348. Thus, the reaction zone 348 and at least part of the inlet manifold 347 are in thermal contact with the cooling medium through walls of the reaction enclosure 346, viz. through the walls of the reaction tubes of the reaction zone 348 and through the walls of the inlet manifold 347.

The cooling medium is arranged to flow around the reaction enclosure 646 along the pipe 665, the rest of the inlet manifold 647, viz. the part of the reaction enclosure 646 extending from the reactant inlet 644 to the first tube sheet 661, as well as the reaction zone 648. Thus, the reaction zone 648 and at least part of the inlet manifold 647 are in thermal contact with the cooling medium through the walls of the reaction enclosure 646, viz. through the walls of the reaction tubes of the reaction zone 648 and through the wall of the inlet manifold 647, including the wall of the pipe 665.

The reactor 340 includes a demister 350. Moreover, the reactor 340 includes a number of baffles 360 in order to ensure an optimal flow of the cooling medium within the reactor shell. The cooling medium thus flows between the reaction tubes of the reaction zone 348 and along the inlet manifold 347.

The reactor 340 moreover comprises a plane plate 352 comprising a second tube sheet 351 and a fastening piece 356 (see figure 4a). When the reactor is positioned as seen in figure 2a, the second tube sheet 351 is an upper tube sheet.

Figure 4b illustrates that the plate 352 has an inner part constituting the second tube sheet 351 and an outer part constituting an annular fastening piece 356. Figure 4b is a cross-section through the boiling water reactor 340 along the dashed line C-C. The second tube sheet 351 has a number of holes corresponding to the number of reaction tubes of the reaction zone 348 (figure 4a), in order to let the reaction tubes be inserted into the second tube sheet 351. The second tube sheet 351 is arranged to form a transition between the reaction tubes and the inlet manifold 347. The outer diameter of the annular fastening piece 356 is arranged to be fastened to the inside of the reactor shell, whilst the inner diameter of the annular fastening piece 356 is arranged to be snug against the outside of the inlet manifold 347. The fastening piece 356 of the plate 352 also comprises through-holes 353 arranged to let water and steam pass through the fastening piece 356. Thus, when the boiling water reactor 340 is in use, cooling medium in the form of water and/or steam is arranged to flow from a cooling medium inlet 342 along and between the reaction tubes 348, directed by the baffles 360 for optimal flow, and through the holes 353 in the fastening piece 356. The holes 353 are thus water down comer holes and steam riser holes.

In figure 4b, the holes 353 are shown to be of substantially equal size; alternatively, different through-holes 343 could be of varying sizes.

The baffles 360 located along the reaction zone 348 are arranged to direct cooling water along the surface of the reaction zone 348. When the water between the reaction tubes of the reaction zone 348 is heated to the boiling point,

determined by the pressure within the reaction shell, steam is created. The steam may be demisted in the demister 350, in which case the recovered mist is recirculated within the reactor shell 341 and the demistified steam is outlet
5 through the cooling medium outlet 343.

Figure 5a illustrates another pseudo-isothermal reactor 440 according to the invention, and figure 5b illustrates a second tube sheet 451 used in the pseudo-isothermal reactor
10 440 as indicated by the dashed line D-D in figure 5a.

The pseudo-isothermal reactor 440 is a boiling water reactor and comprises a reactor shell 441 having one or more cooling medium inlets 442, 442' in the form of water inlets
15 and one or more cooling medium outlets 443 in the form of water and/or steam outlets. In the boiling water reactor 440, a cooling medium outlet is positioned at the top of the reactor 440, whilst the reactant inlet is positioned at a side of the reactor 440.

20 The reactor shell 441 encloses or surrounds a reactor shell volume 430. The reactor shell volume 430 is arranged to hold water under pressure. The reactor shell 441 moreover comprises a reactant inlet 444 and a product outlet 445.

25 Embedded within the boiling water reactor 440 is a reaction enclosure 446. The reaction enclosure 446 comprises a reaction zone 448, an inlet manifold 447 extending between the reactant inlet 444 and the reaction zone 448, and an outlet
30 manifold 449 extending between the reaction zone 448 and the product outlet 445. A part or unit of the inlet manifold 447 is a straight pipe 465. The reaction zone 448 com-

prises a multitude of reaction tubes, e.g. about 2000,
about 3000, about 4000 or about 5000 tubes, having walls
and being at least partly filled with catalyst material,
where the walls of the reaction tubes constitute walls of
5 the reaction zone 448.

The reactor 440 includes a number of baffles 460 in order
to ensure an optimal flow of the cooling medium within the
reactor shell. The cooling medium thus flows between the
10 reaction tubes of the reaction zone 448 and along the inlet
manifold 447.

An upper cooling water inlet 442' is placed in the vicinity
of and below the reactant inlet 444. A cooling medium flow
15 assisting device in the form of a tubular plate 462 extends
along a part of the inside of the reactor shell 441. The
tubular plate 462 separates water led in through the upper
cooling water inlet 442' from water combined with steam
rising up along the reaction zone 448, in zigzag motion due
20 to the horizontal baffles 460, due to the water being heat-
ed by the reaction tubes.

A first tube sheet 461 is positioned at the part of the re-
action zone 448 facing the outlet manifold 445. When the
25 reactor is positioned as seen in figure 5a, the first tube
sheet 461 is a lower tube sheet. The first tube sheet 461
has a number of holes corresponding to the number of reac-
tion tubes in the reaction zone, so that each reaction tube
is inserted into a hole in the lower tube sheet 461. The
30 first tube sheet 461 extends to the inside of the reactor
shell and thus forms a barrier between the part of the re-

actor shell arranged to hold cooling medium and the outlet manifold 449.

5 The cooling medium is arranged to flow around the reaction enclosure along the part of the reaction enclosure extending from the reactant inlet 444 to first tube sheet 461 as well as the reaction zone 448. Thus, the reaction zone 448 and at least part of the inlet manifold 447 are in thermal contact with the cooling medium through walls of the reaction enclosure, viz. through the walls of the reaction
10 tubes of the reaction zone 448 and through the walls of the inlet manifold 447.

Within the outlet manifold 449, flow equilibrating means
15 are positioned in order to even out the flow of gas from the reaction zone towards the product outlet.

The reactor 440 moreover comprises a second tube sheet 451. When the reactor is positioned as seen in figure 5a, the
20 second tube sheet 451 is an upper tube sheet.

Figure 5b illustrates a cross-section through the reactor as indicated by the dashed line D-D in figure 5a.

25 From figures 5a and 5b it is clear that the second tube sheet 451 is not fastened to the inside of the reactor shell 440 in figure 5a by means of a fastening plate. Instead, the second tube sheet 451 may be fastened to the inside of the reactor shell 440 by one or more expansion
30 joints (not shown in figures 5a and 5b). The expansion joints may be in the form of springs or rollers.

In figure 5b it is seen, that the second tube sheet 451 is therefore distanced from the inside of the reactor shell 440 along at least a majority of the outer circumference of the second tube sheet 451. This allows for easy circulation of cooling medium within the reactor shell 441. Moreover a flexible fastening of the reaction enclosure to the inside of the reactor shell allows for different thermal expansions and contractions of the reactor shell and the reaction enclosure without mechanical stresses induced by an inflexible connection between the reactor shell and the reaction enclosure.

Figure 5b shows the second tube sheet 451. The reactor shell 441 is shown in dashed line in figure 5b, and the dashed line 462 indicates the tubular plate 462.

The boiling water reactor 440 of figure 5a also comprises a demister 450. The recovered mist is recirculated within the reactor shell 440 and the demistified steam is outlet through the cooling medium outlet 443.

Figure 6a illustrates another pseudo-isothermal reactor 540 according to the invention, figure 6b illustrates a second tube sheet 551 and figure 6c illustrates a cross-section of a unit 565 of the inlet manifold 547 in the form of a helical or spiral pipe.

In figure 6a, the boiling water reactor 540 comprises a reactor shell 541 having one or more cooling medium inlets 542, 542' in the form of water inlets and one or more cooling medium outlets 543 in the form of water and/or steam outlets. The reactor shell 541 encloses or surrounds a re-

actor shell volume 530. The reactor shell volume 530 is arranged to hold water under pressure. The reactor shell 541 moreover comprises a reactant inlet 544 and a product outlet 545.

5

Embedded within the boiling water reactor 540 is a reaction enclosure 546 comprising a reaction zone 548, an inlet manifold 547 extending between the reactant inlet 544 and the reaction zone 548, and an outlet manifold 549 extending between the reaction zone 548 and the product outlet 545. The reaction zone 548 comprises a multitude of reaction tubes, being at least partly filled with catalyst material, where walls of the reaction tubes constitute walls of the reaction zone 548.

15

A first tube sheet 561 is positioned at the part of the reaction zone facing the outlet manifold 545. When the reactor is positioned as seen in figure 6a, the first tube sheet 561 is a lower tube sheet. The first tube sheet 561 has a number of holes corresponding to the number of reaction tubes in the reaction zone, so that each reaction tube is inserted into a hole in the lower tube sheet 561. The first tube sheet 561 extends to the inside of the reactor shell and thus forms a barrier between the part of the reactor shell arranged to hold cooling medium and the outlet manifold 549.

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The cooling medium is arranged to flow around the reaction enclosure along the part of the reaction enclosure extending from the reactant inlet 544 to first tube sheet 561 as well as the reaction zone 548. Thus, the reaction zone 548 and at least part of the inlet manifold 547 are in thermal

30

contact with the cooling medium through walls of the reaction enclosure, viz. through the walls of the reaction tubes of the reaction zone 548 and through the walls of the inlet manifold 547, in particular through a helical or spiral pipe 565 of the inlet manifold 547.

Within the outlet manifold 549, flow equilibrating means are positioned in order to even out the flow of gas from the reaction zone towards the product outlet.

10

The reactor 540 includes a demister 550. Moreover, the reactor 540 includes a number of horizontal baffles 560 in order to ensure an optimal flow of the cooling medium within the reactor shell. A cooling medium flow assisting device in the form of a tubular plate 562 extends parallel to a part of the inside of the reactor shell 541. The tubular plate 562 separates water led in through the upper cooling water inlet 542' from water combined with steam rising up along the reaction zone 548, in zigzag motion due to the horizontal baffles 560, due to the water being heated by the reaction tubes.

15
20

The reactor 540 moreover comprises a second tube sheet 551. When the reactor is positioned as seen in figure 6a, the second tube sheet 551 is an upper tube sheet.

25

Figure 6b illustrates a cross-section through the reactor as indicated by the dashed line E-E in figure 6a. Figure 6b shows the second tube sheet 551. The reactor shell 541 is shown in dashed line in figure 6b.

30

From figures 6a and 6b it is clear that the second tube sheet 551 is not fastened to the inside of the reactor shell 540 in figure 6a by means of a fastening plate. Instead, the second tube sheet 551 may be fastened to the inside of the reactor shell 540 by one or more expansion joints (not shown in figures 6a and 6b). The expansion joints may be in the form of springs or rollers. The embodiments of the reactor shown in figures 5a-6c are thus embodiments wherein the reaction enclosure has a floating or non-stationary head or upper part.

Again, a flexible fastening of the reaction enclosure to the inside of the reactor shell allows for different thermal expansions and contractions of the reactor shell and the reaction enclosure without mechanical stresses induced by an inflexible connection between the reactor shell and the reaction enclosure.

The design of the inlet manifold 547 of the reactor 540 is different from the inlet manifold 547 of the reactor 440. The inlet manifold 547 comprises a helical or spiral pipe 565 arranged to enhance the thermal contact between the inlet manifold and the cooling medium within the reactor 540. This is seen in figure 6c, which is a cross-section through the reactor unit 540 along line F-F of figure 6a. Figure 6c moreover shows supporters 563 arranged to hold the helical or spiral pipe 565.

The reactor enclosure 546 further comprises a manhole 531 closed off by a manhole cover as well as a corresponding manhole 532 with a manhole cover in the reactor shell 540. During service, the manhole covers may be removed in order

to provide access to the inlet manifold 547 and to the reaction tubes. The manhole in the reactor shell 540 may be in the top of the reactor shell 540; in this case, the cooling medium outlet 543 may function as a cooling medium outlet during operation of the reactor, and may function as the manhole during service, such as exchange of catalyst material within the reactor tubes. This would typically necessitate removal of the demister 550 and piping connected to the cooling medium outlet 543.

Figure 7a illustrates another pseudo-isothermal reactor 540 according to the invention, and figure 7b illustrates a second tube sheet 651.

In figure 7a, the boiling water reactor 640 comprises a reactor shell 641 having one or more cooling medium inlets 642 in the form of water inlets, and one or more cooling medium outlets 643 in the form of water and/or steam outlets. The reactor shell 641 encloses or surrounds a reactor shell volume 630. The reactor shell volume 630 is arranged to hold water under pressure. The reactor shell 641 moreover comprises a reactant inlet 644 and a product outlet 645.

Embedded within the boiling water reactor 640 is a reaction enclosure 646 comprising a reaction zone 648, an inlet manifold 647 extending between the reactant inlet 644 and the reaction zone 648, and an outlet manifold 649 extending between the reaction zone 648 and the product outlet 645. A part or unit of the inlet manifold 647 is a straight pipe 665. The reaction zone 648 comprises a multitude of reaction tubes 648' (even though figure 7a only illustrates

three reaction tubes 648'), each reaction tube 648' being at least partly filled with catalyst material, where walls of the reaction tubes 648' constitute walls of the reaction zone 648.

5

A first tube sheet 661 is positioned at the part of the reaction zone facing the outlet manifold 645. When the reactor is positioned as seen in figure 7a, the first tube sheet 661 is a lower tube sheet. The first tube sheet 661 has a number of holes corresponding to the number of reaction tubes 648' in the reaction zone, so that each reaction tube 648' is inserted into a hole in the lower tube sheet 661. The first tube sheet 661 extends to the inside of the reactor shell and thus forms a barrier between the part of the reactor shell arranged to hold cooling medium and the outlet manifold 649.

The reactor 640 moreover comprises a second tube sheet 651. When the reactor is positioned as seen in figure 7a, the second tube sheet 651 is an upper tube sheet, and the reaction zone 648 is the area within the reaction tubes between the first and second tube sheet 661, 651.

The cooling medium is arranged to flow around the reaction enclosure 646 along the pipe 665, the rest of the inlet manifold 647, viz. the part of the reaction enclosure 646 extending from the reactant inlet 644 to the first tube sheet 661, as well as the reaction zone 648. Thus, the reaction zone 648 and at least part of the inlet manifold 647 are in thermal contact with the cooling medium through the walls of the reaction enclosure 646, viz. through the walls of the reaction tubes of the reaction zone 648 and through

the wall of the inlet manifold 647, including the wall of the pipe 665.

Within the outlet manifold 649, flow equilibrating means
5 670 are positioned in order to even out the flow of gas from the reaction zone towards the product outlet. In the embodiment shown in figure 7a, the flow equilibrating means are shaped as a truncated cone; however, the shape of the flow equilibrating means 670 could be any appropriate
10 shape, such as a truncated ellipsoid, arranged to hold catalyst or other material arranged within the outlet manifold 649.

The reactor 640 may also include a demister (not shown in
15 figure 7a). Moreover, the reactor 640 includes a number of horizontal baffles 660 in order to ensure an optimal flow of the cooling medium within the reactor shell.

Figure 7b illustrates a cross-section through the reactor
20 as indicated by the dashed line E-E in figure 7a. Figure 7b shows the second tube sheet 651. The reactor shell 641 is shown in dashed line in figure 7b.

From figures 7a and 7b it is clear that the second tube
25 sheet 651 is not fastened to the inside of the reactor shell 640 in figure 7a by means of a fastening plate. Instead, the second tube sheet 651 may be fastened to the inside of the reactor shell 640 by one or more expansion joints (not shown in figures 7a and 7b). The expansion
30 joints may be in the form of springs or rollers. The embodiment of the reactor shown in figures 7a and 7b is thus an

embodiment wherein the reaction enclosure has a floating or non-stationary head or upper part.

The reactor enclosure 646 further comprises a manhole 631 closed off by a manhole cover as well as a corresponding manhole 632 with a manhole cover in the reactor shell 640. During service, the manhole covers may be removed in order to provide access to the inlet manifold 547 and to the reaction tubes.

Figure 8 is a schematic drawing of an embodiment resembling the embodiment of figure 7a-7b. Similar reference numbers in figures 7a-7b and 8 indicate similar features. Figure 8 shows a pseudo-isothermal reactor 740 according to the invention. In figure 8, the boiling water reactor 740 comprises a reactor shell 741 having one or more cooling medium inlets (not shown in figure 8), and one or more cooling medium outlets 643. The reactor shell 741 encloses or surrounds a reactor shell volume 630 arranged to hold water under pressure. The reactor shell 641 moreover comprises a reactant inlet 644 and a product outlet 645.

The reaction enclosure 646 comprising the inlet manifold 647, including the straight pipe 665, the manholes 631, 632, the reaction zone 648 with reaction tube 648' is as described in relation to figure 7a, as are the outlet manifold 649 and the first and second tube sheets 661, 651. Figure 8 also shows vertical cooling medium flow assisting devices 762 for assisting circulation and/or recirculation of cooling medium around and/or along the reaction tubes. Horizontal cooling medium flow assisting devices are also present, but not shown in figure 8.

The reactant inlet 644 is connected to the straight pipe 665. The reactant inlet 664 may include means for providing flexibility, such as a flexible bellow 780 in order to allow for thermal expansions/contractions of the connecting pipe 647a, the reactor shell 640 and/or the reaction enclosure 646. Despite its flexibility, the bellow 780 is arranged allow a sealed connection between the straight pipe 665 and the reactant inlet 644, so that the reactor shell volume 630 can be pressurized during operation of the reactor 740.

The bellow 780 providing a flexible fastening of the reaction enclosure 646 to the reactor shell 741 allows different thermal expansions and contractions of the reactor shell 741 and the reaction enclosure 646 with substantially less mechanical stresses than in the case of an inflexible connection between the reactor shell and the reaction enclosure.

It should be noted that more cooling medium inlets, cooling medium outlets, reactant inlets and product outlets than those shown in figures 2a-8 are conceivable. A plurality of cooling medium inlets would typically lead to better temperature control, in particular in the case where more cooling medium inlets are positioned along the longitudinal direction of the reactor.

In all the embodiments of the reactors shown in figures 2a-8, the steam drum is integrated within the reactor. Thus, no external steam drum is necessary. This is due to the fact that the steam drum functionality, viz. the separation

between water and steam, is integrated within the reactor of the invention. Since the reactor of the invention includes a reactor shell being arranged to hold a cooling medium under pressure and an embedded reaction enclosure, where the cooling medium is arranged to fill substantially any part of the reactor shell not taken up by the reaction enclosure or other units within the shell, the functionality of an external steam drum is integrated within the reactor of the invention.

As described in relation to the embodiment of figure 2a, for all the embodiments of figures 2a-8, the liquid phase of the cooling medium covers substantially the entire reaction zone. When in operation, at least one cooling medium inlet is located near the lower side of the reaction zone and at least one cooling medium outlet is located above the reaction zone. Moreover, the amount of cooling medium and the pressure of the reactor are to be controlled so as to ensure that the transition between liquid and gas phase within the reaction volume is positioned between the upper side of the reaction zone and the position of the cooling medium outlet. This arrangement ensures the possibility to control the temperature of the reaction zone with the reactor of the invention, without an external steam drum.

While the invention has been illustrated by a description of various embodiments and while these embodiments have been described in considerable detail, it is not the intention of the applicant to restrict or in any way limit the scope of the appended claims to such detail. Additional advantages and modifications will readily appear to those skilled in the art. The invention in its broader aspects is

therefore not limited to the specific details, representative methods, and illustrative examples shown and described. Accordingly, departures may be made from such details without departing from the spirit or scope of applicant's general inventive concept.

CLAIMS:

1. A pseudo-isothermal reactor for an exothermal reaction, said reactor comprising a reactor shell having a reactor shell volume, said reactor shell volume comprising at least one cooling medium inlet and at least one cooling medium outlet, said reactor shell volume being arranged to hold a cooling medium under pressure,
- said reactor shell comprising a reactant inlet and a product outlet,
- said pseudo-isothermal reactor further comprising a reaction enclosure embedded within said reactor shell volume, said reaction enclosure comprising a reaction zone with a plurality of reaction tubes, an inlet manifold extending between said reactant inlet and said reaction zone, and an outlet manifold extending between said reaction zone and said product outlet
- wherein said cooling medium is arranged to flow between said cooling medium inlet and said cooling medium outlet, around said reaction tubes , so that said reaction tubes are in thermal contact with said cooling medium, and
- wherein said reactor shell volume is dimensioned so as to allow separation of a gas phase from a liquid phase of the cooling medium within the reactor shell volume, such that, during operation of the reactor, cooling medium outlet through at least one cooling medium outlet is substantially in gas phase.
2. A reactor according to claim 1, wherein said reactor is a boiling water reactor.

3. A reactor according to claim 1 or 2, wherein said inlet manifold comprises a unit in thermal contact with said cooling medium.

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4. A reactor according to any of the claims 1 to 3, wherein said reactor comprises a demister upstream of said at least one cooling medium outlet, said demister being arranged to separate liquid droplets from the cooling medium in gas phase and to recirculate said liquid droplets within the reaction shell volume.

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5. A reactor according to any of the preceding claims, wherein said reactor comprises a first tube sheet between said reaction zone and said outlet manifold, and a second tube sheet between said inlet manifold and said reaction zone.

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6. A reactor according to claim 5, wherein said reactor further comprises a fastening piece arranged to fasten said reaction enclosure to an inside of said reactor shell.

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7. A reactor according to claim 6, wherein said fastening piece comprises cooling medium passages in order to let cooling medium pass between said reaction enclosure and the inside of said reactor shell, along at least part of said inlet manifold and said reaction zone.

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8. A reactor according to any of the claims 5 to 7,
wherein said second tube sheet and said fastening
piece are in substantially one plane.
- 5 9. A reactor according to any of the claims 5 to 7,
wherein said second tube sheet is positioned down-
stream along said reaction enclosure compared to the
position of said fastening piece.
- 10 10. A reactor according to claim 5, wherein an outer
circumference of said second tube sheet is distanced
from said reactor shell, at least over a majority of
said outer circumference.
- 15 11. A reactor according to claim 10, wherein said
second tube sheet is fastened to said reactor shell by
an expansion joint.
- 20 12. A reactor according to claim 11, wherein said ex-
pansion joint comprise one or more springs or rollers.
- 25 13. A reactor according to any of the preceding
claims, wherein the reactor comprises one or more
cooling medium flow assisting devices for assisting
circulation and/or recirculation of cooling medium
around and/or along the reaction tubes.
- 30 14. A reactor according to any of the preceding
claims, wherein said reaction tubes comprise catalyst
material.

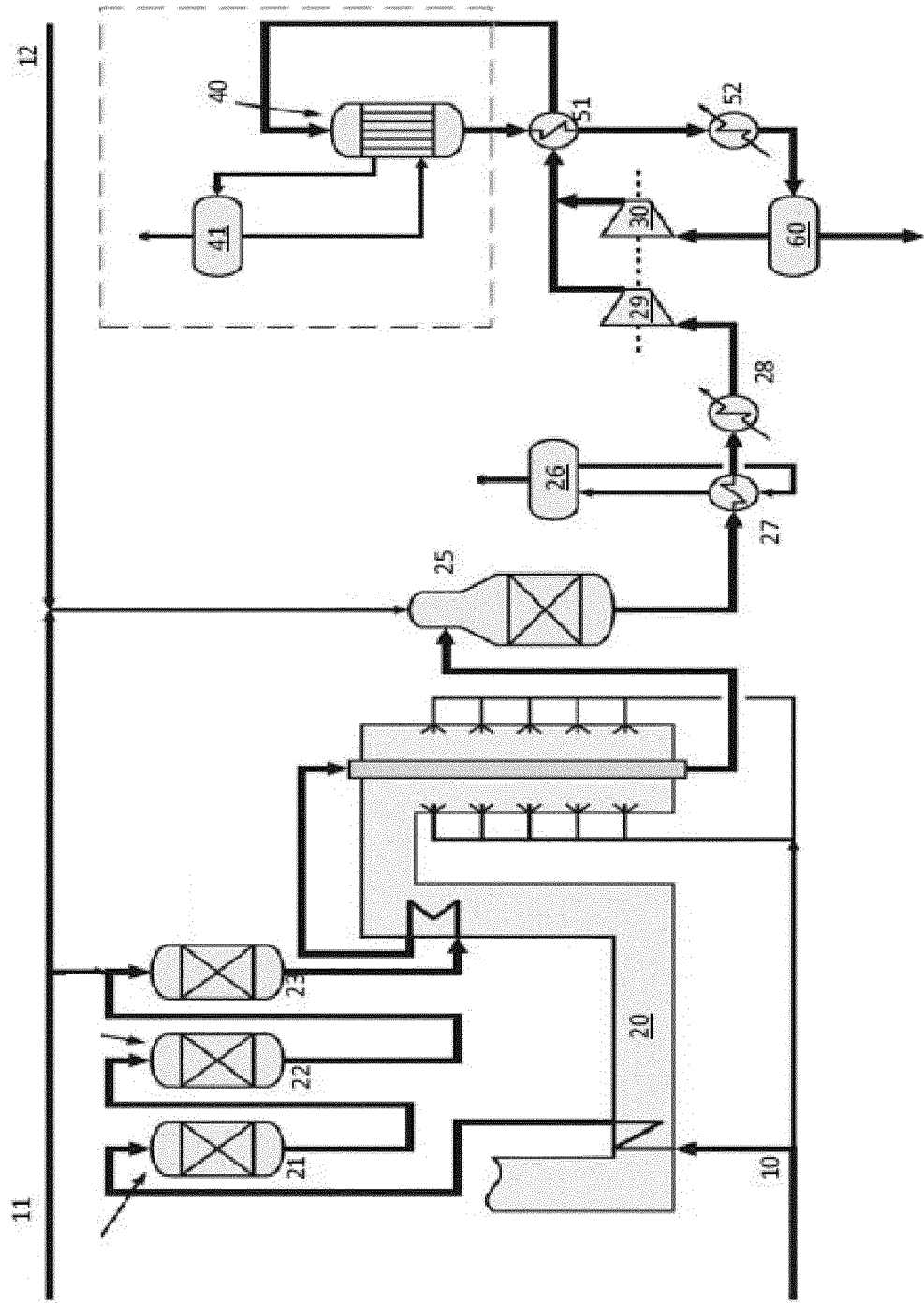


Fig. 1

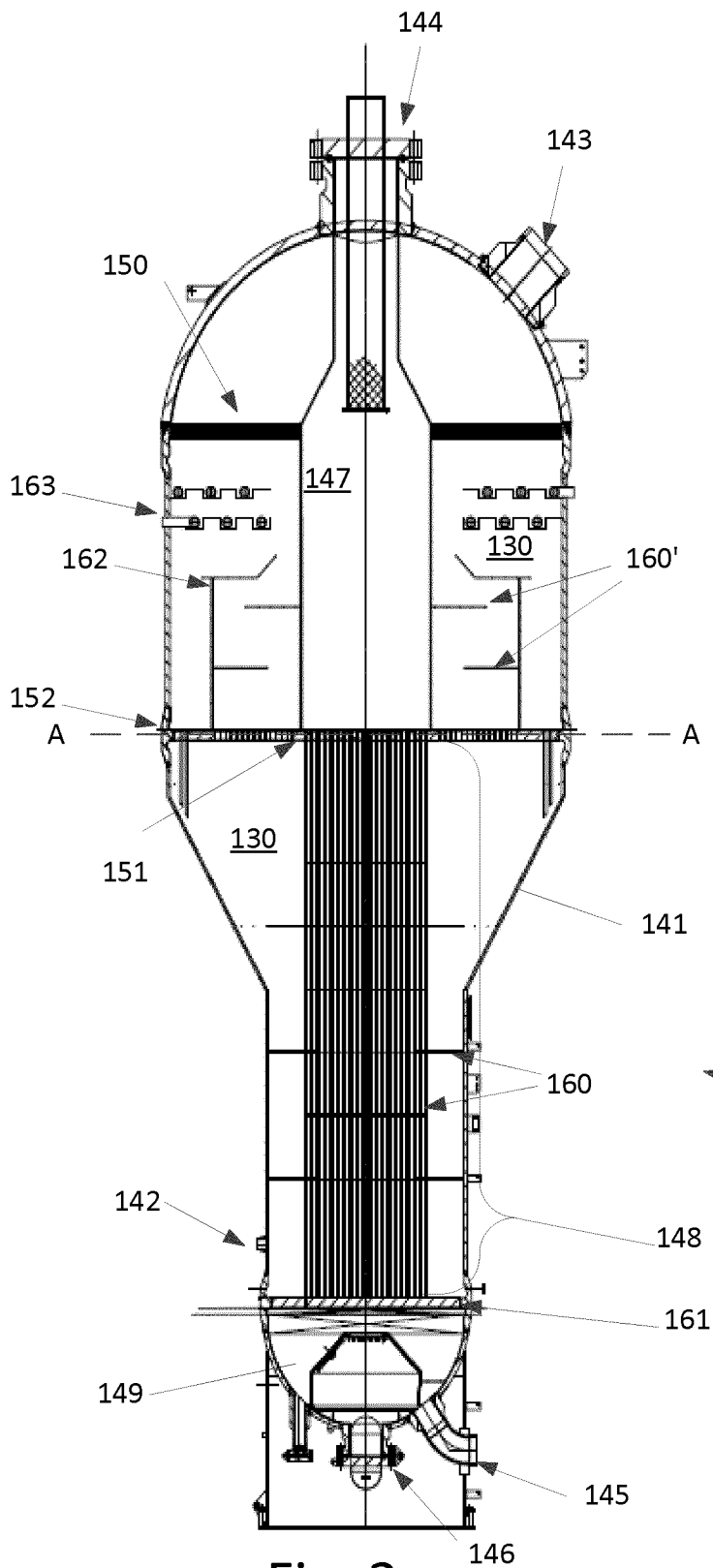


Fig. 2a

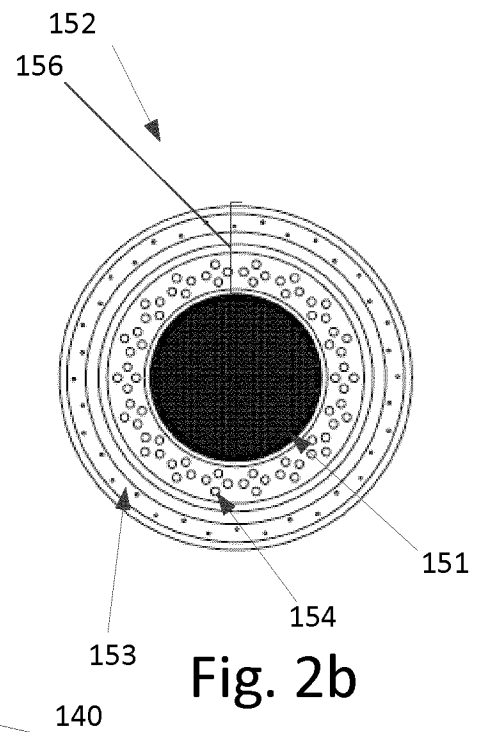
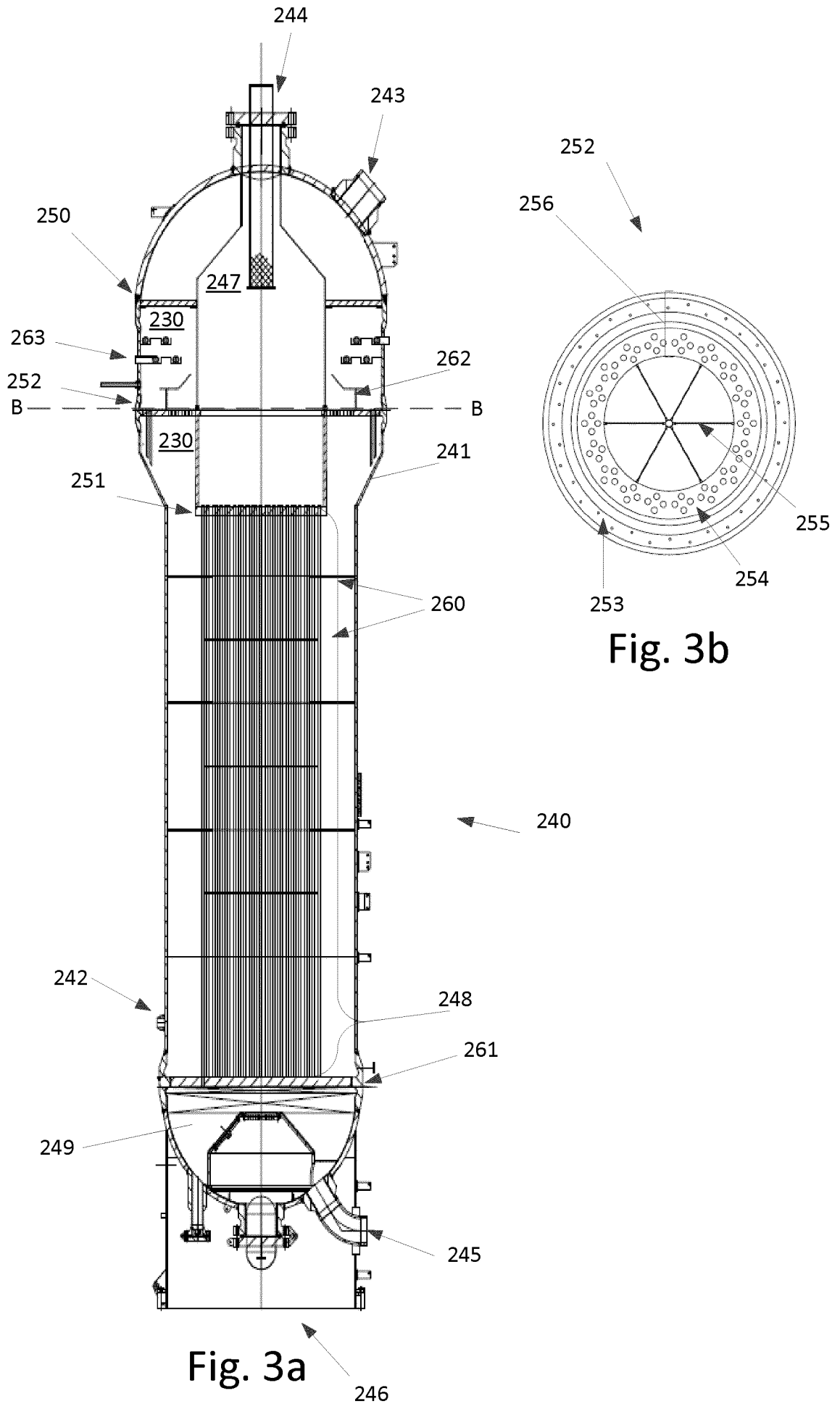


Fig. 2b



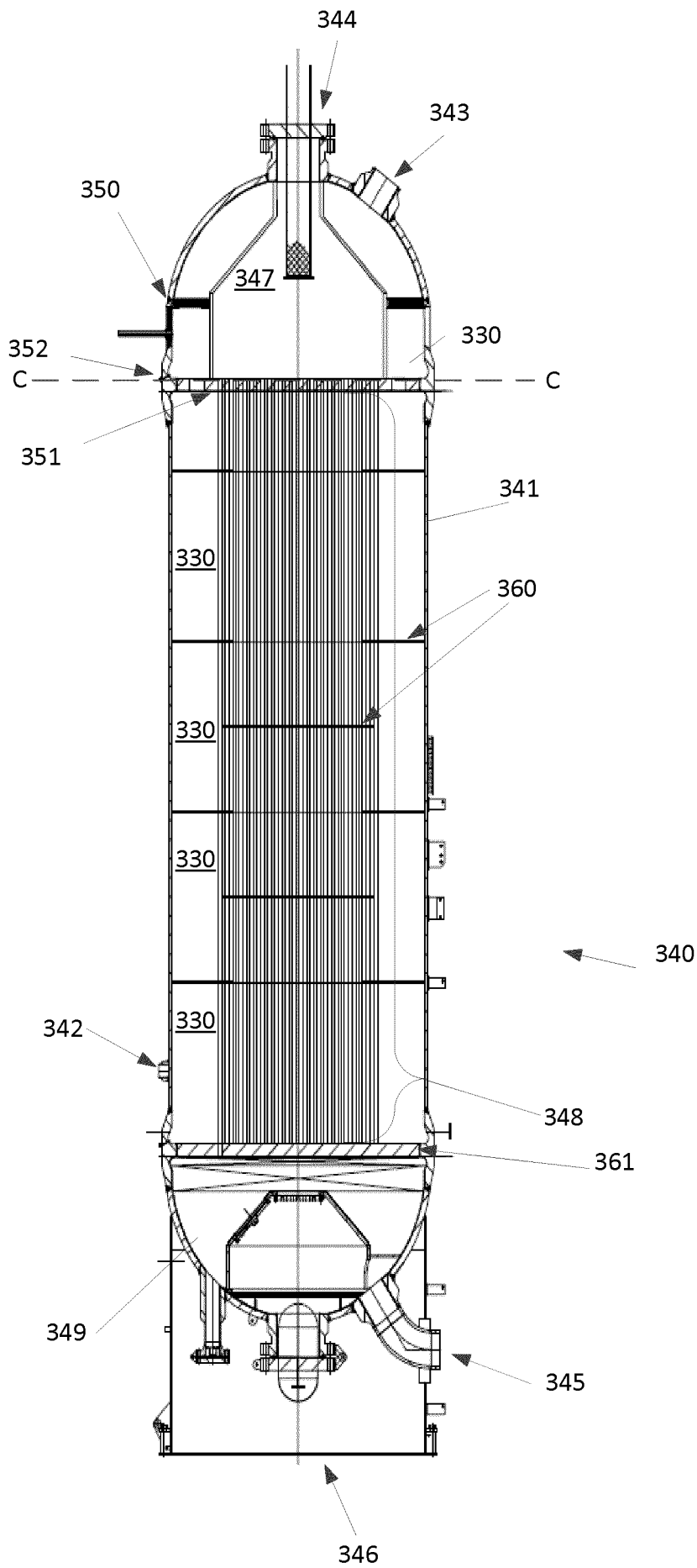


Fig. 4a

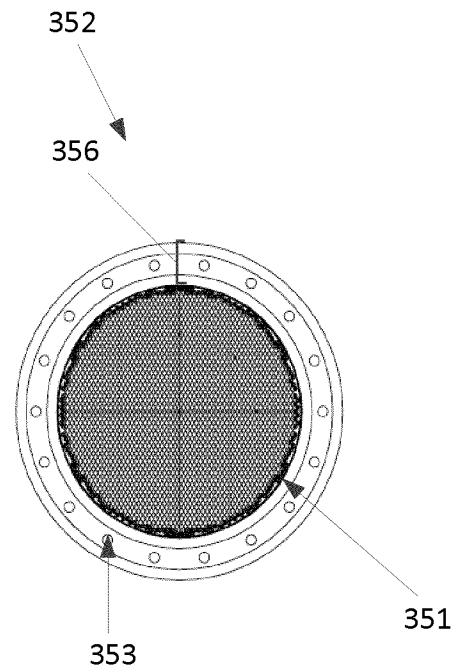


Fig. 4b

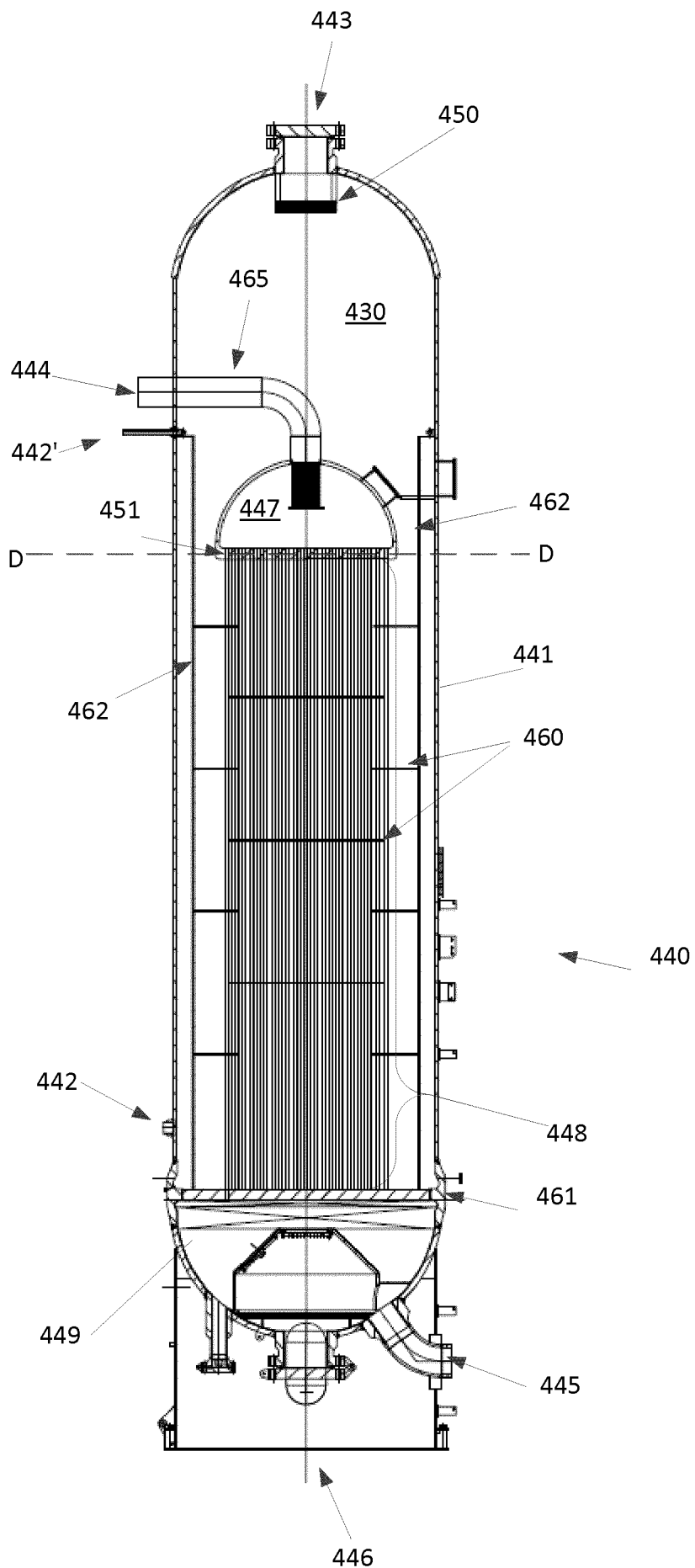


Fig. 5a

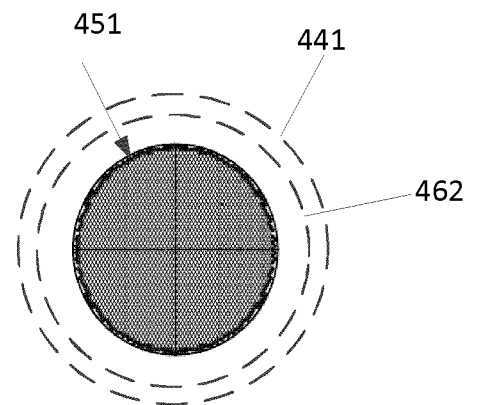


Fig. 5b

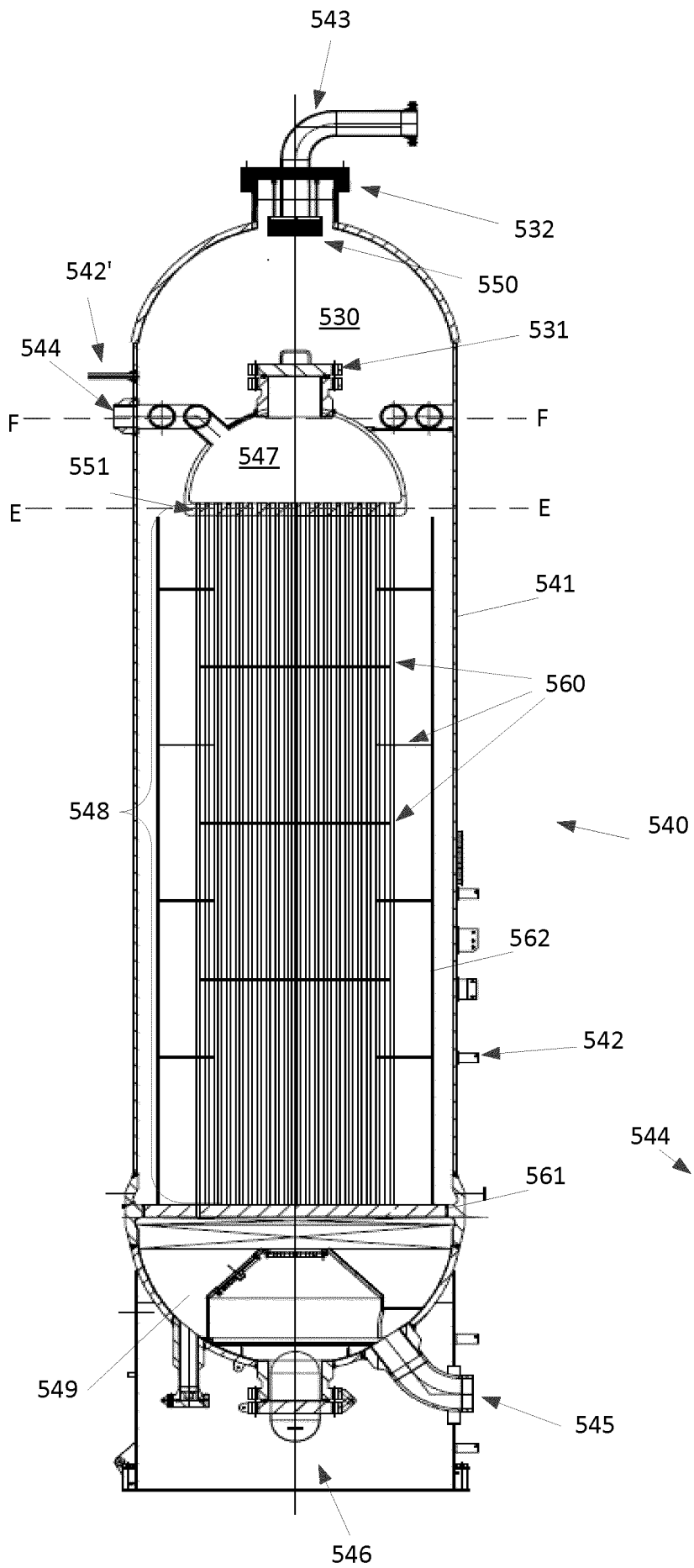


Fig. 6a

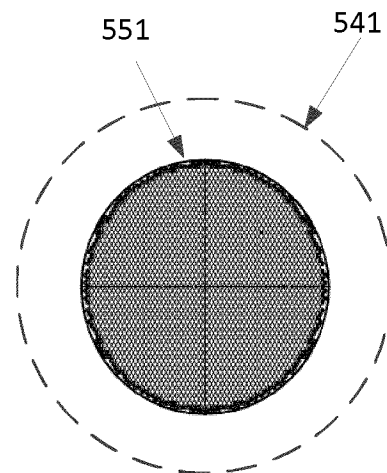


Fig. 6b

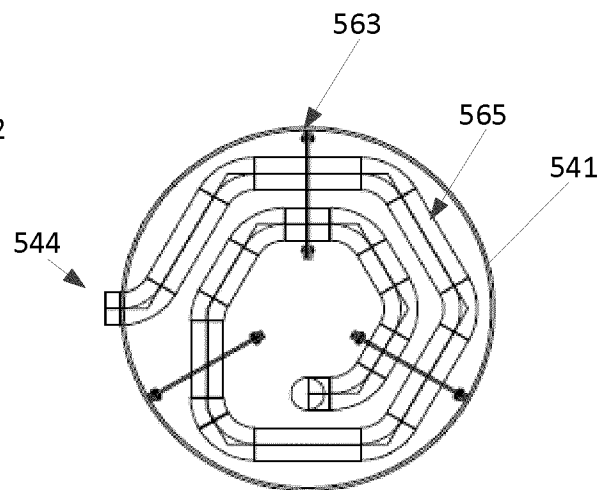


Fig. 6c

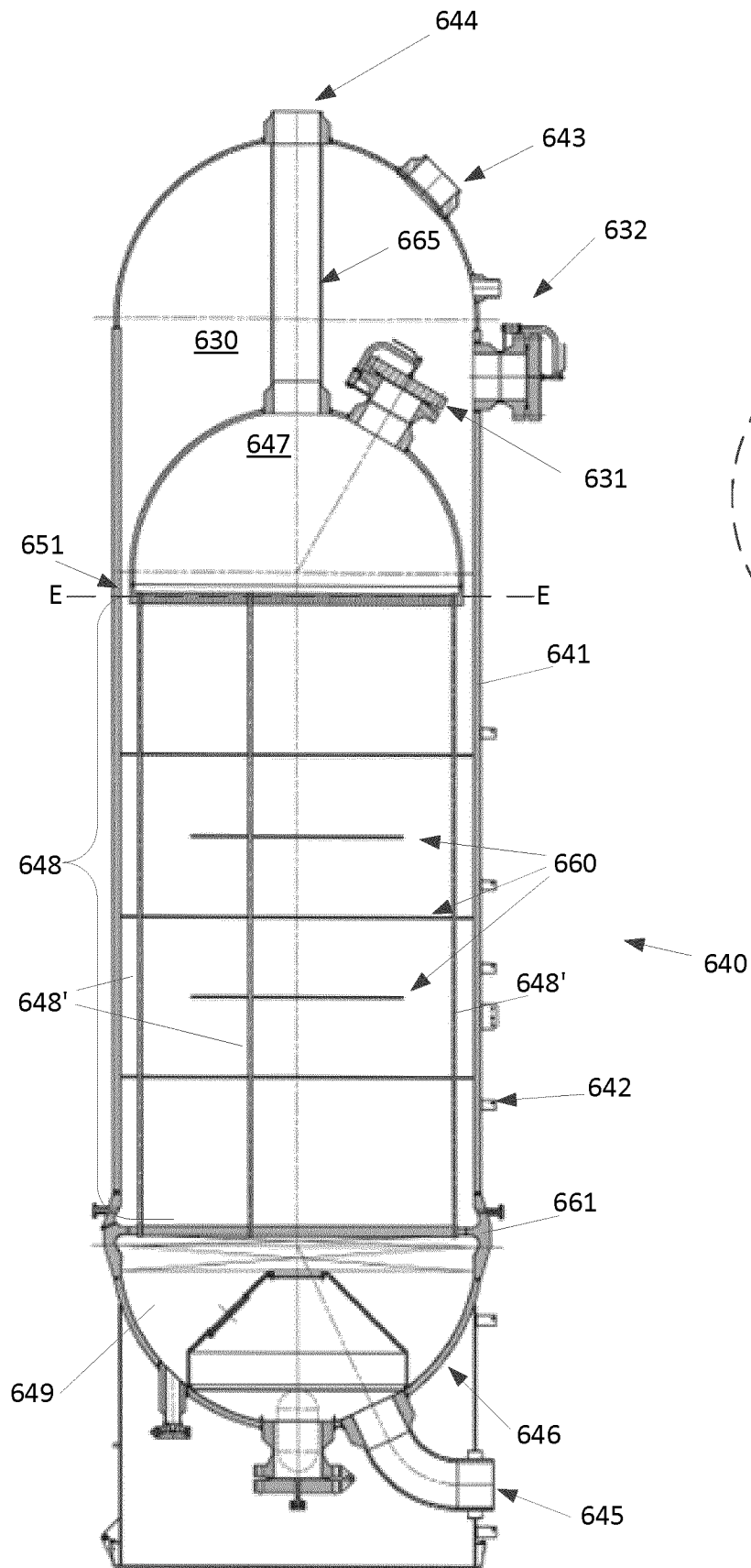


Fig. 7a

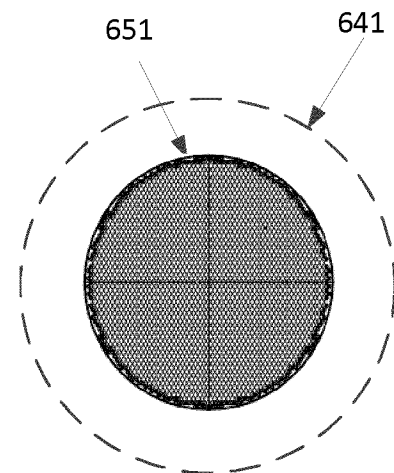


Fig. 7b

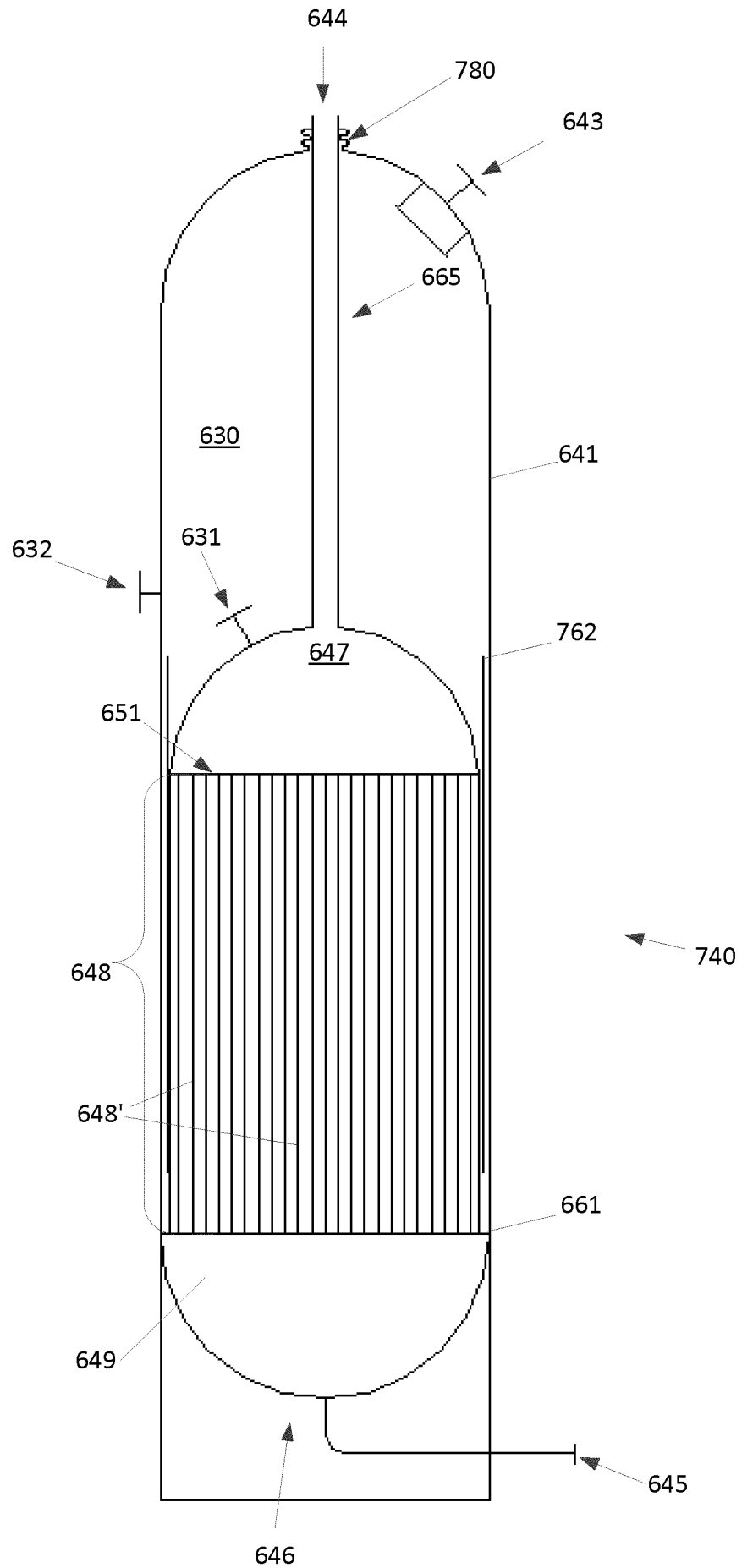


Fig. 8

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2015/065856

A. CLASSIFICATION OF SUBJECT MATTER
INV. B01J8/06
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

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	DE 199 48 585 A1 (KRUPP UHDE GMBH [DE]) 8 March 2001 (2001-03-08) column 2, lines 30-46; figure 1 -----	1,2,5,6, 14
A	US 2008/023175 A1 (LEHR MANFRED [DE] ET AL) 31 January 2008 (2008-01-31) paragraphs [0238], [0239]; figure 3 -----	1,4
A	US 2007/036697 A1 (GUTLHUBER FRIEDRICH [DE] ET AL) 15 February 2007 (2007-02-15) -----	1



Further documents are listed in the continuation of Box C.



See patent family annex.

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Date of the actual completion of the international search

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Name and mailing address of the ISA/

European Patent Office, P.B. 5818 Patentlaan 2
NL - 2280 HV Rijswijk
Tel. (+31-70) 340-2040,
Fax: (+31-70) 340-3016

Authorized officer

Veronesi, Sergio

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

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