

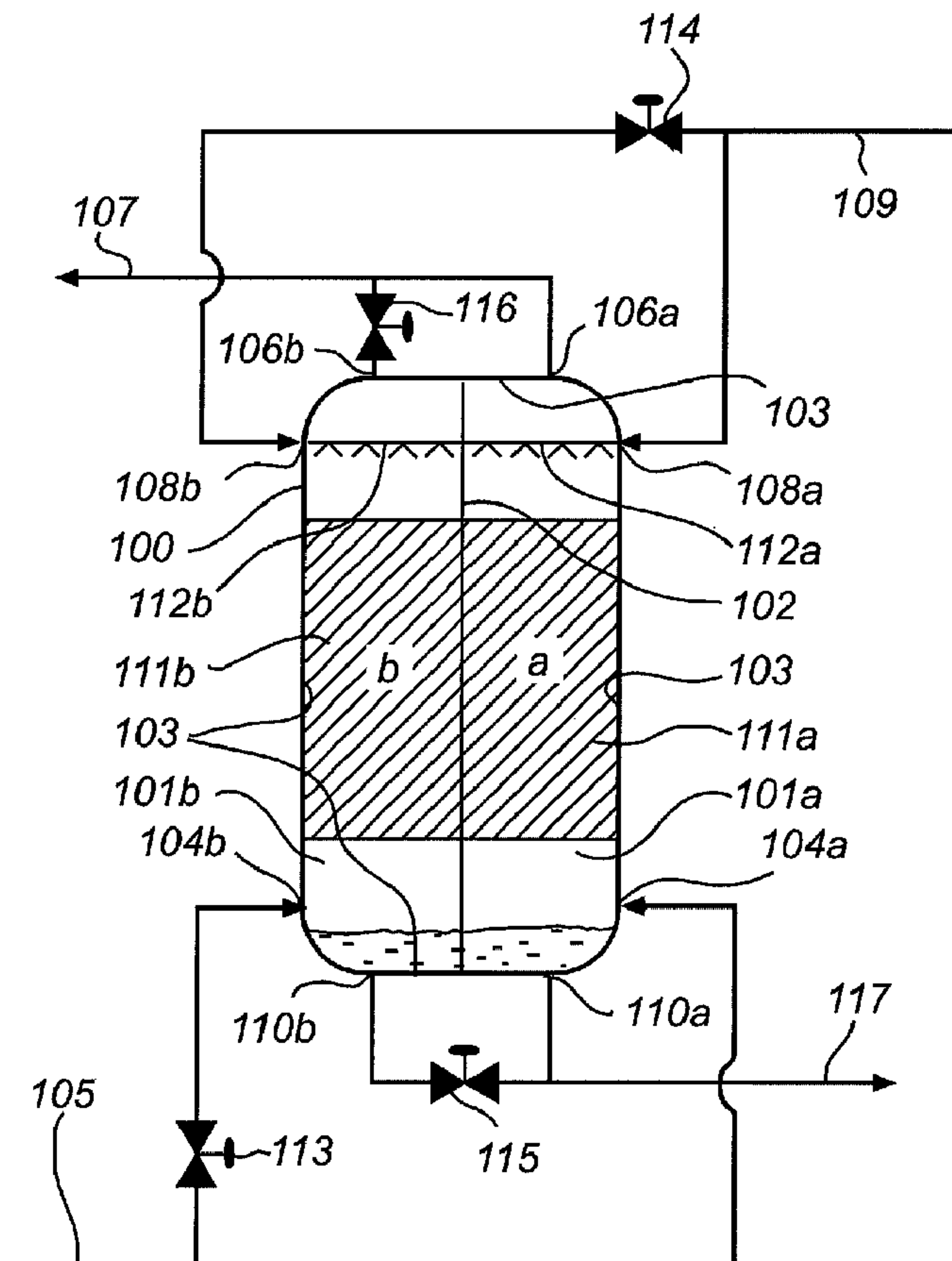


(86) **Date de dépôt PCT/PCT Filing Date:** 2012/05/01
(87) **Date publication PCT/PCT Publication Date:** 2012/11/08
(45) **Date de délivrance/Issue Date:** 2017/02/28
(85) **Entrée phase nationale/National Entry:** 2013/10/30
(86) **N° demande PCT/PCT Application No.:** IB 2012/000844
(87) **N° publication PCT/PCT Publication No.:** 2012/150493
(30) **Priorité/Priority:** 2011/05/02 (EP11164420.9)

(51) **Cl.Int./Int.Cl. B01D 53/14** (2006.01),
B01D 53/78 (2006.01)
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(54) **Titre : RECIPIENT DE MISE EN CONTACT D'UN GAZ ET D'UN LIQUIDE ET SON UTILISATION DANS UN SYSTEME DE TRAITEMENT DE GAZ DE CARNEAU**

(54) **Title: GAS/LIQUID CONTACTING VESSEL AND THE USE THEREOF IN A FLUE GAS TREATMENT SYSTEM**



(57) **Abrégé/Abstract:**

The proposed invention relates to a gas/liquid contacting vessel (100) for treatment of a gas stream at varying mass flow rates, said vessel comprising at least two distinct gas/liquid contacting compartments (101a, 101 b) separated from each other by a



(57) Abrégé(suite)/Abstract(continued):

substantially vertical partition (102), each compartment having a gas inlet (104a, 104b) and a liquid outlet (110a, 110b) near a bottom end thereof and a gas outlet (106a, 106b) and a liquid inlet (108a, 108b) near a top end thereof, and a mass transfer device (111a, 111b) arranged between said bottom end and top end, wherein one of said compartments is operable for gas/liquid contacting independently of another of said compartments. The proposed invention further relates to a flue gas treatment system for removal of carbon dioxide (CO₂) from a flue gas using a liquid absorbent and to a power plant comprising such a gas/liquid contacting vessel or flue gas treatment system.

(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property
Organization
International Bureau



(43) International Publication Date
8 November 2012 (08.11.2012)

(10) International Publication Number
WO 2012/150493 A1

- (51) International Patent Classification:
B01D 53/14 (2006.01) *B01D 53/78* (2006.01)
- (21) International Application Number:
PCT/IB2012/000844
- (22) International Filing Date:
1 May 2012 (01.05.2012)
- (25) Filing Language: English
- (26) Publication Language: English
- (30) Priority Data:
11164420.9 2 May 2011 (02.05.2011) EP
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- (81) Designated States (unless otherwise indicated, for every kind of national protection available): AE, AG, AL, AM,

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

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

Declarations under Rule 4.17:

- as to applicant's entitlement to apply for and be granted a patent (Rule 4.17(ii))
- as to the applicant's entitlement to claim the priority of the earlier application (Rule 4.17(iii))

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(54) Title: GAS/LIQUID CONTACTING VESSEL AND THE USE THEREOF IN A FLUE GAS TREATMENT SYSTEM

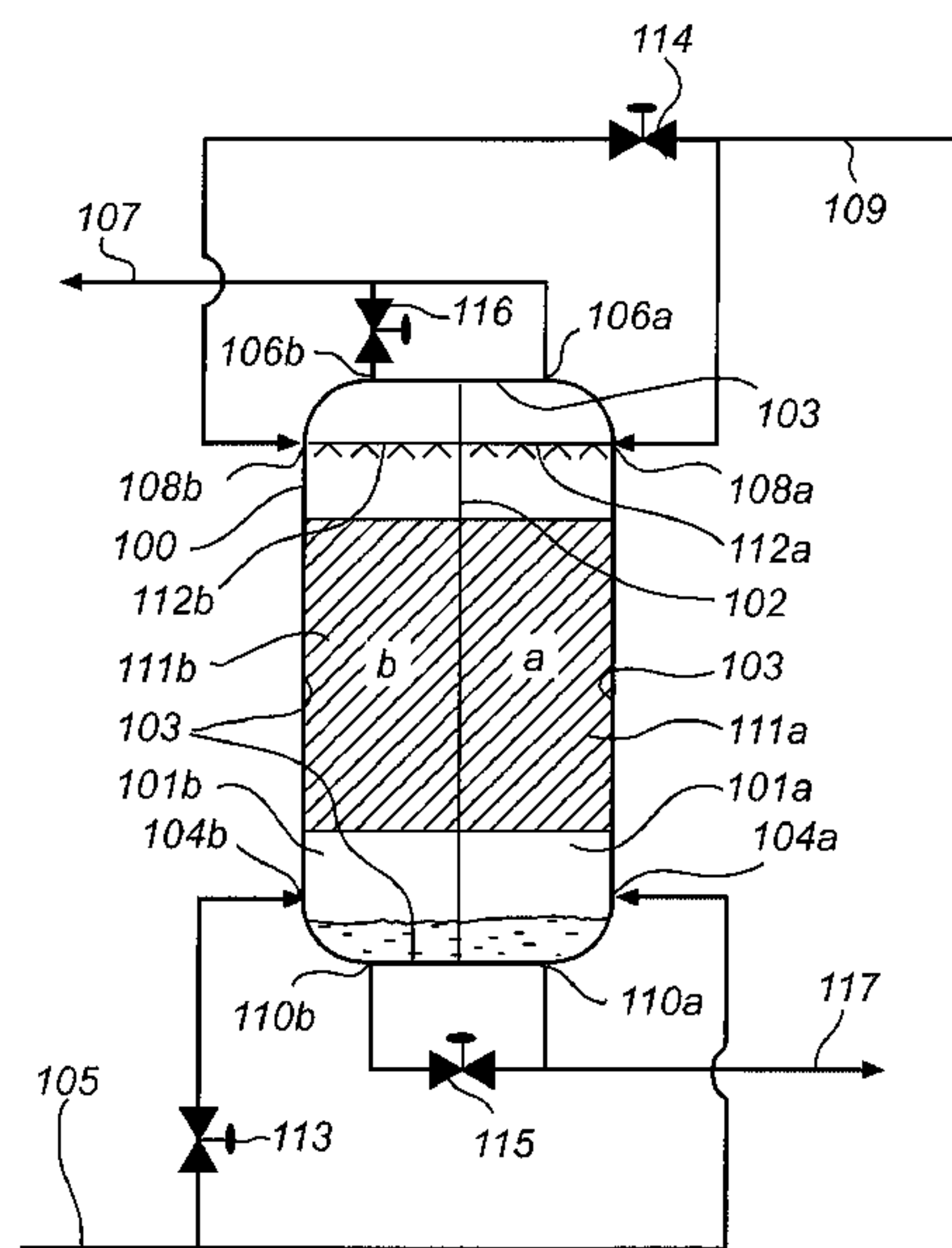


Fig. 1

(57) Abstract: The proposed invention relates to a gas/liquid contacting vessel (100) for treatment of a gas stream at varying mass flow rates, said vessel comprising at least two distinct gas/liquid contacting compartments (101a, 101b) separated from each other by a substantially vertical partition (102), each compartment having a gas inlet (104a, 104b) and a liquid outlet (110a, 110b) near a bottom end thereof and a gas outlet (106a, 106b) and a liquid inlet (108a, 108b) near a top end thereof, and a mass transfer device (111a, 111b) arranged between said bottom end and top end, wherein one of said compartments is operable for gas/liquid contacting independently of another of said compartments. The proposed invention further relates to a flue gas treatment system for removal of carbon dioxide (CO₂) from a flue gas using a liquid absorbent and to a power plant comprising such a gas/liquid contacting vessel or flue gas treatment system.

WO 2012/150493 A1

Published:

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

GAS/LIQUID CONTACTING VESSEL AND THE USE THEREOF IN A FLUE GAS TREATMENT SYSTEM

Field of the invention

[0001] The proposed invention relates to a gas/liquid contacting vessel for treatment of a gas stream, and to a flue gas treatment system for removal of carbon dioxide (CO₂) from a flue gas using a liquid absorbent.

Background

[0002] In the combustion of a fuel, such as coal, oil, peat, waste, etc., in a combustion plant, such as those associated with boiler systems for providing steam to a power plant, a hot process gas (or flue gas) is generated. Such a flue gas will often contain, among other things, carbon dioxide (CO₂). The negative environmental effects of releasing carbon dioxide to the atmosphere have been widely recognized, and have resulted in the development of processes adapted for removing carbon dioxide from the flue gas generated in the combustion of the above mentioned fuels.

[0003] Many of the developed flue gas cleaning processes involve contacting the flue gas with an absorbent liquid capable of absorbing CO₂ from the gas to produce a flue gas which is lean in CO₂ and an absorbent which is rich in CO₂. In processes used for industrial separation of CO₂, liquid solutions or slurries comprising amine compounds, e.g. monoethanolamine (MEA), or ammonia are commonly used as absorbents. A CO₂ absorber is employed to establish suitable conditions (temperature, pressure, turbulence, etc.) for chemical absorption of CO₂ into the absorbent from a mixed gas stream. The "rich" absorbent containing absorbed CO₂ is subsequently regenerated, whereby absorbed CO₂ is separated from the absorbent, and the regenerated "lean" absorbent is then reused in the CO₂ absorption process. Thus, a circulating absorbent stream is formed. Regeneration is generally achieved by heating the absorbent in a reboiler to a temperature at which CO₂ is released from the absorbent.

[0004] Another type of flue gas treatment process, is the chilled ammonia process. The chilled ammonia based systems and processes (CAP) provide a relatively low cost means for capturing and removing CO₂ from a gas stream, such as, for example, a post combustion flue gas stream. An example of such a system and process has previously been disclosed in the published international patent application WO 2006/022885 titled "Ultra Cleaning of Combustion Gas Including the Removal of CO₂". The general principle of the chilled ammonia process resembles

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that of the amine based process described above. The term "chilled" refers to the operating temperature of the absorber vessel in the chilled ammonia process, which is generally in the range of 0-20 °C, and preferably in the range of 0-10 °C. In the process described in WO 2006/022885, the absorption of CO₂ from a flue gas stream is achieved by contacting a chilled ammonia ionic solution or slurry in an absorber with a flue gas stream containing CO₂. The ionic solution containing absorbed CO₂ is subsequently regenerated by heating under increased pressure, whereby CO₂ is removed from the ionic solution, and the regenerated ionic solution can be reused in the CO₂ absorption process.

[0005] The absorbers and regenerators in both of the above described techniques rely on solvent contacting flue gas or steam, in order to capture and release CO₂, respectively. In order for the necessary mass transfer to occur efficiently, the packing in the columns must be adequately wetted, so as to prevent breakthrough of flue gas or steam. The design of these columns draws upon experience in the chemical industry, whereby the majority of operation occurs at or near the "design point".

[0006] Many industrial combustion processes, however, operate at varying loads, resulting in varying flue gas flow rates. One example is the combined cycle power plant (CCPP). One of the large advantages of CCPP is the operational flexibility, in which the entire load range can be covered within short periods of time. For this reason, CCPP are viewed as a means of complementing the highly variable power output from more unpredictable renewable sources (e.g. wind, solar). The flue gas flow rate is a strong function of the gas turbine load, with the value almost halving between 100% and 50% gas turbine load. When implementing a CO₂ absorption system in a CCPP, the varying flue gas flow rate is problematic because the absorber and regenerator columns in the absorption system are rarely operated near their design point, thereby resulting in both technical and financial inefficiency. In particular, at low loads, the fluid flow rate may be too small to uniformly wet the packing, thereby permitting breakthrough of the flue gas.

[0007] One approach to overcome this problem is by using multiple trains (consisting of several smaller units), but this is an expensive solution that could be difficult to control.

Summary of the invention

[0008]

[0009] According to aspects illustrated herein, there is provided a gas/liquid contacting vessel for treatment of a gas stream at varying mass flow rates, said vessel comprising

at least two distinct gas/liquid contacting compartments separated from each other by a substantially vertical partition, each compartment having a gas inlet and a liquid outlet near a bottom end thereof and a gas outlet and a liquid inlet near a top end thereof, and a mass transfer device arranged between said bottom end and top end,

wherein one of said compartments is operable for gas/liquid contacting independently of another of said compartments.

[0010] In other words, it is proposed to utilize a single column that is split into two or more substantially vertical compartments, to which the incoming fluids and gases can be distributed according to the mass flow rate of the flue gas. This allows for the ratio of flow rate to residence time (liquid-to-gas ratio) to be maintained closer to a predetermined value than possible with conventional single compartment vessels. This means the operation can be conducted closer to the design point and that CO₂ capture efficiency can be kept high across a larger load range. Furthermore, the liquid absorbent flow rate can be optimized, resulting in lower liquid absorbent consumption. Also, in systems utilizing regeneration of the liquid absorbent by heating, this in turn leads to reduced regenerator steam consumption when operating the system at partial load.

[0011] A gas/liquid contacting vessel, such as an absorber vessel, generally comprises a substantially cylindrical container, wherein at least a portion of the inner volume of the container is filled with a mass transfer device operative for facilitating contact between a gas and a liquid. The gas/liquid contacting vessel is commonly arranged in a substantially vertical orientation and configured to receive a liquid through a liquid inlet near the top of the vessel and a gas through a gas inlet near the bottom of the vessel. During operation of the vessel, a gas fed through the gas inlet and a liquid fed through the liquid inlet are brought into contact with each other in the mass transfer device.

[0012] The bottom end generally refers to a section of the vessel below a mass transfer device, whereas the top end generally refers to a section of the vessel above a mass transfer device. The gas inlet and liquid outlet may generally be positioned below the mass transfer device, and the gas outlet and liquid inlet may generally be positioned above the mass transfer device. The gas inlet may be positioned between the liquid outlet and the mass transfer device.

[0013] According to some embodiments, all of the gas inlets of the gas/liquid contacting compartments are fluidly connectable to a common gas source.

[0014] According to some embodiments, all of the liquid inlets of the gas/liquid contacting compartments are fluidly connectable to a common liquid source.

[0015] According to some embodiments, the gas/liquid contacting vessel comprises shut-off means, whereby gas and/or liquid flow to a gas/liquid contacting compartment can be blocked independently of another of said compartments.

[0016] According to some embodiments, the mass transfer devices comprised packed beds.

[0017] According to some embodiments, the gas/liquid contacting vessel defines an inner volume having a circular horizontal cross-section, and the at least two distinct gas/liquid contacting compartments are defined by an inside wall of the vessel and one or more substantially vertical walls extending throughout a substantially vertical cross-section of the inner volume of the vessel.

[0018] According to other embodiments, the gas/liquid contacting vessel defines an inner volume having a circular horizontal cross-section, and at least one of the distinct gas/liquid contacting compartments is defined by a tubular wall extending substantially vertically throughout the inner volume of the vessel.

[0019] According to some embodiments, the gas/liquid contacting vessel has two gas/liquid contacting compartments. For practical reasons, two gas/liquid contacting compartments are often sufficient for achieving a substantially improved efficiency of the vessel during large variations in the mass flow rate of the flue gas. Two gas/liquid contacting compartments also involve a minimum of adaption of present vessel designs for implementation. An additional advantage is the potential use of the vessel in a combustion plant utilizing, or prepared for, flue gas recirculation (FGR). In combustion plants utilizing FGR, often about 50 percent of the flue gas produced is recirculated back to the combustion process, resulting in an about 50 percent decrease in the mass flow rate of the flue gas to the flue gas treatment system. Thus, a gas/liquid contacting vessel having two gas/liquid contacting compartments may easily be adapted for operation with flue gas recirculation.

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[0019a] According to another aspect, there is provided a flue gas treatment system for removal of carbon dioxide (CO₂) from a flue gas using a liquid absorbent, the system comprising: a CO₂ absorber vessel including: at least two distinct gas/liquid contacting compartments separated from each other by a substantially vertical partition, each compartment having a gas inlet and a liquid outlet near a bottom end thereof and a gas outlet and a liquid inlet near a top end thereof, and a mass transfer device arranged between said bottom end and top end, wherein one of said compartments is operable for gas/liquid contacting independently of another of said compartments; and an absorbent regenerator vessel having at least one liquid inlet and at least one liquid outlet, each of which are in fluid communication with the CO₂ absorber vessel.

[0020] According to other aspects illustrated herein, there is provided a flue gas treatment system for removal of carbon dioxide (CO₂) from a flue gas using a liquid absorbent, comprising

15 a CO₂ absorber vessel and
an absorbent regenerator vessel,

wherein the CO₂ absorber vessel comprises a gas/liquid contacting vessel for treatment of a gas stream at varying mass flow rates, said vessel comprising

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at least two distinct gas/liquid contacting compartments separated from each other by a substantially vertical partition, each compartment having a gas inlet and a liquid outlet near a bottom end and a gas outlet and a liquid inlet near a top end, and a mass transfer device arranged between said bottom end and top end,

wherein one of said compartments is operable for gas/liquid contacting independently of another of said compartments.

[0021] The gas/liquid contacting vessel of the flue gas treatment system may be further defined as described above with reference to the first aspect.

[0022] According to some embodiments of the flue gas treatment system, each of said CO₂ absorber vessel and said absorbent regenerator vessel comprise a gas/liquid contacting vessel as defined above.

[0023] According to some embodiments, said CO₂ absorber vessel and said absorbent regenerator vessel each comprises two gas/liquid contacting compartments.

[0024] According to some embodiments, the flue gas treatment system is selected from the group consisting of an amine based gas treatment system and an ammonia based gas treatment system, such as a chilled ammonia based gas treatment system.

[0025] According to other aspects illustrated herein, there is provided a combined cycle power plant comprising a gas/liquid contacting vessel or a flue gas treatment system according to the aspects described above.

[0026] According to other aspects illustrated herein, there is provided the use of a gas/liquid contacting vessel or a flue gas treatment system according to the aspects described above for removal of CO₂ from a flue gas stream.

[0027] According to other aspects illustrated herein, there is provided a method of operating a gas/liquid contacting vessel according to the aspects described above, comprising

- a) determining the mass flow rate of a flue gas stream to be treated,
- b) opening or blocking one or more gas/liquid contacting compartment(s) of a gas/liquid contacting vessel to adjust the capacity of the gas/liquid contacting vessel to the mass flow rate of the flue gas stream determined in a), and
- c) treating the flue gas stream by contacting it with a liquid absorbent in the open gas/liquid contacting compartment(s) of the gas/liquid contacting vessel.

[0028] According to some embodiments, the gas/liquid contacting vessel is a CO₂ absorber vessel of a flue gas treatment system according to the aspects described above.

[0029] According to some embodiments, the flue gas stream to be treated in the method is produced in a combustion plant utilizing, or prepared for, flue gas recirculation.

[0030] The above described and other features are exemplified by the following figures and detailed description. Further objects and features of the present invention will be apparent from the description and the claims.

Brief description of the Drawings

[0031] Referring now to the figures, which are exemplary embodiments, and wherein the like elements are numbered alike:

[0032] FIG. 1 is a diagram schematically depicting a gas/liquid contacting vessel, e.g. an absorber vessel, having two distinct gas/liquid contacting compartments.

[0033] FIG. 2 is a diagram schematically depicting a gas/liquid contacting vessel, e.g. a regenerator vessel, having two distinct gas/liquid contacting compartments.

[0034] FIG. 3a-3e are schematic horizontal cross section views of gas/liquid contacting vessels having different substantially vertical partition configurations.

[0035] FIG. 4 is a diagram schematically depicting an amine based carbon dioxide (CO₂) capture system wherein the CO₂ absorber vessel and liquid absorbent regenerator vessel both comprises two distinct gas/liquid contacting compartments.

Detailed description of preferred embodiments

[0036] Herein, the inventive concept as applied to the absorber and/or regenerator vessels of an amine absorption based CO₂ capture system will be described in detail with reference to the drawings. It is realized that the inventive concept may also be applied to other gas/liquid contacting components of a flue gas treatment system, for example water wash units for removal of trace contaminants, strippers and direct contact coolers/heaters.

[0037] The term "gas", as used herein, is intended to encompass gases as well as liquids in vapor form. Specifically, the gas processed in the gas/liquid contacting vessels described herein may be a gas, such as CO₂, or a liquid, for example water, in vapor form.

[0038] The term "in fluid contact with" with regard to two components of a

[0039] system, one component being upstream of the other, then during the normal operation of the system, essentially all of the fluid passing through

[0040] the system passes first through the upstream component and then through

the other component. The terms "fluid contact" and "fluid communication" as used herein are synonymous.

[0041] The term "configured to receive", as used herein, means that the system may comprise piping, tubing, fittings and/or other similar means for fluid transport, as well as suitable pumps or other similar liquid displacement devices, such that a fluid may be transported from one position to another.

[0042] FIG. 1 schematically depicts a gas/liquid contacting vessel 100, e.g. an absorber vessel, having two distinct gas/liquid contacting compartments 101a, 101b separated from each other by a substantially vertical partition 102.

[0043] The gas/liquid contacting vessel 100 comprises a substantially vertically oriented substantially cylindrical container, defining an inner volume having a circular horizontal cross-section. The inner volume of the gas/liquid contacting vessel 100 is divided into two distinct gas/liquid contacting compartments 101a, 101b by an inside wall 103 of the vessel, i.e. an inner surface of an exterior wall of the vessel, and one or more substantially vertical walls 102 extending throughout a substantially vertical cross-section of the inner volume of the vessel. The gas/liquid contacting vessel 100 and substantially vertical partition(s) can be of any suitable construction material, e.g. stainless steel, as will be recognized by a person skilled in the art. The partition(s) may be attached to the inside walls, e.g. by welding or other suitable techniques, such that the partition(s) together with the inside walls of the vessel define the distinct gas/liquid contacting compartments.

[0044] The gas/liquid contacting compartments 101a, 101b are distinct, meaning that gas and or liquid in one compartment may be prevented from entering the other compartment. This allows one of the two compartments to be operable for gas/liquid contacting independently of the other compartment.

[0045] Each gas/liquid contacting compartment 101a, 101b has a gas inlet 104a, 104b arranged near a bottom end of the compartment, which is configured to receive a gas stream from a gas duct 105, and a gas outlet 106a, 106b arranged near a top end of the compartment configured to discharge the gas stream from the compartment via a gas duct 107. Each gas/liquid contacting compartment 101a, 101b further has a liquid inlet 108a, 108b arranged near a top end of the compartment, which is configured to receive a liquid absorbent from a liquid

absorbent supply duct 109, and a liquid outlet 110a, 110b arranged near a bottom end of the compartment configured to discharge the liquid absorbent from the compartment to a liquid discharge duct 117.

[0046] Each gas/liquid contacting compartment 101a, 101b further comprises a mass transfer device 111a, 111b operative for facilitating contact between a gas and a liquid, arranged between said gas inlet 104a, 104b and said liquid inlet 108a, 108b.

[0047] The mass transfer device 111a, 111b is configured to provide efficient contact between a gas stream and an liquid stream fed through the respective gas and liquid inlets of the compartment. The mass transfer device may, e.g., comprise one or more commonly known structured or random packing materials, or a combination thereof, provided in the form of an absorption column, such as a packed bed column. The mass transfer device may preferably be arranged to operate in countercurrent flow mode. As an example, the mass transfer device may comprise an absorption column arranged to operate in countercurrent flow mode, wherein the gas stream is fed near a bottom end of the compartment, below the mass transfer device, and a liquid absorbent is fed near a top end of the compartment, above the mass transfer device, such that the gas stream is brought into contact with the liquid absorbent as it rises up through the column. The gas stream then leaves the column near the top of the compartment, while the liquid absorbent leaves the column near the bottom of the compartment.

[0048] Each gas/liquid contacting compartment 101a, 101b may also be provided with a liquid distribution device 112a, 112b, e.g. comprising an array of spray heads, in liquid connection with the liquid inlet 108a, 108b and operative for distributing a liquid fed via the liquid inlet evenly onto the mass transfer device 111a, 111b.

[0049] The gas/liquid contacting compartments 101a, 101b described with reference to FIG. 1 comprise a single mass transfer device. According to alternative embodiments, each gas/liquid contacting compartments may also comprise two or more mass transfer devices arranged in series, such that a gas stream fed through the gas inlet first passes through a first mass transfer device and then passes through a second mass transfer device, etc., before being discharged via the gas outlet. In such embodiments, each gas/liquid contacting compartment may also comprise two or more liquid inlets and, optionally, two or more liquid distribution devices, wherein a first liquid inlet is arranged above the topmost mass transfer device, and a second liquid inlet is arranged between two mass transfer devices. In such embodiments, the gas may be contacted with a first liquid in a first mass transfer device and contacted with a second liquid in a second mass transfer device, etc.

[0050] In order to enable independent operation of one or more of the gas/liquid contacting compartments 101a, 101b, the vessel comprises shut-off means, whereby gas and/or liquid flow to one of the a gas/liquid contacting compartments can be blocked independently of the other of said compartments.

[0051] Referring to the embodiment of FIG. 1, the gas/liquid contacting vessel 100 comprises a system of fluid valves that enables the liquid and/or gas supply to one of the gas/liquid contacting compartments to be opened or closed. The system comprises inlet valves 113, 114 and optionally also outlet valves 115, 116. When both inlet valves 113, 114 are closed, the entire gas stream coming from the gas duct 105 is directed to the gas inlet 104a of gas/liquid contacting compartment 101a, and the entire liquid stream coming from liquid absorbent supply duct 109 is directed to the liquid inlet 108a of gas/liquid contacting compartment 101a. When both inlet valves 113, 114 are open, the gas stream and the liquid stream are instead distributed, e.g. equally, between the two gas/liquid contacting compartments 101a and 101b. Optional outlet valves 115, 116 prevent gas leaving gas/liquid contacting compartment 101a from entering gas/liquid contacting compartment 101b via gas outlet 106b, and/or prevent liquid leaving gas/liquid contacting compartment 101a from entering gas/liquid contacting compartment 101b via liquid outlet 110b.

[0052] The shut-off means, e.g. fluid valves, may be arranged on the gas and/or liquid supply ducts 105, 109 as indicated in FIG. 1. Alternatively, the shut-off means may be arranged directly at the gas and/or liquid inlets 104a, 104b, 106a, 106b or inside the gas/liquid contacting vessel 100 at a partition 102 separating the gas/liquid contacting compartments. For example a valve or damper may be arranged at the partition 102 separating a first and a second gas/liquid contacting compartment, below the mass transfer device, such that said valve or damper, when opened, allows a gas stream fed to the first compartment to be distributed between the first and the second compartment.

[0053] FIG. 2 schematically depicts a regenerator vessel 200, which may for example be employed in an amine based CO₂ absorption system, said regenerator vessel having two distinct gas/liquid contacting compartments 201a and 201b separated from each other by a substantially vertical partition 202. The regenerator vessel 200 of FIG. 2 is similar to the gas/liquid contacting vessel 100 of FIG. 1, but further comprises a reboiler 220 operative for heating liquid absorbent, collected from the bottom of the two distinct gas/liquid contacting compartments, to generate steam. The steam produced in the reboiler 220 may be fed back through gas inlets 204a, 204b to the gas/liquid contacting compartments 201a, 201b. In the gas/liquid contacting compartments 201a, 201b, the steam is contacted with CO₂ rich liquid absorbent in the mass transfer devices 211a, 211b.

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[0054] The regenerator vessel 200 comprises a substantially vertically oriented substantially cylindrical container, defining an inner volume having a circular horizontal cross-section. The inner volume of the gas/liquid contacting vessel 200 is divided into two distinct gas/liquid contacting compartments 201a and 201b by an inside wall 203 of the vessel, i.e. an inner surface of an exterior wall of the vessel, and one or more substantially vertical walls 202 extending throughout a substantially vertical cross-section of the inner volume of the vessel. The gas/liquid contacting vessel 200 and substantially vertical partition(s) can be of any suitable construction material, e.g. stainless steel, as will be recognized by a person skilled in the art. The partition(s) may be attached to the inside walls, e.g. by welding or other suitable techniques, such that the partition(s) together with the inside walls of the vessel define the distinct gas/liquid contacting compartments. The regenerator vessel and gas/liquid contacting compartments may optionally be designed for operation at increased pressure, such as pressures in the range of 1 to 50 bar gauge or in the range of 10 to 30 bar gauge.

[0055] The gas/liquid contacting compartments 201a, 201b are distinct, meaning that gas and or liquid in one compartment may be prevented from entering the other compartment. This allows one of the compartments 201a or 201b to be operable for gas/liquid contacting independently of the other compartment.

[0056] Each gas/liquid contacting compartment 201a, 201b has a gas inlet 204a, 204b arranged near a bottom end of the compartment, which is configured to receive a gas stream (i.e. steam) from the reboiler 220, and a gas outlet 206a, 206b arranged near a top end of the compartment configured to discharge released CO₂ and residual water vapor from the compartment via gas duct 207. Each gas/liquid contacting compartment further has a liquid inlet 208a, 208b arranged near a top end of the compartment, which is configured to receive a CO₂ rich liquid absorbent from the absorber vessel via a liquid absorbent supply duct 209, and a liquid outlet 210a, 210b arranged near a bottom end of the compartment configured to discharge the CO₂ lean liquid absorbent from the compartment to a liquid discharge duct 217. One portion of the discharged CO₂ lean liquid absorbent may be

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returned to the absorber vessel via liquid duct 218 for absorbing more CO₂, while another portion is directed via liquid duct 219 to the reboiler 220 for production of steam for the regeneration process.

[0057] Each gas/liquid contacting compartment 201a, 201b further
5 comprises a mass transfer device 211a, 211b, arranged between said gas inlet 204a, 204b and said liquid inlet 208a, 208b, and operative for facilitating contact between the steam produced by the reboiler 220 and the CO₂ rich liquid absorbent.

[0058] The mass transfer device 211a, 211b may, e.g., comprise one or more commonly known structured or random packing materials, or a combination thereof, provided in the form of an absorption column, such as a packed bed column. The mass transfer device may preferably be arranged to operate in countercurrent flow mode. As an example, the mass transfer device may comprise an absorption column arranged to operate in countercurrent flow mode, wherein the steam from the reboiler is fed near a bottom end of the compartment, below the mass transfer device, and the CO₂ rich liquid absorbent is fed near a top end of the compartment, above the mass transfer device, such that the steam is brought into contact with the liquid absorbent as it rises up through the column.

[0059] Each gas/liquid contacting compartment 201a, 201b may also be provided with a liquid distribution device 212a, 212b, e.g. comprising an array of spray heads, in liquid connection with the liquid inlet 208a, 208b and operative for distributing a liquid fed via the liquid inlet evenly onto the mass transfer device 211a, 211b.

[0060] In order to enable independent operation of one or more of the gas/liquid contacting compartments 201a, 201b, the vessel comprises shut-off means, whereby gas and/or liquid flow to one of the a gas/liquid contacting compartments can be blocked independently of the other of said compartments.

[0061] Referring to the embodiment of FIG. 2, the gas/liquid contacting vessel 200 comprises a system of fluid valves that enables the liquid and/or gas supply to one of the gas/liquid contacting compartments to be opened or closed. The system comprises inlet valves 213, 214 and optionally also outlet valves 215, 216. When both inlet valves 213, 214 are closed, the entire gas stream coming from the gas duct 205 is directed to the gas inlet 204a of gas/liquid contacting compartment 201a, and the entire liquid stream coming from liquid absorbent supply duct 209 is directed to the liquid inlet 208a of gas/liquid contacting compartment 201a. When both inlet valves 213, 214 are open, the gas stream and the liquid stream are instead distributed, e.g. equally, between the two gas/liquid contacting compartments 201a and 201b. Optional outlet valves 215, 216 prevent gas leaving gas/liquid contacting compartment 201a from entering gas/liquid contacting compartment 201b via gas outlet 206b, and/or prevent liquid leaving gas/liquid contacting compartment 201a from entering gas/liquid contacting compartment 201b via liquid outlet 210b.

[0062] The shut-off means, e.g. fluid valves, may be arranged on the gas and/or liquid supply ducts 205, 209 as indicated in FIG. 2. Alternatively, the shut-off means may be arranged directly at the gas and/or liquid inlets 204a, 204b, 206a, 206b or inside the gas/liquid contacting vessel 200 at a partition 202 separating the gas/liquid contacting compartments. For example a valve or damper may be

arranged at the partition 202 separating a first and a second gas/liquid contacting compartment, below the mass transfer device, such that said valve or damper, when opened, allows a gas stream fed to the first compartment to be distributed between the first and the second compartment.

[0063] FIG. 3 schematically depicts horizontal cross section views of gas/liquid contacting vessels, such as the gas/liquid contacting vessel 100 described above with reference to FIG. 1 or the regenerator vessel 200 described above with reference to FIG. 2, having different substantially vertical partition configurations. The various partition configurations could be employed within a gas/liquid contacting vessel comprising a substantially vertically oriented substantially cylindrical container.

[0064] FIG. 3a represents a gas/liquid contacting vessel having two gas/liquid contacting compartments, a and b, each defined by an inside wall of the vessel and a substantially vertical wall extending throughout a substantially vertical cross-section plane of the inner volume of the vessel. The two compartments a and b may preferably be volumetrically equal, but can also be volumetrically different.

[0065] FIG. 3b represents a gas/liquid contacting vessel having four gas/liquid contacting compartments, a-d, each defined by an inside wall of the vessel and a two substantially vertical walls extending throughout two different substantially vertical cross-section planes of the inner volume of the vessel. The four compartments a-d may preferably be volumetrically equal, but can also be volumetrically different.

[0066] FIG. 3c represents a gas/liquid contacting vessel having eight gas/liquid contacting compartments, a-h, each defined by an inside wall of the vessel and a two substantially vertical walls extending throughout two different substantially vertical cross-section planes of the inner volume of the vessel. The eight compartments a-h may preferably be volumetrically equal, but can also be volumetrically different.

[0067] FIG. 3d represents a gas/liquid contacting vessel having a first gas/liquid contacting compartment, a, defined by a tubular wall extending substantially vertically throughout the inner volume of the vessel and a second gas/liquid contacting compartment, b, defined by an outside surface of the first gas/liquid contacting compartment and an inside wall of the vessel.

[0068] FIG. 3e represents a gas/liquid contacting vessel having a plurality of distinct gas/liquid contacting compartments, each defined by a tubular wall extending substantially vertically throughout the inner volume of the vessel.

[0069] A gas/liquid contacting vessel as described above with reference to FIG. 1, and a regenerator vessel as described above with reference to FIG. 2, comprising at least two distinct gas/liquid contacting compartments, may for example be employed in an absorption based flue gas treatment system for removal of carbon dioxide (CO₂) from a flue gas, e.g. produced by a combustion plant. Examples of flue

gas treatment systems where the present gas/liquid contacting vessels would be useful include amine absorption systems and ammonia based CO₂ absorption systems, such as chilled ammonia systems. Herein below, the concept will be illustrated with reference to an ammonia based CO₂ absorption system.

[0070] The amine based CO₂ absorption process is based on the chemistry of the amine-CO₂-H₂O system and the ability of the amine solution to absorb CO₂ at low temperature (approx. 45 °C) and to release the CO₂ at moderately elevated temperature (approx. 125 °C). Examples of amine compounds commonly used in absorption of CO₂ include, but are not limited to, monoethanolamine (MEA), diethanolamine (DEA) and methyldiethanolamine (MDEA). CO₂ and water produce carbonic acid which reacts with the amine solution in the absorption column, forming chemical compounds (carbonates) and resulting in the removal of CO₂ from the gaseous stream. At higher temperatures, the reaction is reversed to release CO₂ in a concentrated form.

[0071] FIG. 4 is a schematic representation of an amine based carbon dioxide (CO₂) capture system. According to one embodiment, the system comprises an absorber vessel 100 comprising a gas/liquid contacting vessel as described herein above with reference to FIG. 1. Optionally, the system further comprises a regenerator vessel 200 as described herein above with reference to FIG. 2.

[0072] When each of the absorber vessel 100 and the regenerator vessel 200 of an absorption based carbon dioxide (CO₂) capture system comprise gas/liquid contacting vessels having at least two distinct gas/liquid contacting compartments, the absorber vessel and the regenerator vessel may preferably have the same number of gas/liquid contacting compartments.

[0073] When one or each of the absorber vessel and the regenerator vessel of the absorption based carbon dioxide (CO₂) capture system comprise gas/liquid contacting vessels having at least two distinct gas/liquid contacting compartments, the capacity of the flue gas treatment system can be adjusted according to the mass flow rate of the incoming flue gas to be treated. This allows for the ratio of flow rate to residence time (liquid-to-gas ratio) to be maintained closer to a predetermined value than possible with conventional single compartment vessels. This means the operation can be conducted closer to the design point and that CO₂ capture efficiency can be kept high across a larger load range. Furthermore, the liquid absorbent flow rate can be optimized, which in turn leads to reduced regenerator steam consumption when operating the system at partial load.

[0074] While the invention has been described with reference to a number of preferred embodiments, it will be understood by those skilled in the art that various changes may be made and equivalents may be substituted for elements thereof

without departing from the scope of the invention. In addition, many modifications may be made to adapt a particular situation or material to the teachings of the invention without departing from the essential scope thereof. Therefore, it is intended that the invention not be limited to the particular embodiments disclosed as the best mode contemplated for carrying out this invention, but that the invention will include all embodiments falling within the scope of the appended claims. Moreover, the use of the terms first, second, etc. do not denote any order or importance, but rather the terms first, second, etc. are used to distinguish one element from another.

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CLAIMS:

1. A gas/liquid contacting vessel for treatment of a gas stream at varying mass flow rates, said vessel comprising

at least two distinct gas/liquid contacting compartments separated from
5 each other by a substantially vertical partition, each compartment having a gas inlet and a liquid outlet near a bottom end thereof and a gas outlet and a liquid inlet near a top end thereof, and a mass transfer device arranged between said bottom end and top end,

wherein one of said compartments is operable for gas/liquid contacting
10 independently of another of said compartments.
2. A gas/liquid contacting vessel according to claim 1, wherein all of said gas inlets are fluidly connectable to a common gas source.
3. A gas/liquid contacting vessel according claim 1 or 2, wherein all of said liquid inlets are fluidly connectable to a common liquid source.
- 15 4. A gas/liquid contacting vessel according to any one of claims 1 to 3, wherein the vessel comprises shut-off means, whereby gas and/or liquid flow to a gas/liquid contacting compartment can be blocked independently of another of said compartments.
5. A gas/liquid contacting vessel according to any one of claims 1 to 4,
20 wherein the mass transfer devices comprise packed beds.
6. A gas/liquid contacting vessel according to any one of claims 1 to 5, wherein the vessel defines an inner volume having a circular horizontal cross-section, and wherein the at least two distinct gas/liquid contacting compartments are defined by an inside wall of the vessel and one or more substantially vertical walls extending
25 throughout a substantially vertical cross-section of the inner volume of the vessel.

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7. A gas/liquid contacting vessel according to any one of claims 1 to 5, wherein the vessel defines an inner volume having a circular horizontal cross-section, and wherein at least one of the distinct gas/liquid contacting compartments is defined by a tubular wall extending substantially vertically throughout the inner volume of the vessel.

8. A gas/liquid contacting vessel according to any one of claims 1 to 7, wherein the vessel comprises only two gas/liquid contacting compartments.

9. A flue gas treatment system for removal of carbon dioxide (CO₂) from a flue gas using a liquid absorbent, the system comprising:

a CO₂ absorber vessel including:

at least two distinct gas/liquid contacting compartments separated from each other by a substantially vertical partition, each compartment having a gas inlet and a liquid outlet near a bottom end thereof and a gas outlet and a liquid inlet near a top end thereof, and a mass transfer device arranged between said bottom end and top end,

wherein one of said compartments is operable for gas/liquid contacting independently of another of said compartments; and

an absorbent regenerator vessel having at least one liquid inlet and at least one liquid outlet, each of which are in fluid communication with the CO₂ absorber vessel.

10. A flue gas treatment system according to claim 9, wherein the liquid sorbent is provided to the liquid inlets of the absorber vessel and a gas stream having CO₂ provided to the gas inlets of the absorber vessel to the gas stream and the liquid stream flow in a counter-current direction through the mass transfer device within the absorber vessel whereby a CO₂-lean gas stream exits through the gas outlets and the CO₂-rich liquid absorbent exits through the liquid outlets of the absorber vessel.

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11. A flue gas treatment system according to claim 10, wherein said absorbent regenerator vessel comprises:

at least two distinct gas/liquid contacting compartments separated from each other by a substantially vertical partition, each compartment having a gas inlet and one of the liquid outlets near a bottom end thereof and a gas outlet and one of the liquid inlets near a top end thereof, and a mass transfer device arranged between said bottom end and top end,

wherein one of said compartments is operable for gas/liquid contacting independently of another of said compartments of the absorbent regenerator vessel.

12. A flue gas treatment system according to claim 11, wherein the CO₂-rich liquid absorbent is provided to the liquid inlets of the regenerator vessel and a heated gas stream provided to the gas inlets of the regenerator vessel to the heated gas stream and the liquid stream flow in a counter-current direction through the mass transfer device within the regenerator vessel whereby a CO₂ gas stream exits through the gas outlets and the CO₂-lean absorbent liquid exits through the liquid outlets of the regenerator vessel; and

wherein the CO₂-lean absorbent liquid exiting the regenerator vessel is provided to the liquid inlets of the absorber vessel.

13. A flue gas treatment system according to claim 12, wherein said CO₂ absorber vessel and said absorbent regenerator vessel each comprises only two gas/liquid contacting compartments.

14. A flue gas treatment system according to claim 9, wherein the treatment system is an amine based gas treatment system or an ammonia based gas treatment system.

15. A method of operating a gas/liquid contacting vessel according to any one of claims 1 to 8, the method comprising:

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a) determining the mass flow rate of a flue gas stream to be treated,

b) opening or blocking one or more gas/liquid contacting compartment(s) of a gas/liquid contacting vessel to adjust the capacity of the gas/liquid contacting vessel to the mass flow rate of the flue gas stream determined in a), and

c) treating the flue gas stream by contacting it with a liquid absorbent in the open gas/liquid contacting compartment(s) of the gas/liquid contacting vessel.

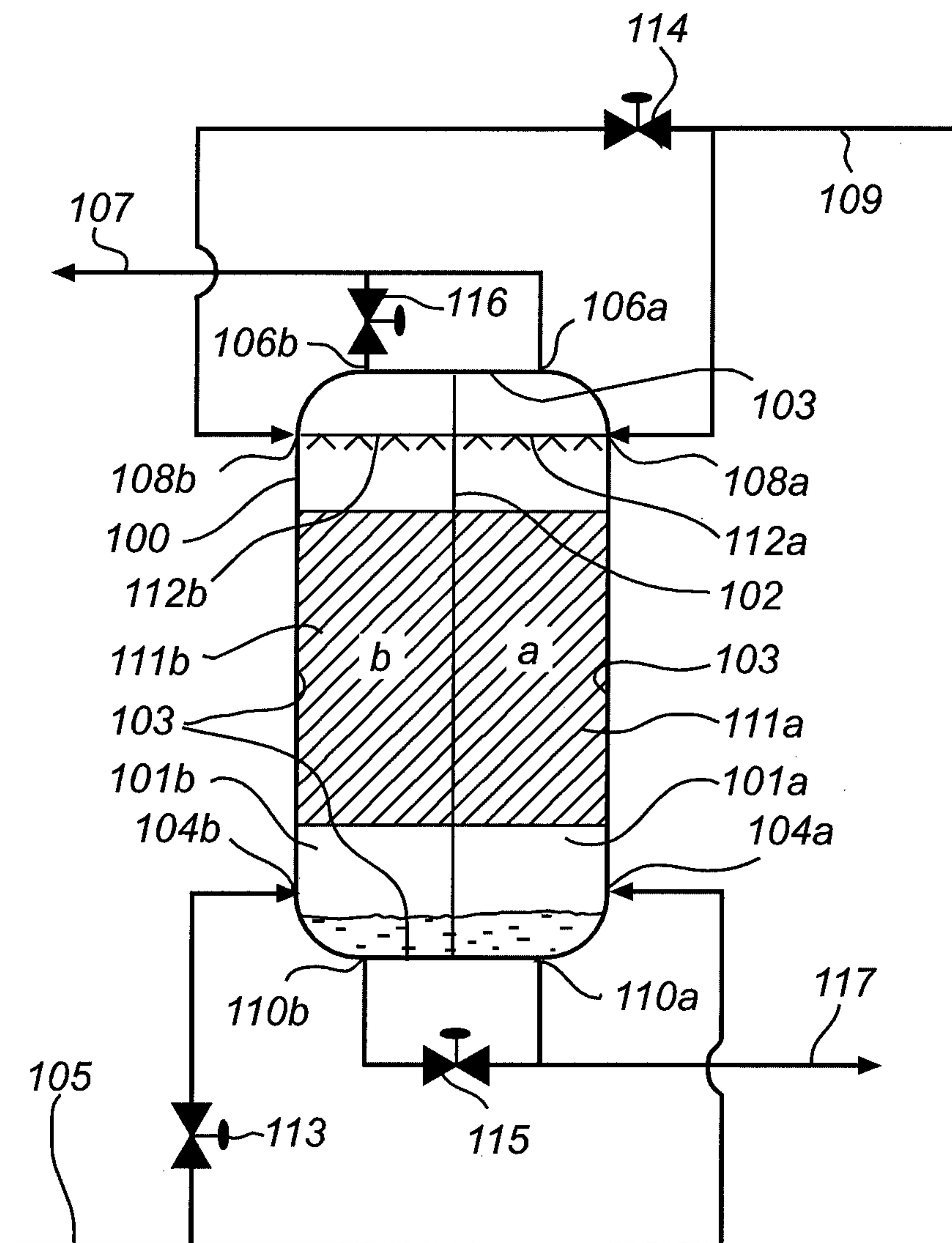
16. The method of claim 15, wherein the gas/liquid contacting vessel is a CO₂ absorber vessel of a flue gas treatment system comprising:

at least two distinct gas/liquid contacting compartments separated from each other by a substantially vertical partition, each compartment having a gas inlet and a liquid outlet near a bottom end thereof and a gas outlet and a liquid inlet near a top end thereof, and a mass transfer device arranged between said bottom end and top end,

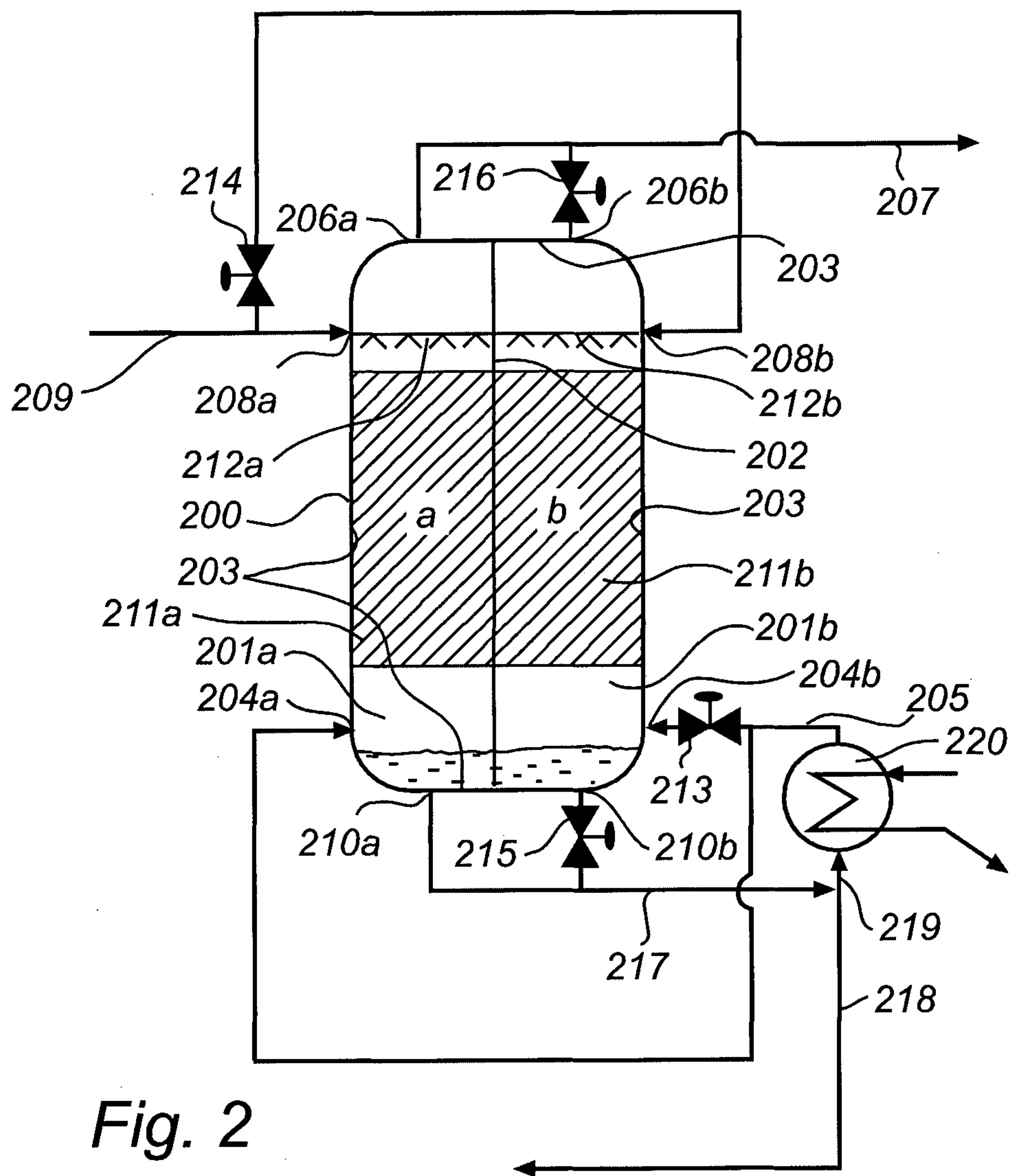
wherein one of said compartments is operable for gas/liquid contacting independently of another of said compartments.

17. The method of claim 15 or 16, wherein the flue gas stream to be treated is produced in a combustion plant utilizing, or prepared for, flue gas recirculation.

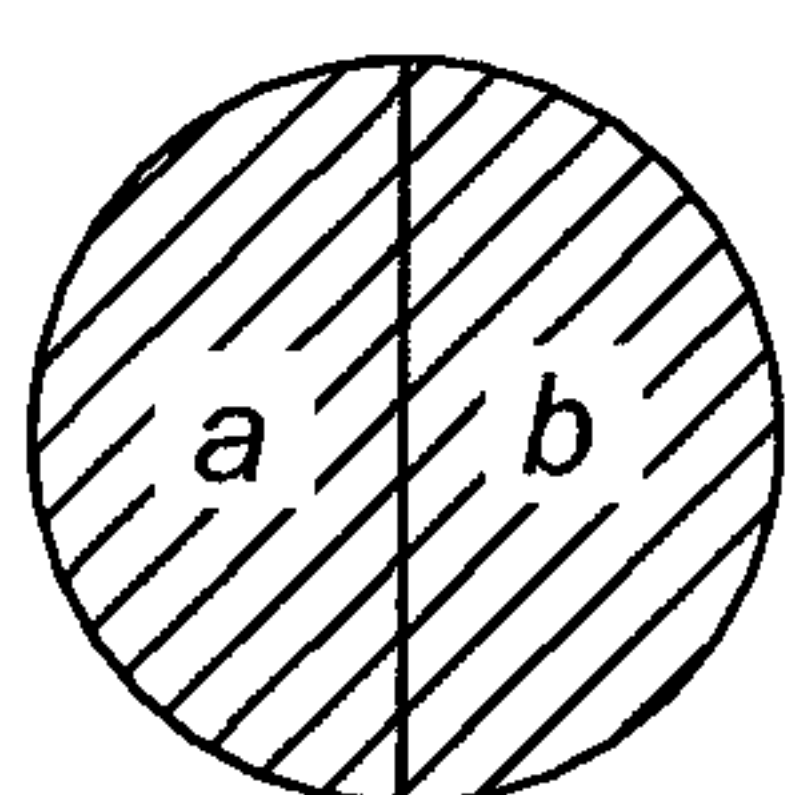
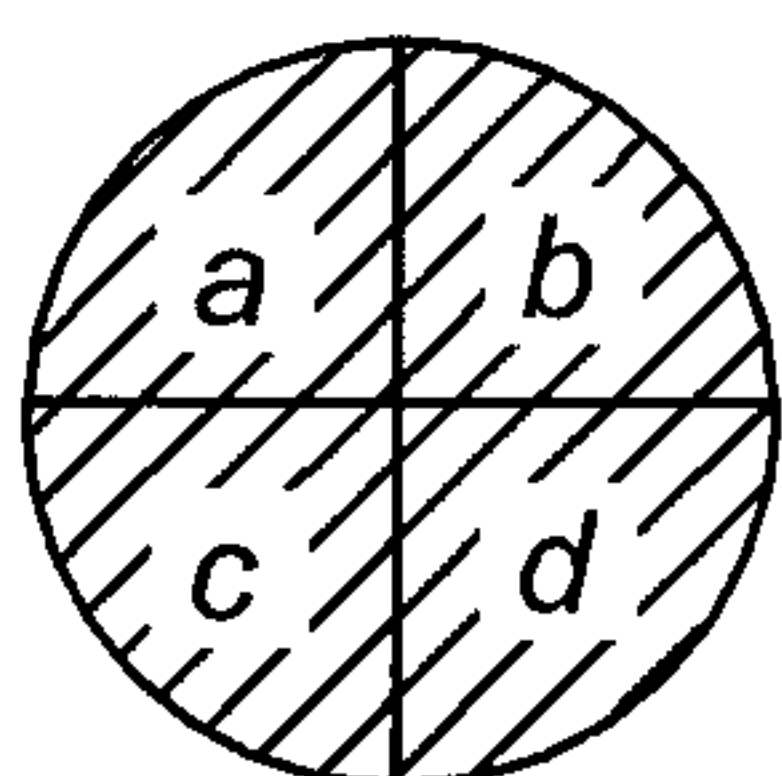
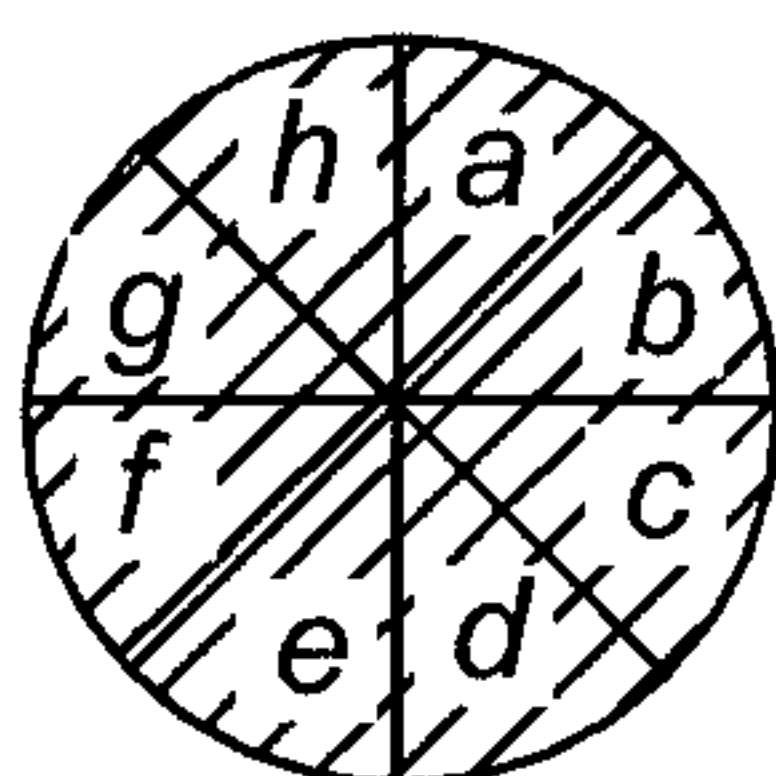
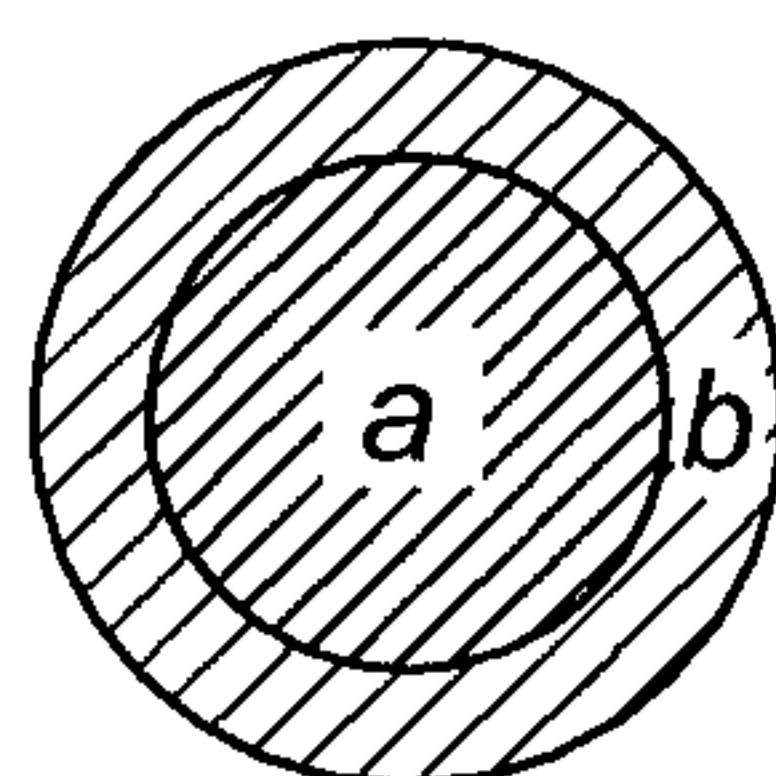
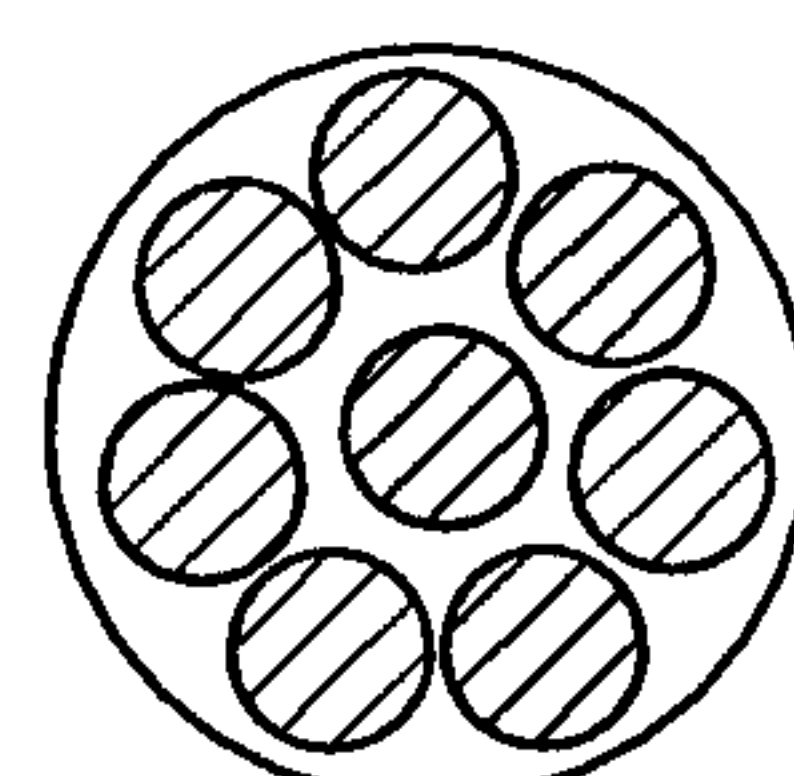
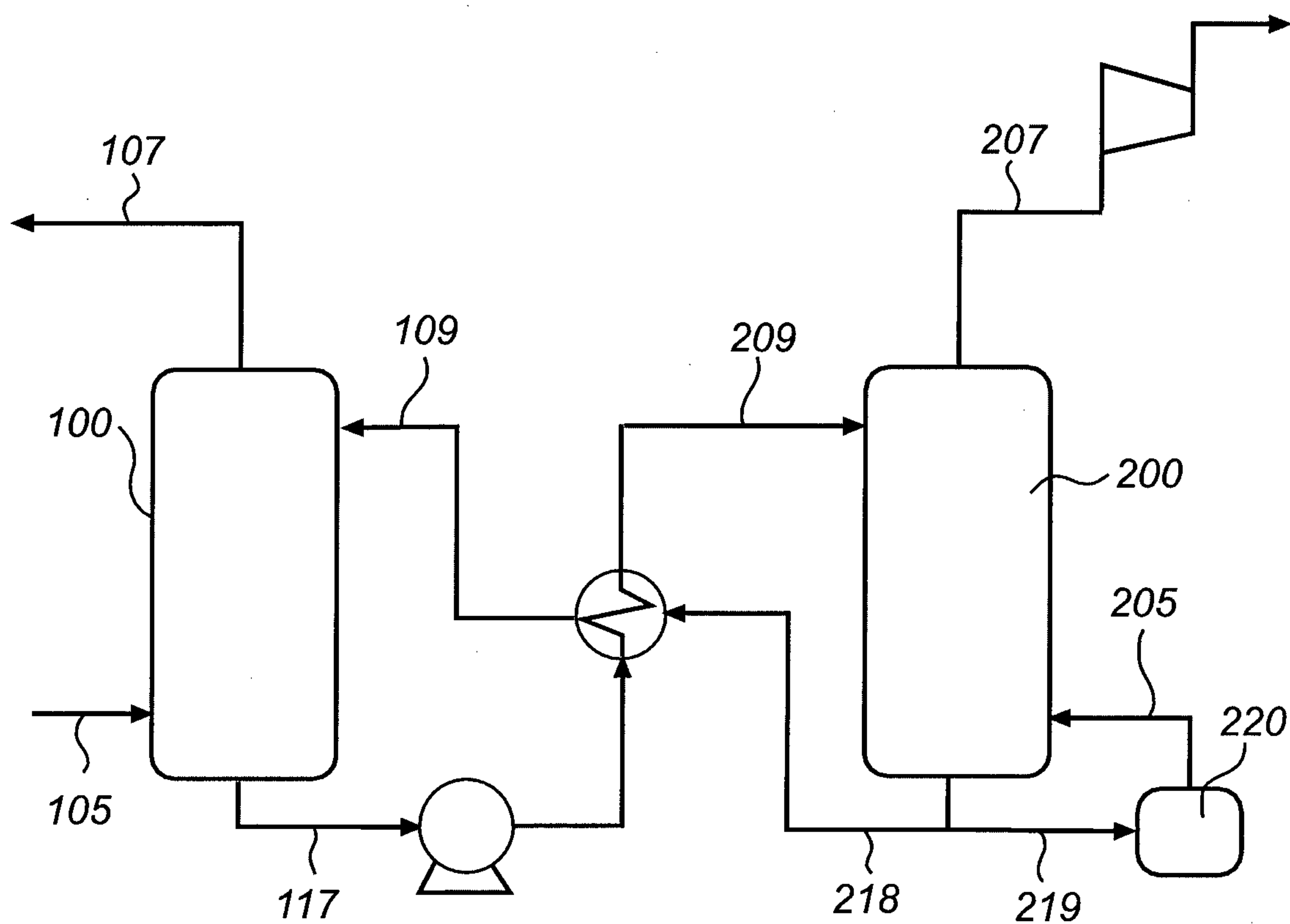
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*Fig. 1*

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*Fig. 3a**Fig. 3b**Fig. 3c**Fig. 3d**Fig. 3e**Fig. 4*

