(19) **United States**

(12) **Patent Application Publication** (10) Pub. No.: **US 2025/0256959 A1**

STRAND et al. (43) **Pub. Date: Aug. 14, 2025**

(54) **METHOD OF GENERATING GAS TURBINE FUEL AND GAS TURBINE SYSTEM**

(71) Applicant: **Amtech AS**, Bergen (NO)

(72) Inventors: **Asbjørn STRAND**, Bergen (NO); **Kumar Ranjan Rout**, Trondheim (NO); **De Chen**, Trondheim (NO)

(73) Assignee: **Amtech AS**, Bergen (NO)

Publication Classification

(51) **Int. Cl.**
    C01B 3/38 (2006.01)
(52) **U.S. Cl.**
    CPC *C01B 3/384* (2013.01); *C01B 2203/0233* (2013.01); *C01B 2203/0425* (2013.01); *F23R 2900/00016* (2013.01); *F23R 2900/03341* (2013.01)

(57) **ABSTRACT**

A method of generating fuel for use in a combustor of a gas turbine includes generating an exhaust gas by a first combustor, generating reformate comprising hydrogen, and generating a fuel that is a gas mixture of the reformate and exhaust gas from the first combustor, and using the fuel in a combustor in a gas turbine. The reformate may be generated in dependence on at least some of the heat generated by the first combustor. The method may also include supplying air that has not been oxygen depleted and combusting the supplied air and fuel in the combustor of the gas turbine.
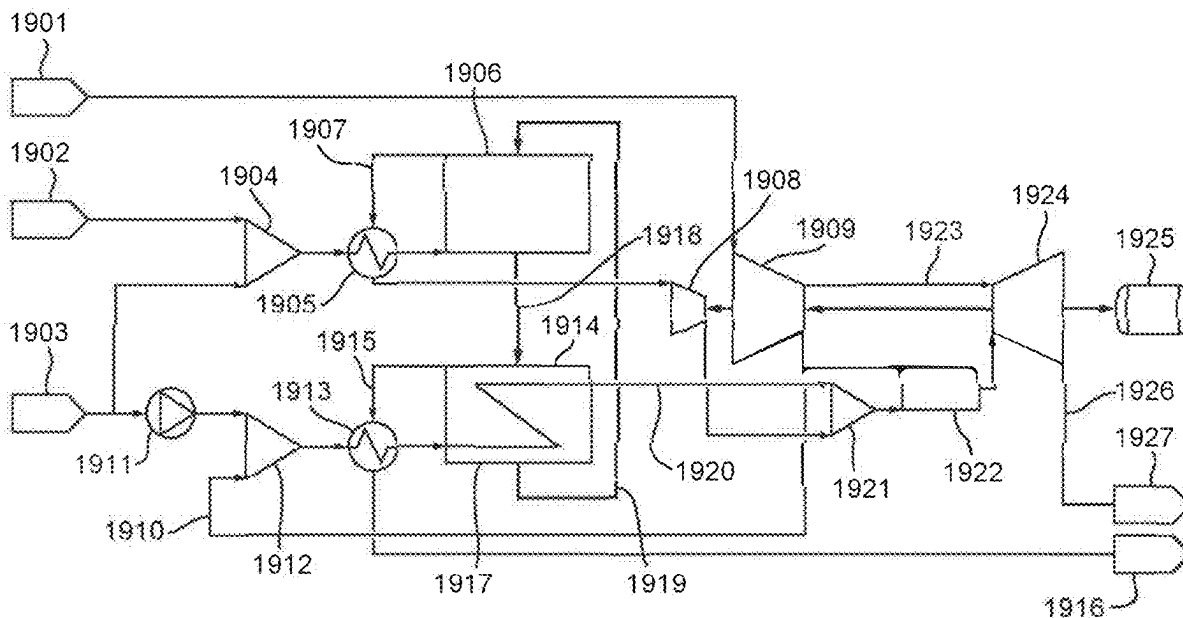
Fig. 1
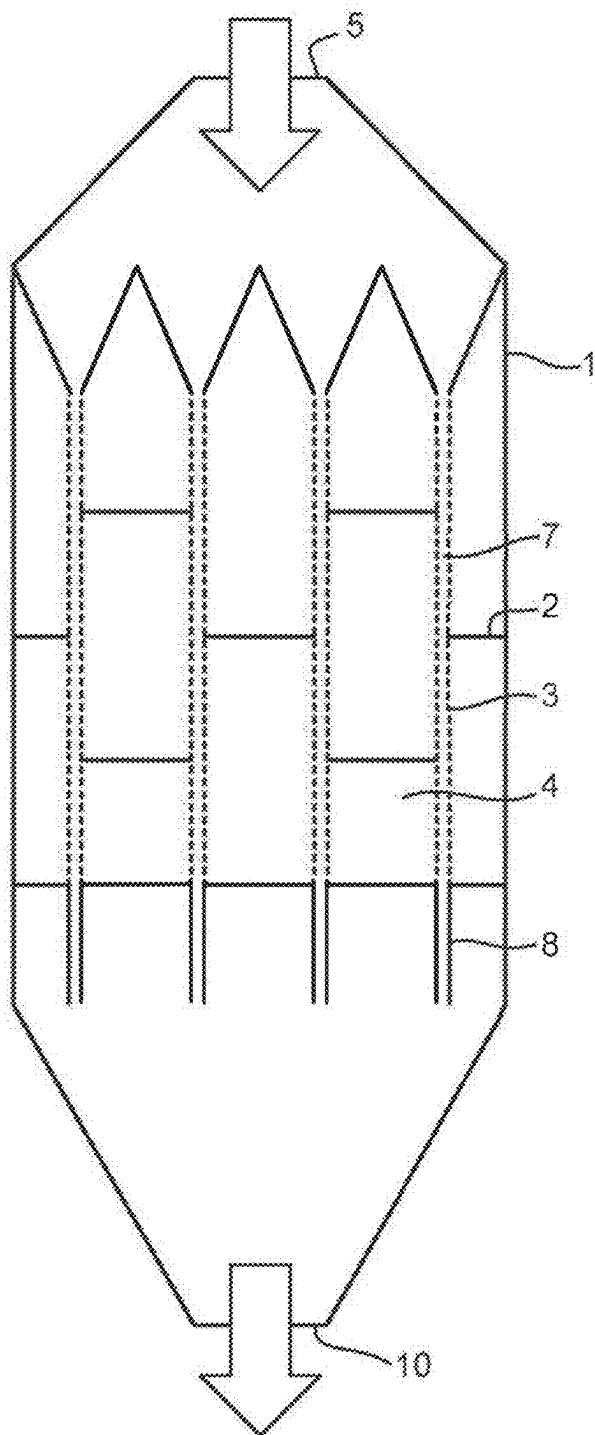
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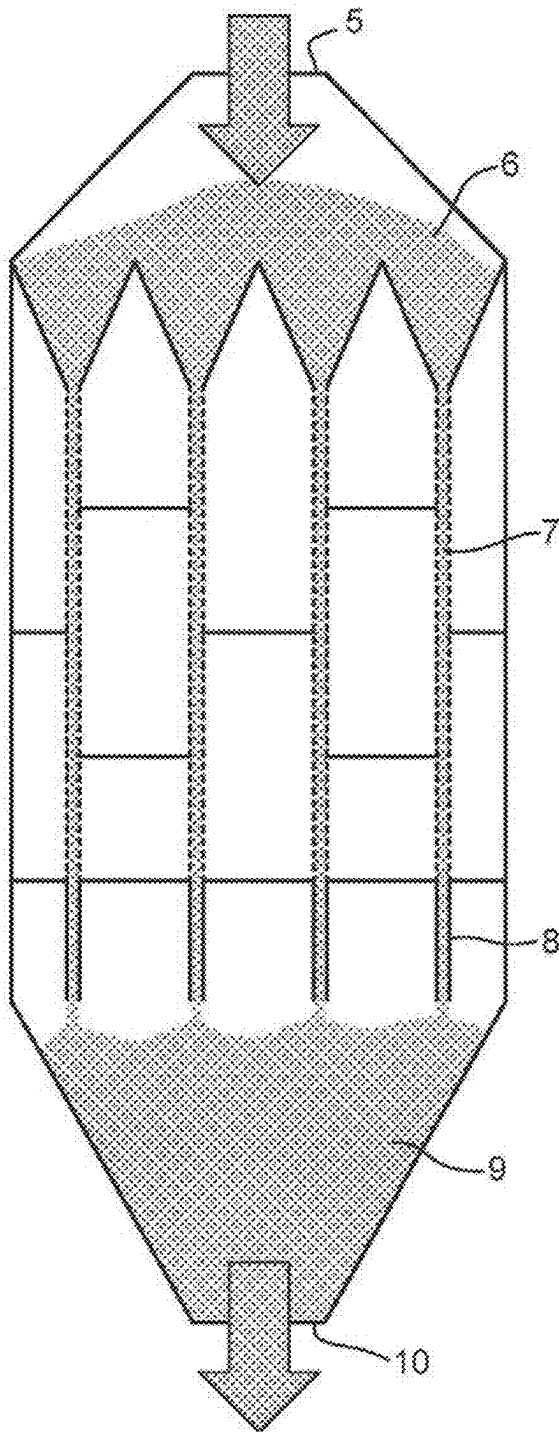
Fig. 3

Fig. 4

Fig. 5

Fig. 6

Fig. 7A

Solids Inlet

A →   5

Cooling Loop →   13

→ Gas Outlet

→ Gas Inlet

14

10

A →

Solids Outlet

Fig. 7B

Fig. 7C

Gas Outlet

Gas Inlet

B

B

C

SECTION A-A

Fig. 7D

Moving Bed

Wedge wire

Wedge wire

SECTION B-B

Fig. 7E

Wedge wire

SECTION D-D

Fig. 7F

Loop seals

D

D

DETAIL C
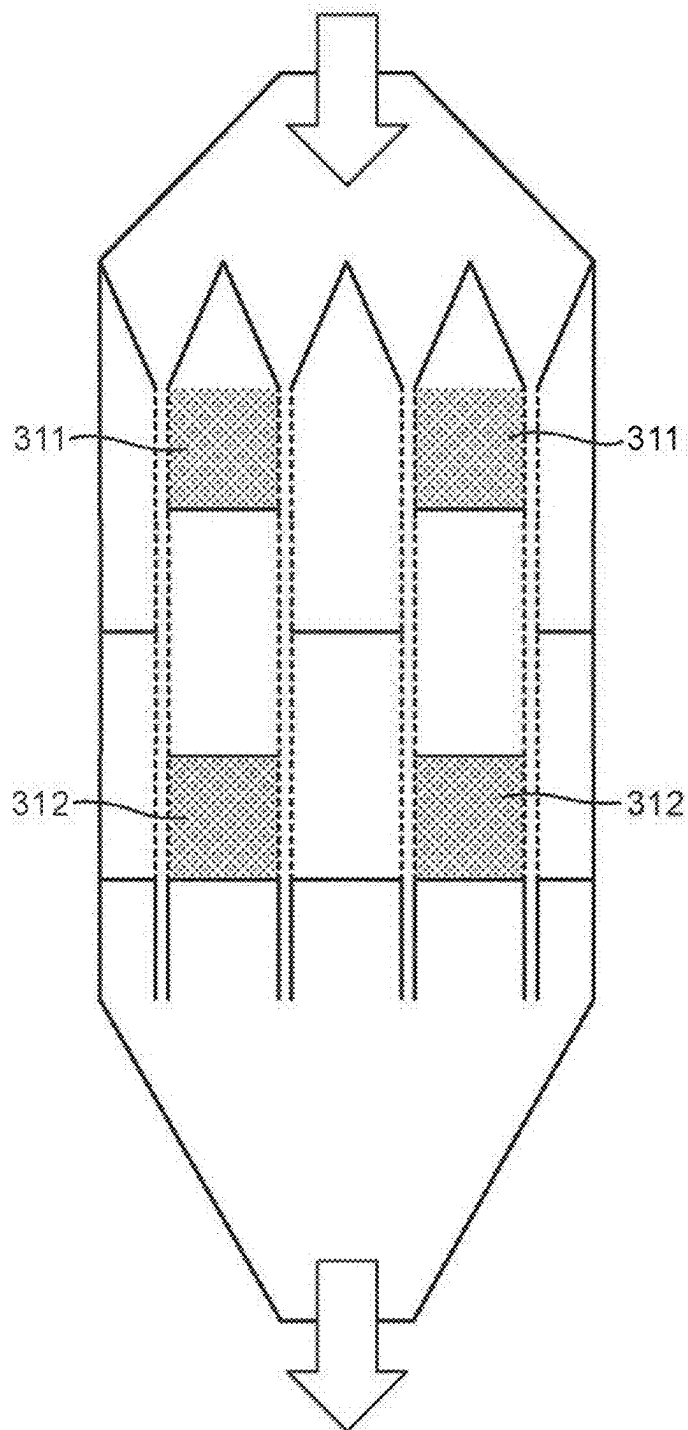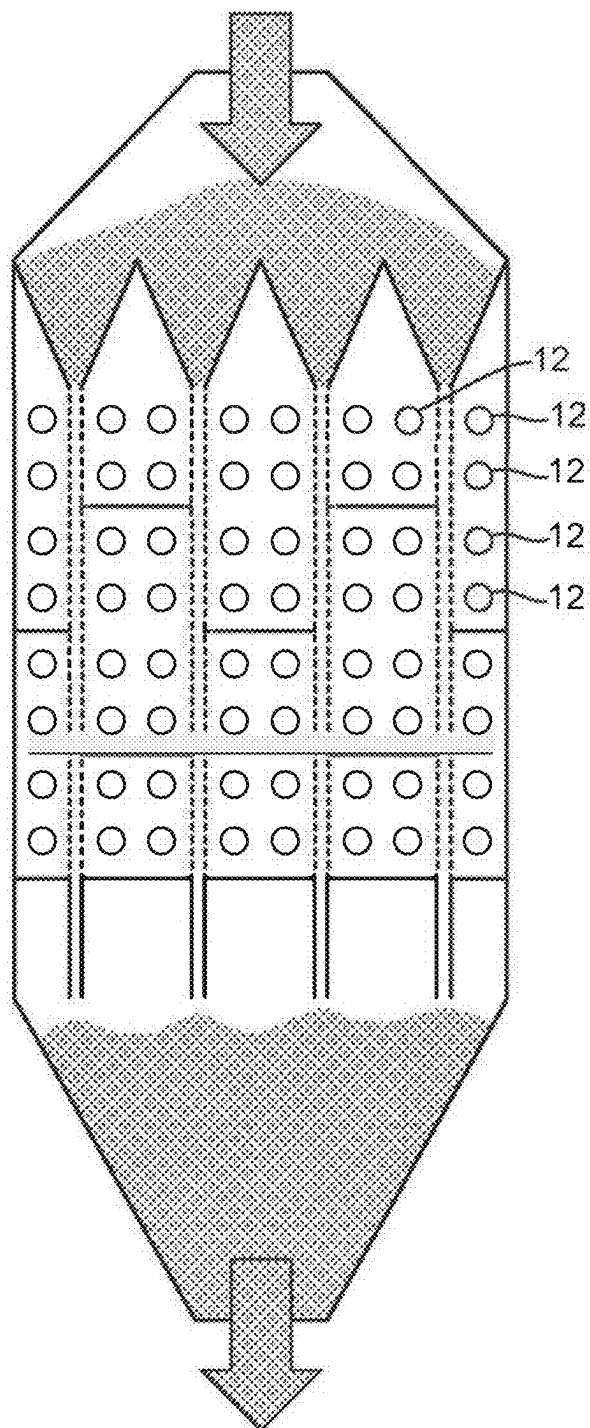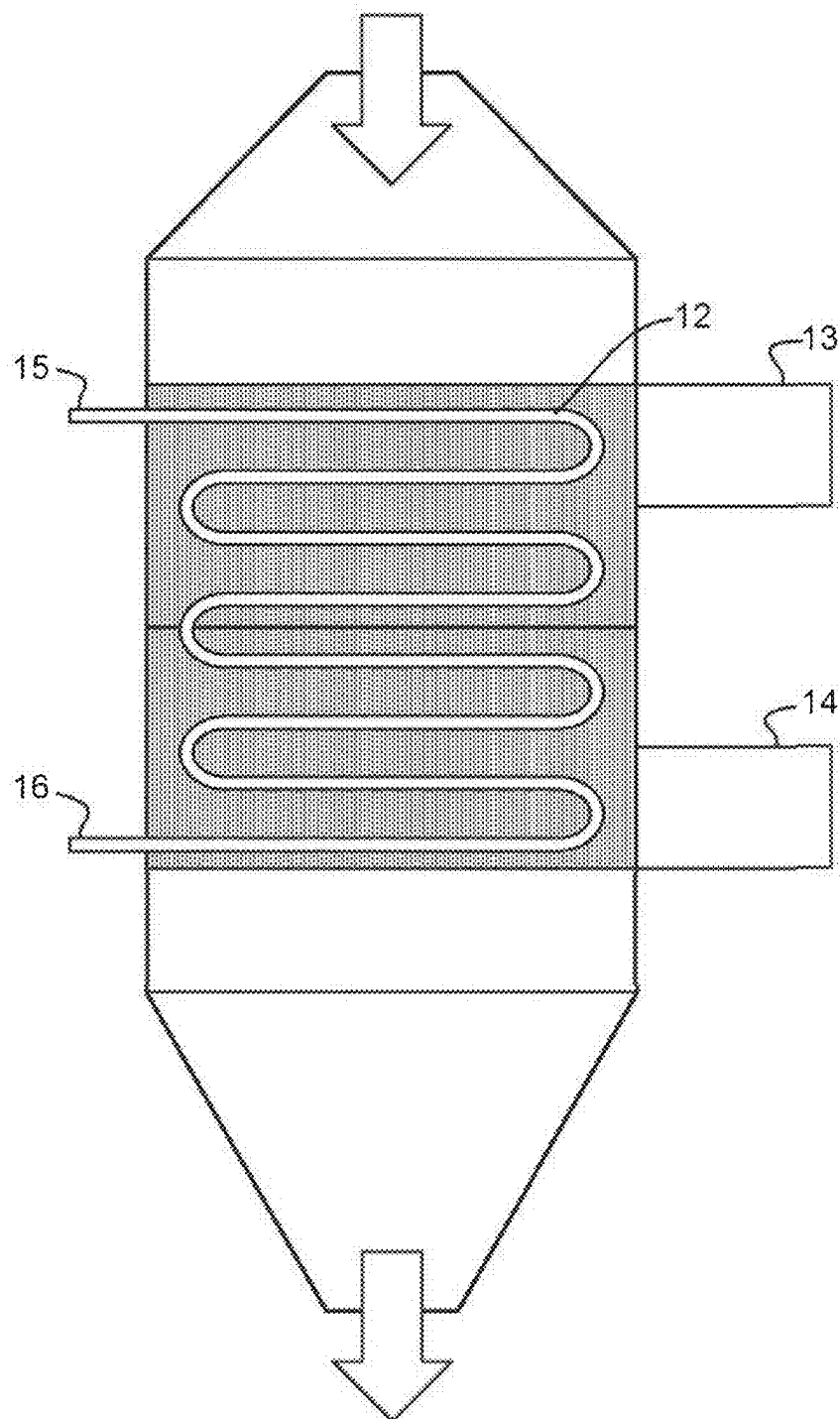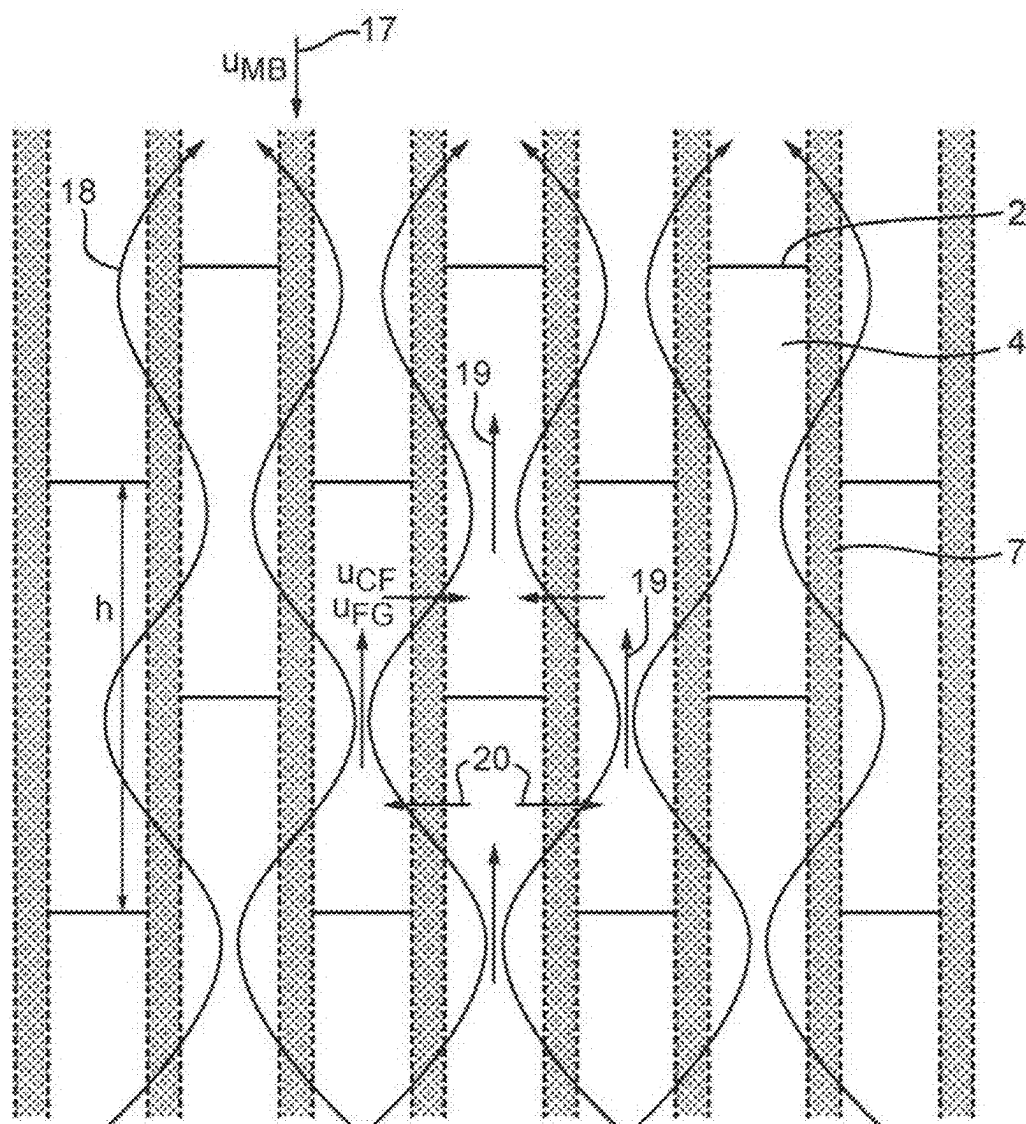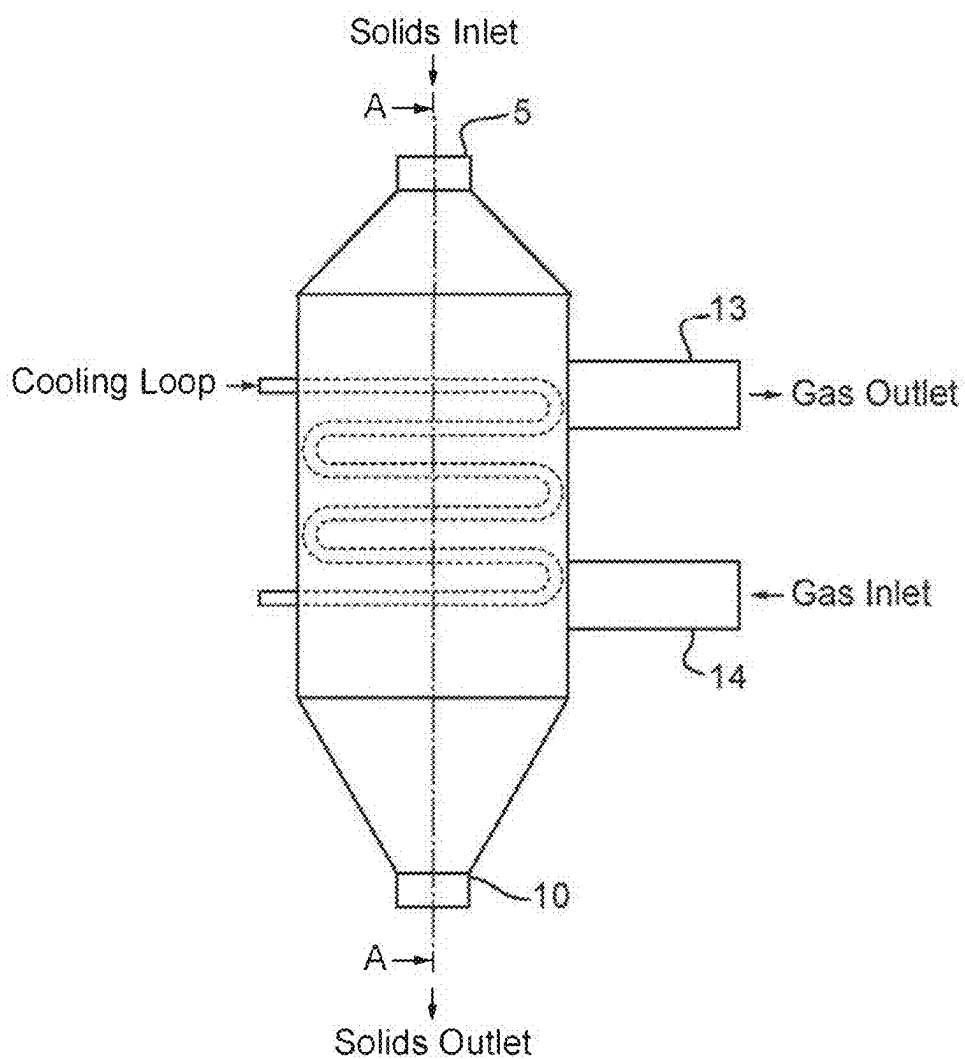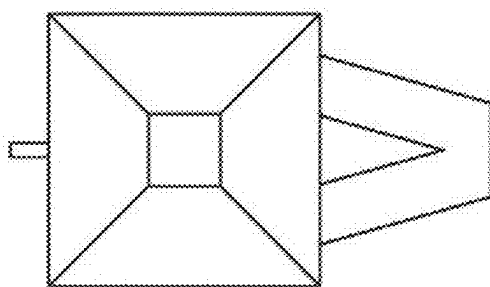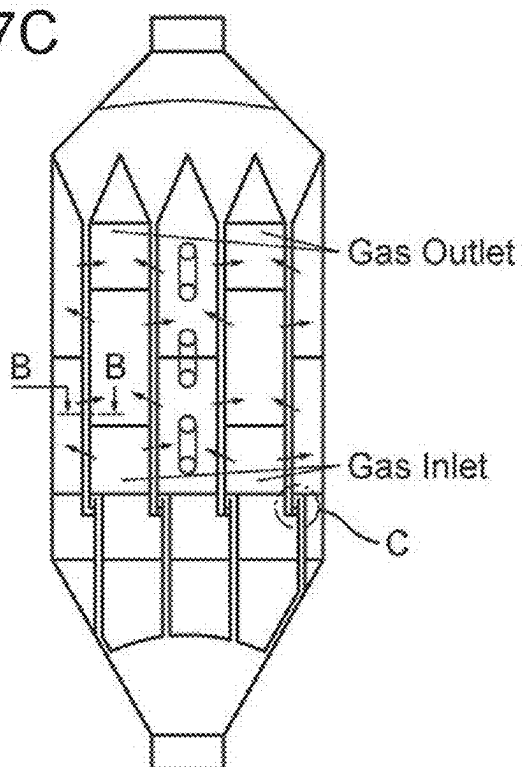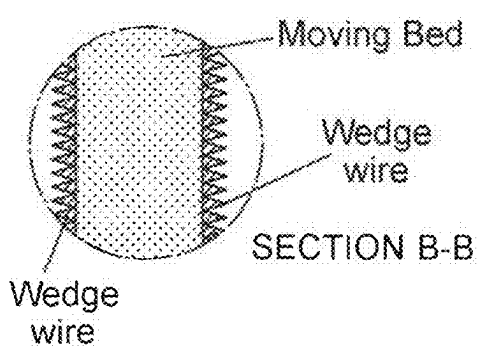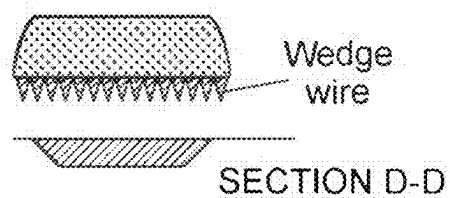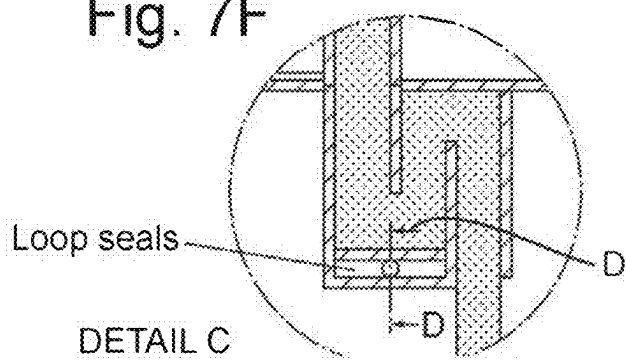
Fig. 8

Fig. 9

Fig. 10

Fig. 11A

Fig. 11B

Fig. 11C

Fig. 11D
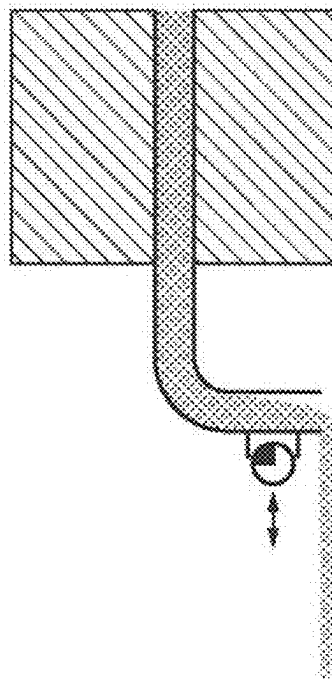
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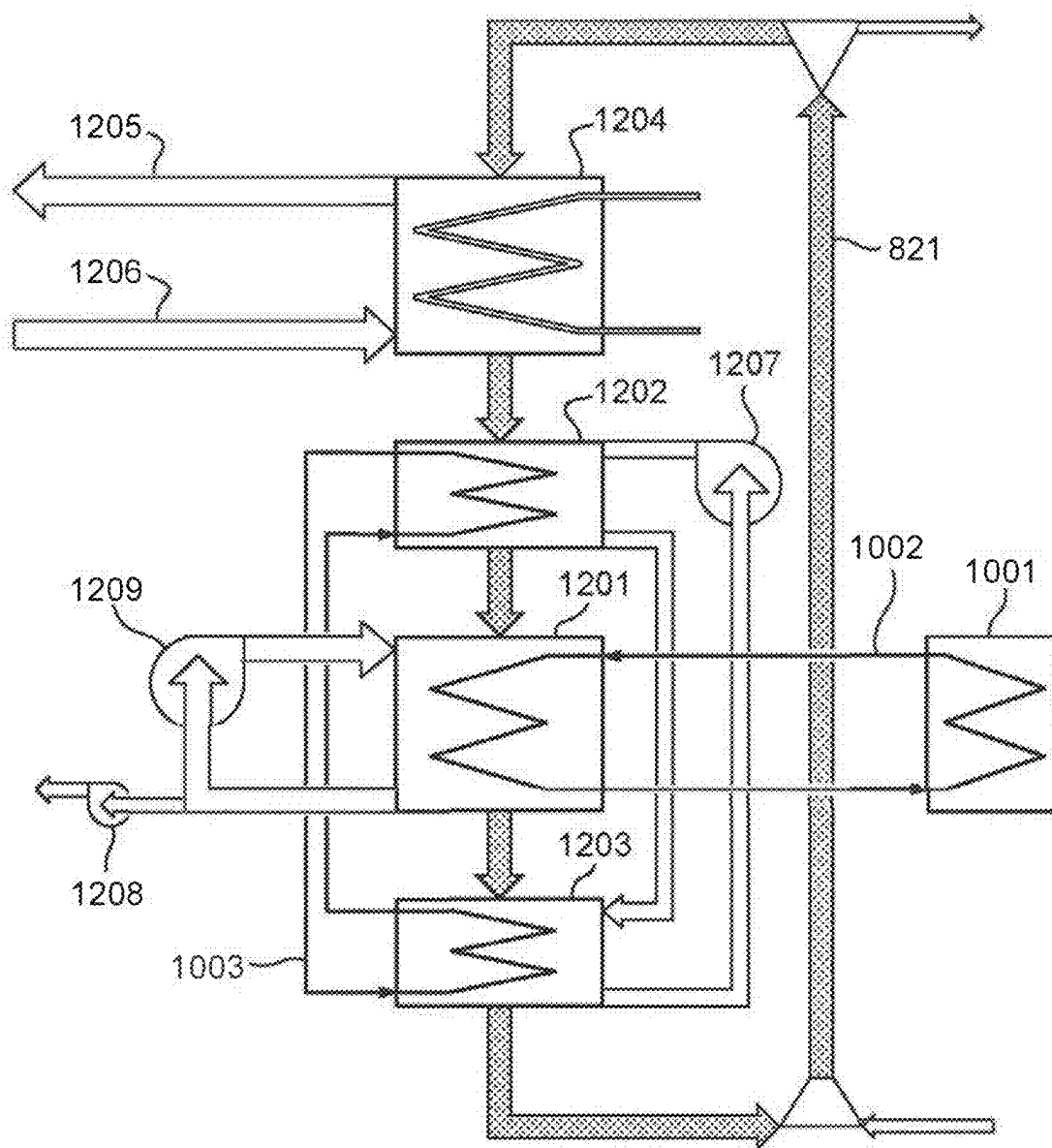
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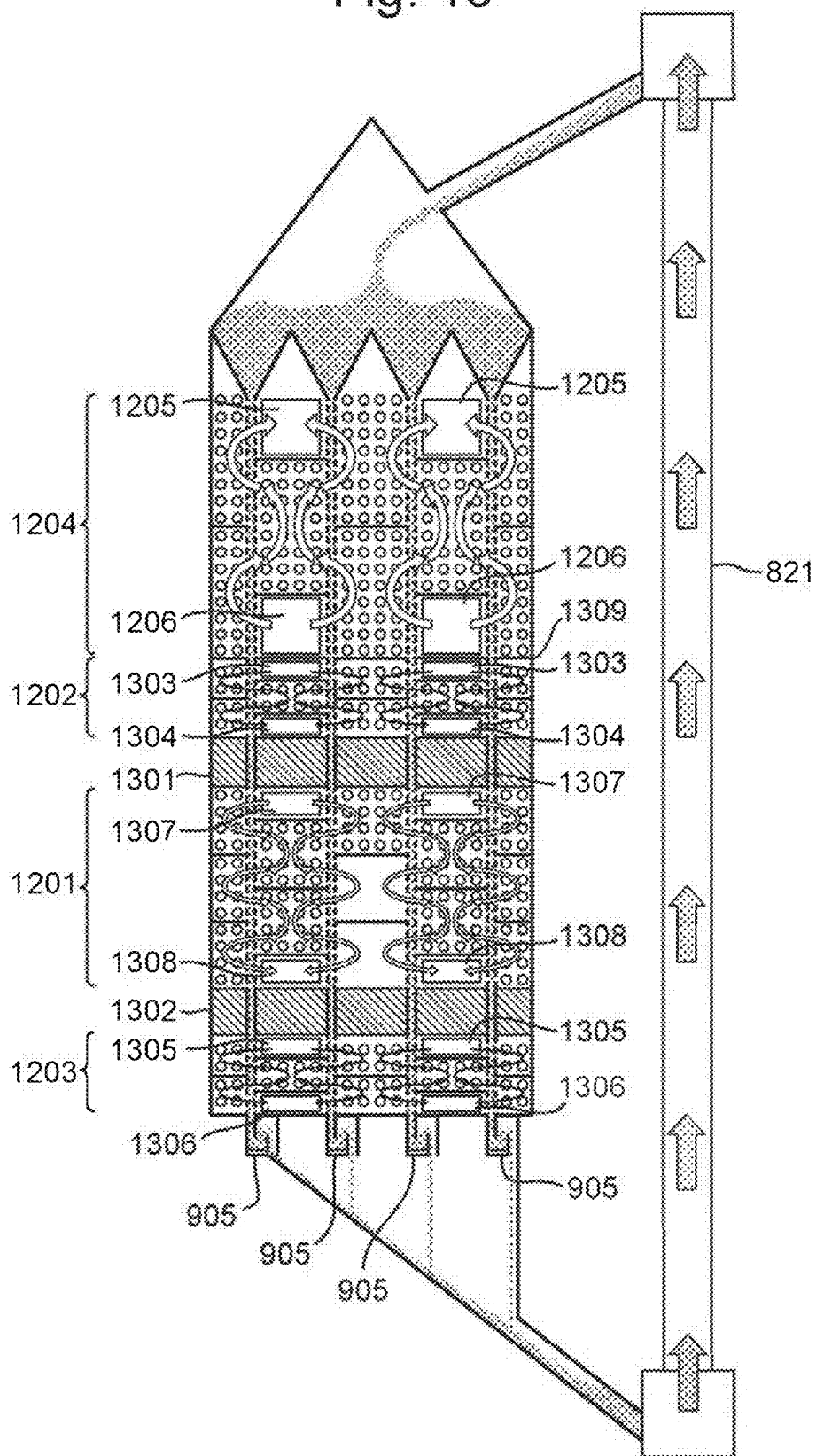
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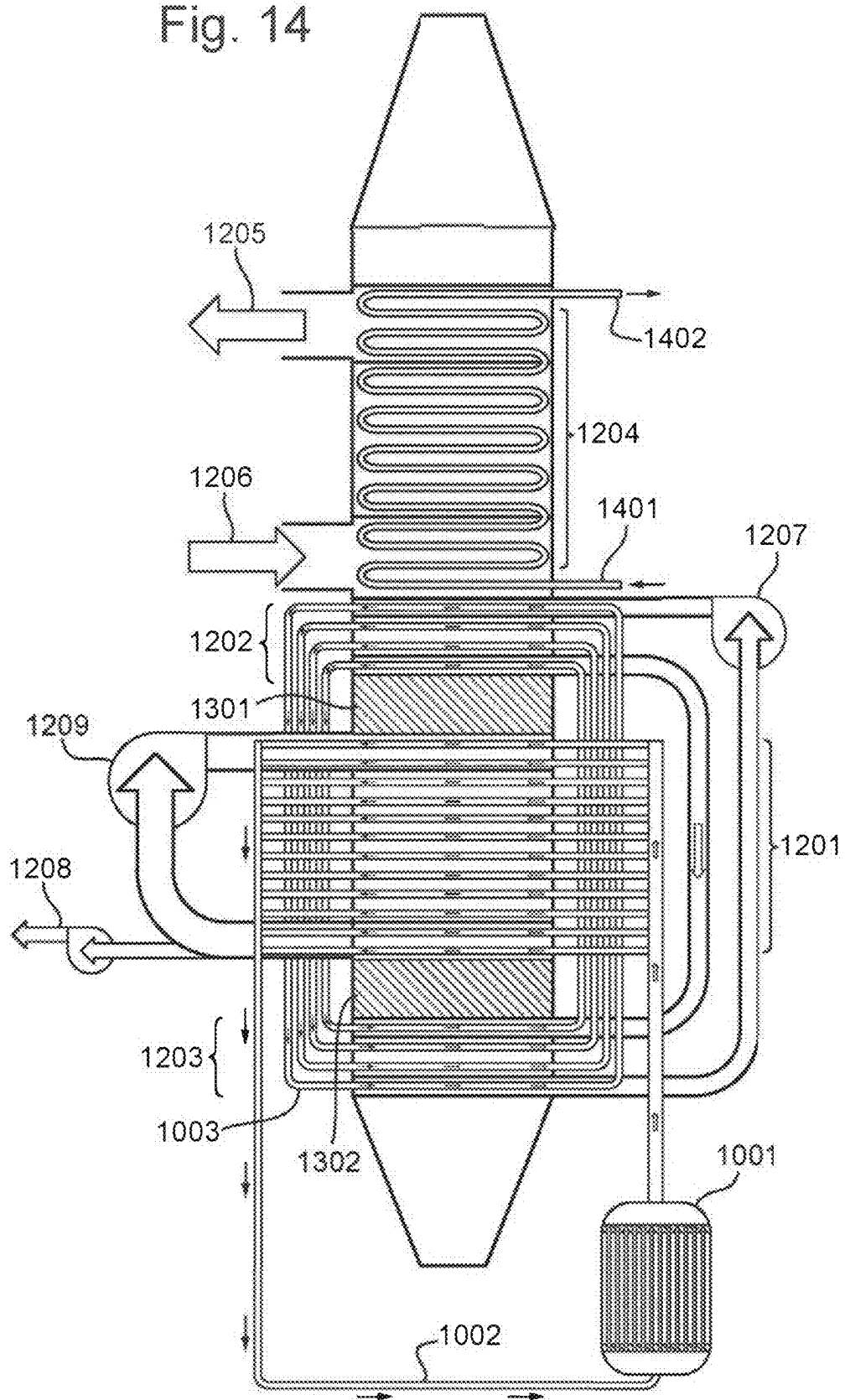
Fig. 15
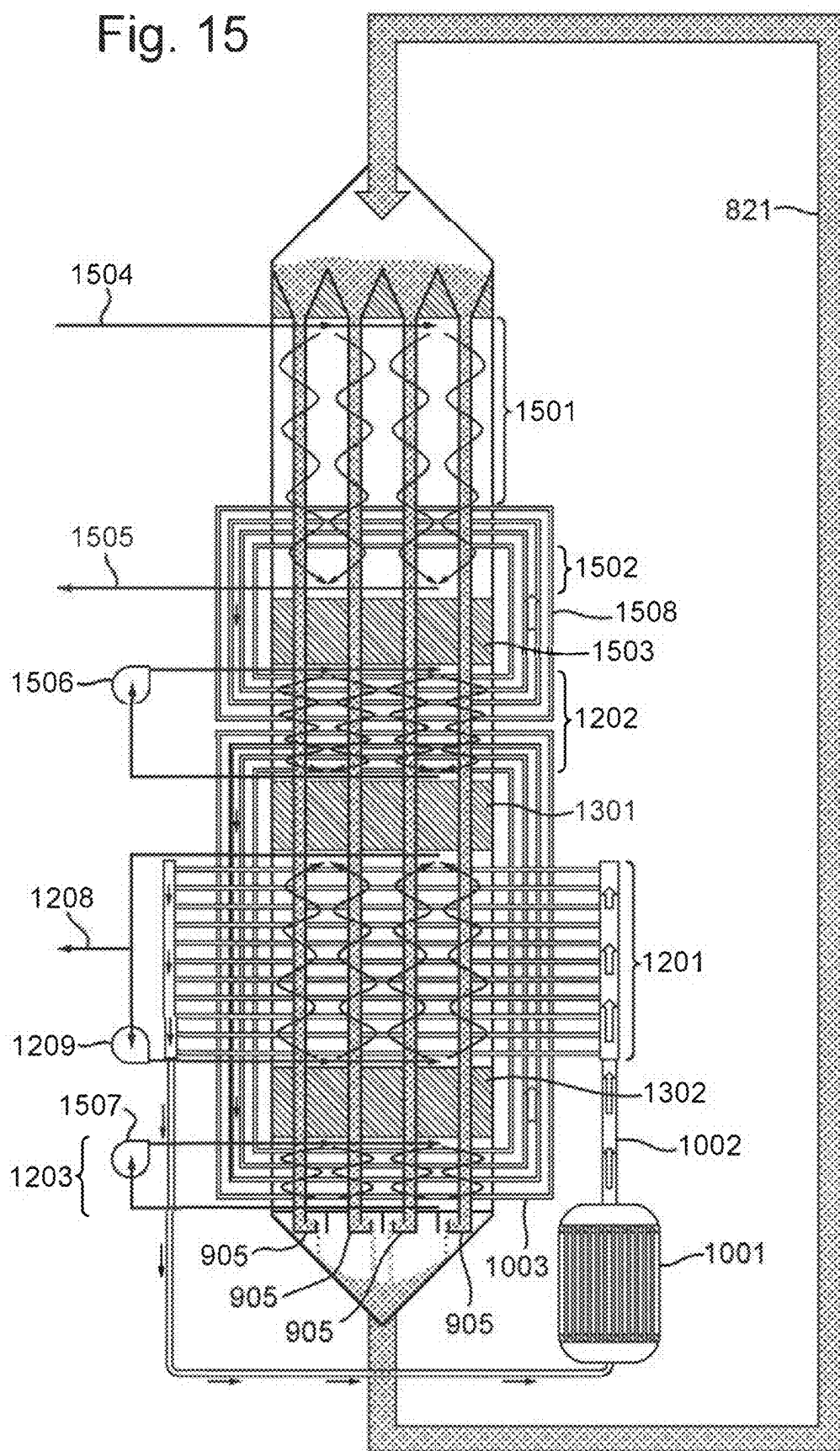
Fig. 16

Fig. 17
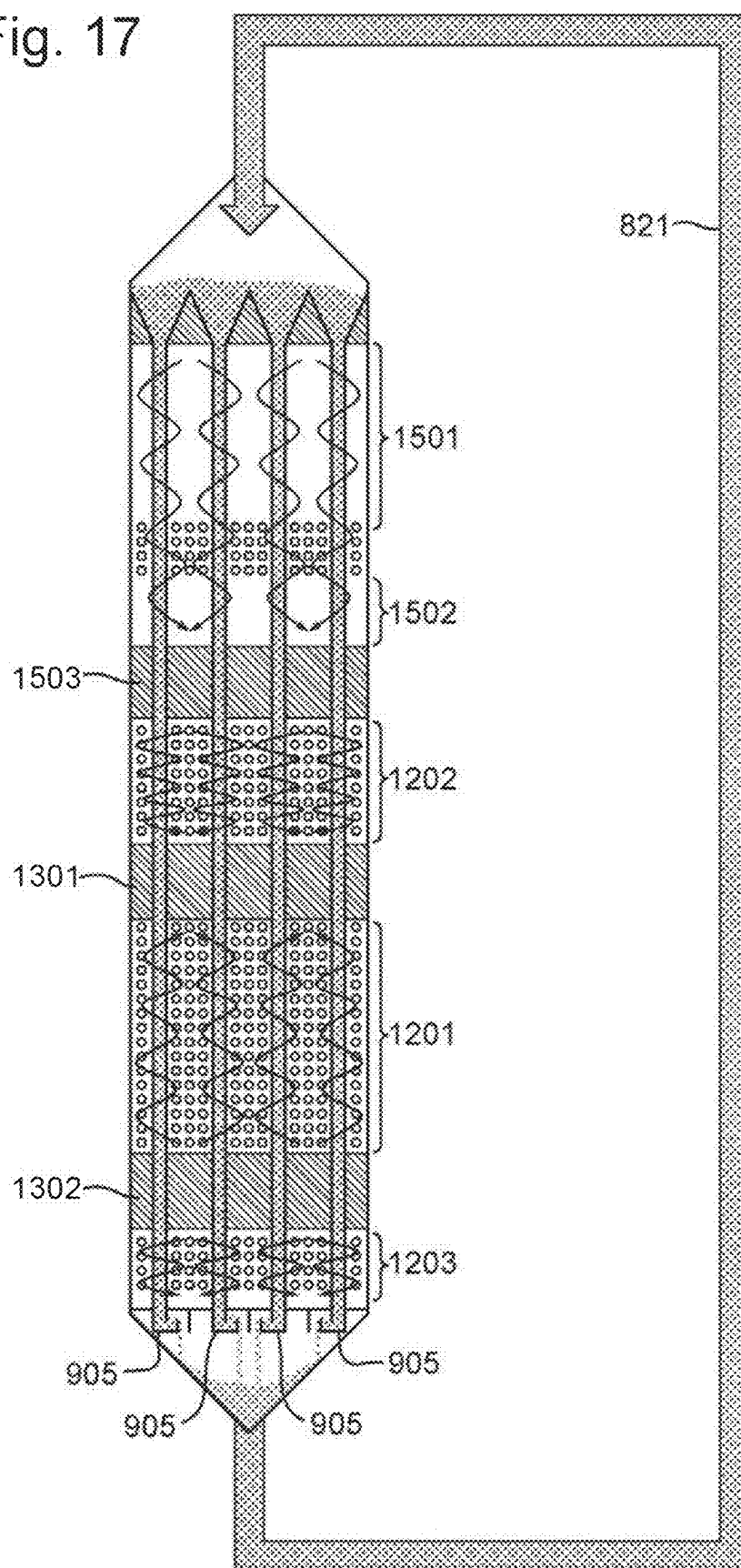
Fig. 18
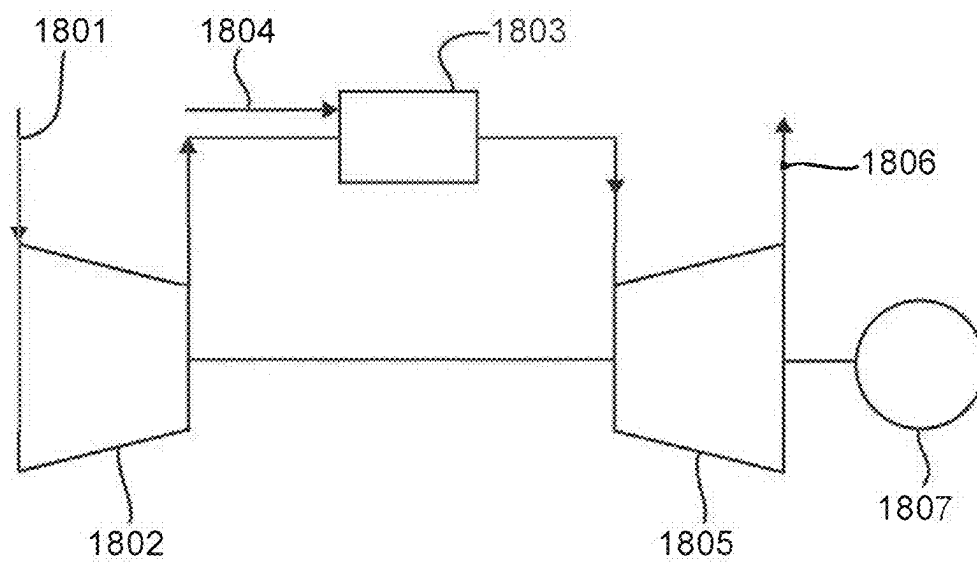
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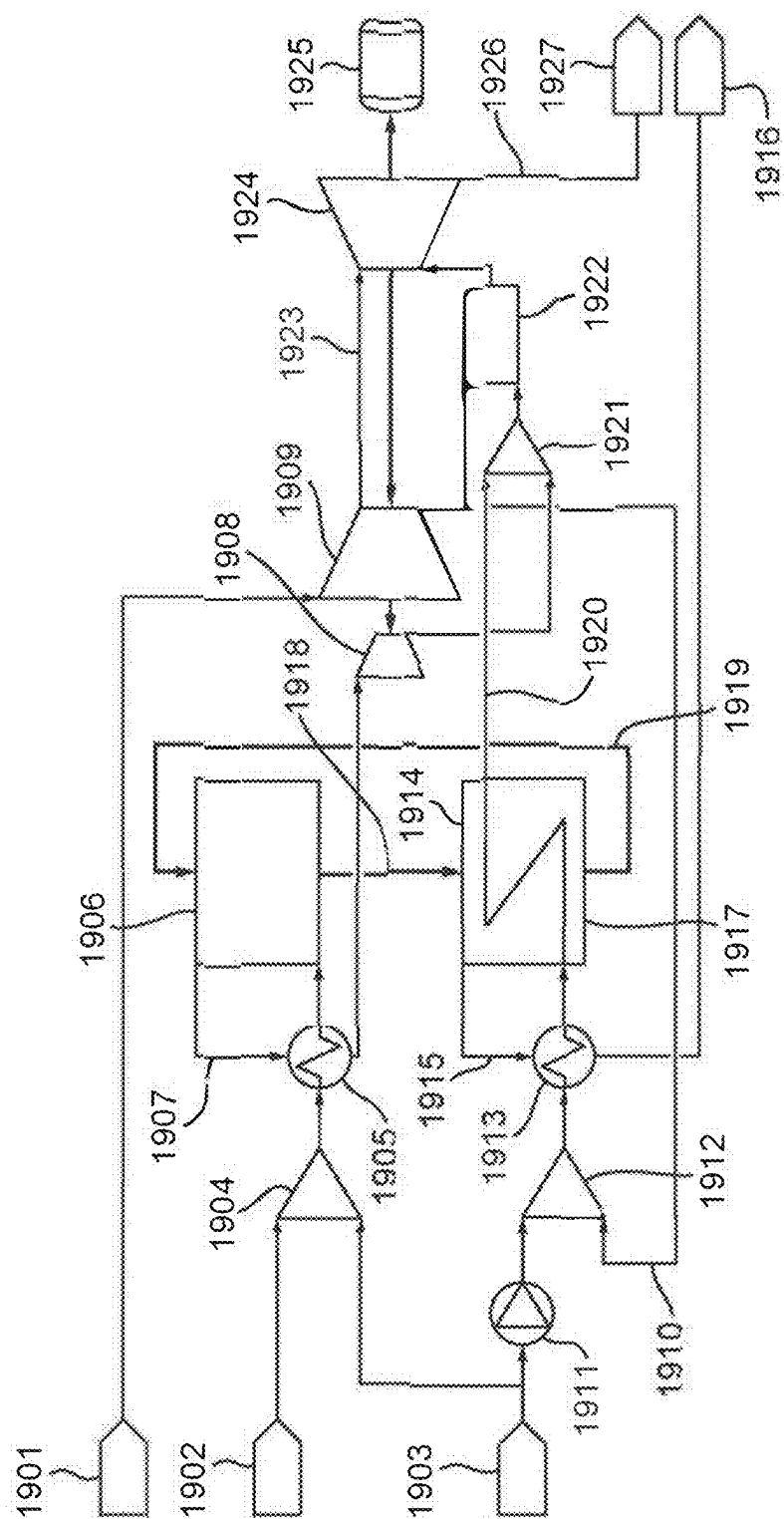
METHOD OF GENERATING GAS TURBINE FUEL AND GAS TURBINE SYSTEM

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application is a continuation application of U.S. application Ser. No. 17/431,095, filed Aug. 13, 2021, which is a U.S. National Phase Application under 35 U.S.C. 371 of International Application No. PCT/EP2020/053968, filed Feb. 14, 2020, which claims priority to Great Britain Patent Application No. 1902131.0, filed Feb. 15, 2019. The entire disclosures of the above applications are expressly incorporated by reference herein.

FIELD

[0002] The field of the invention is the provision of a fuel, that comprises hydrogen, for use in a combustor of a gas turbine. Embodiments also comprise a new reactor design for the generation of the fuel.

BACKGROUND

[0003] Fossil fuels provide a significant portion of the world's energy needs. A problem with fossil fuel combustion is that it is a major source of anthropogenic carbon dioxide (CO_2) emissions.

[0004] A known technology for reducing CO_2 emissions into the atmosphere is carbon capture and storage (CCS). The three main options for capturing CO_2 from fossil fuel plants are post-combustion, pre-combustion, and oxy-combustion. An important advantage of post-combustion technologies is that the technology can be retro-fitted to existing power plants.
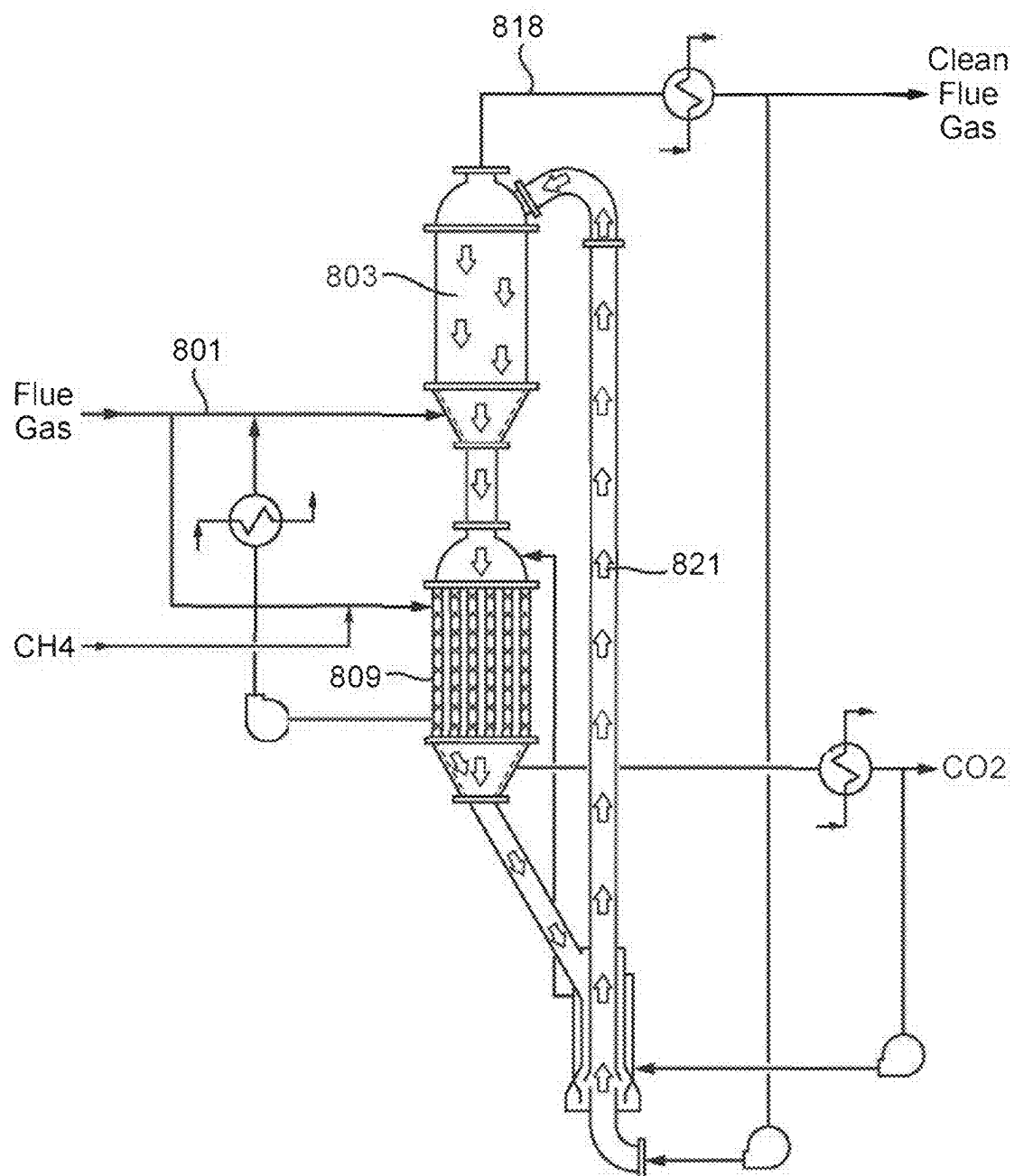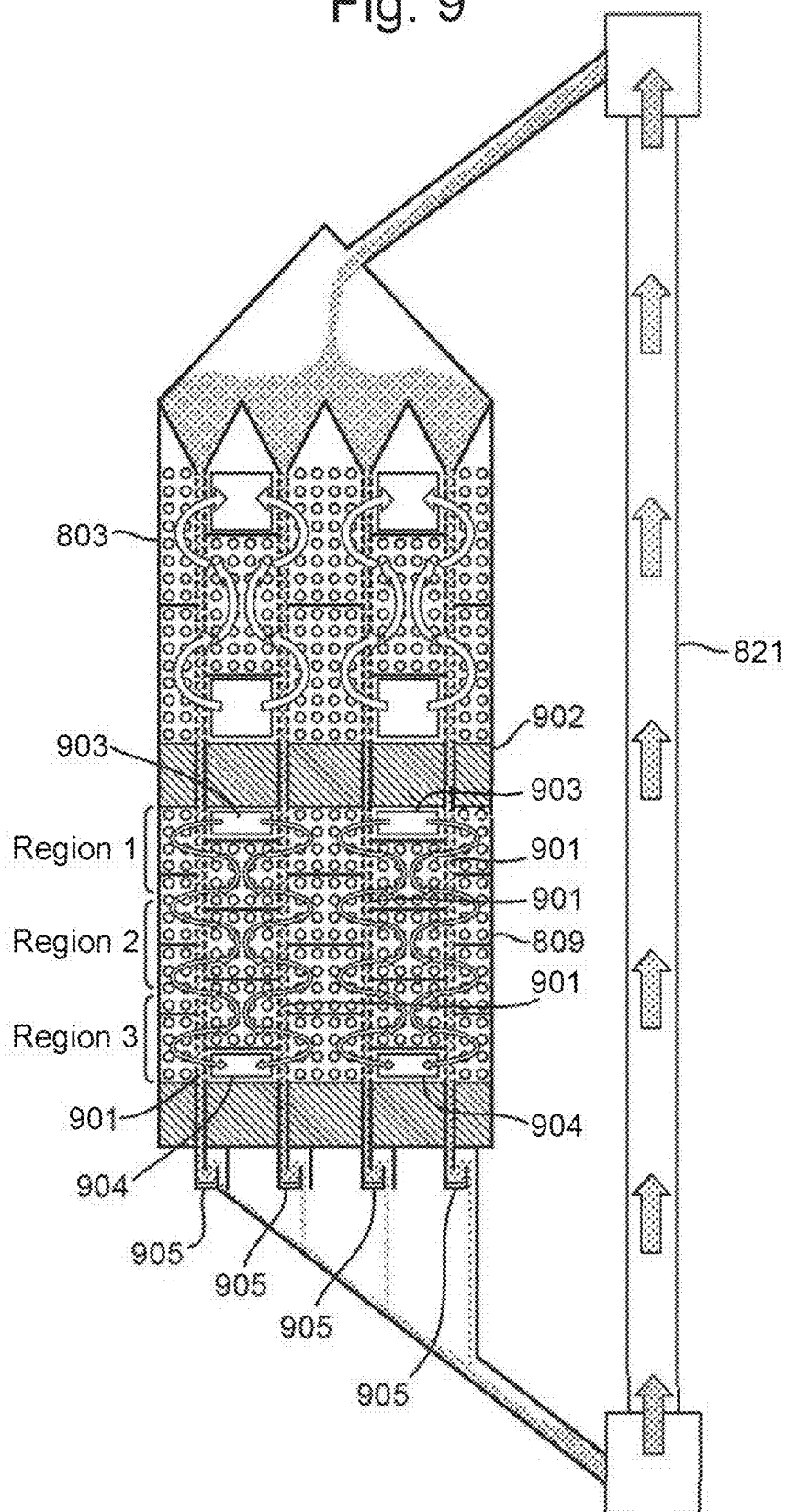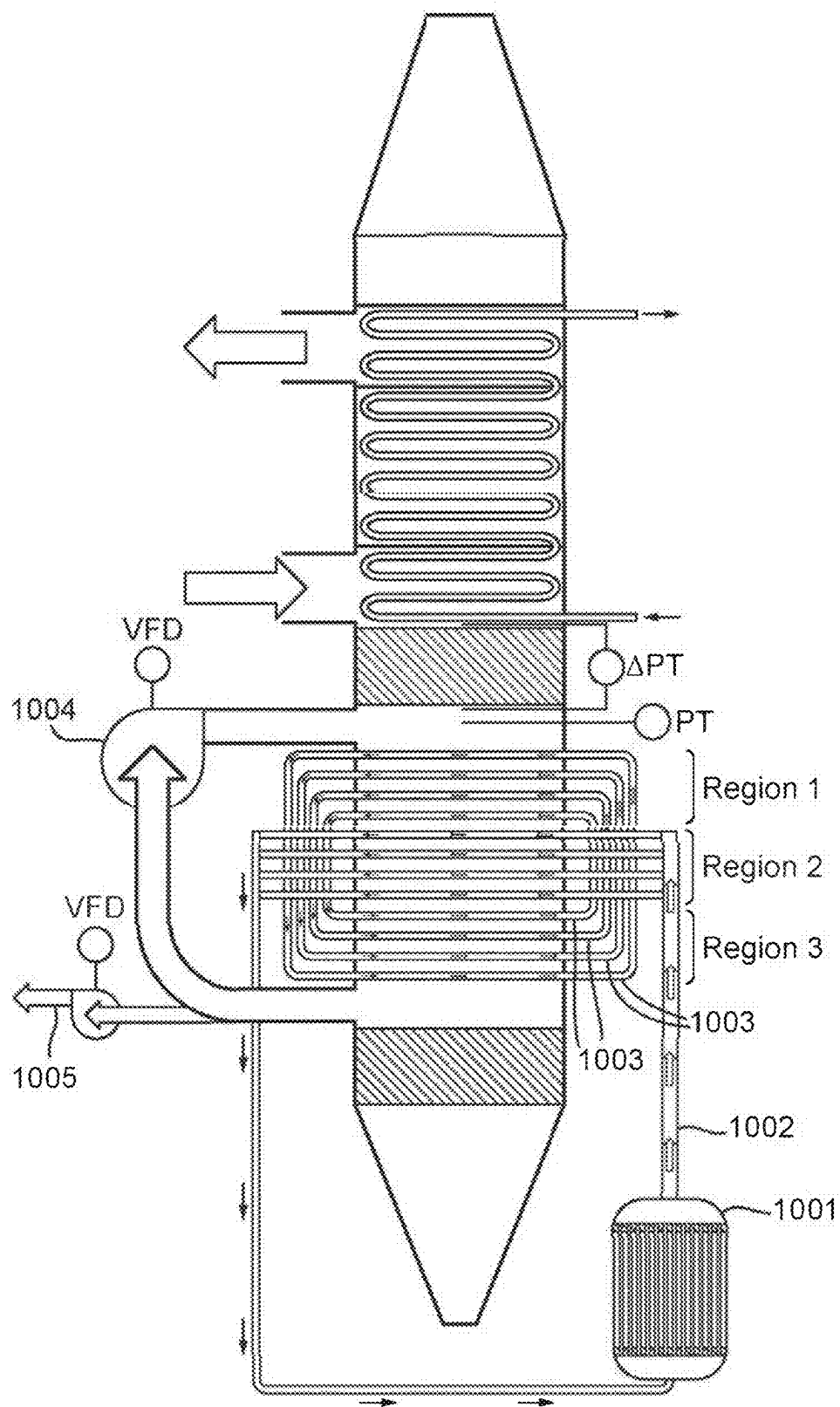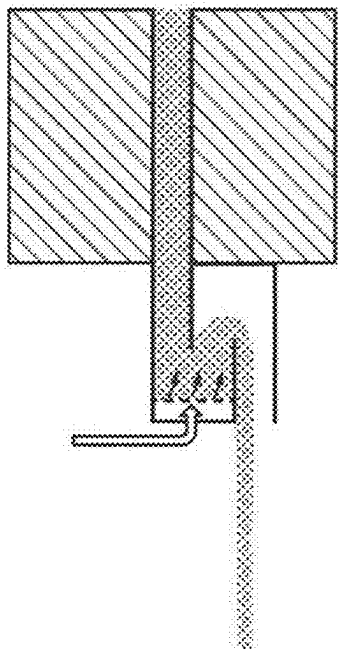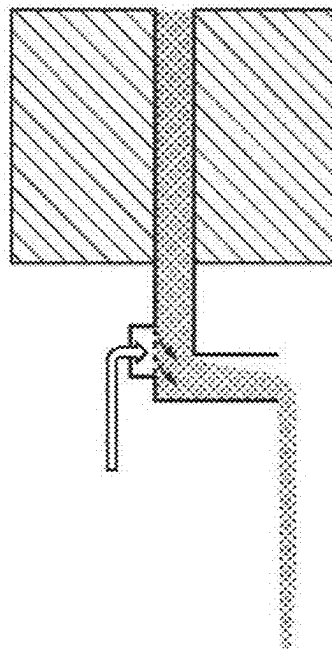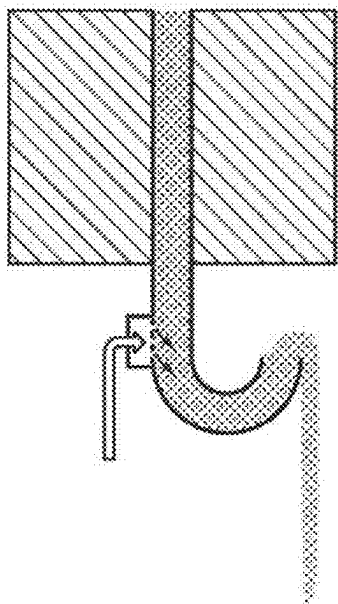
[0005] In a CCS system, a sorbent removes CO_2 from a carbonaceous gas. The CCS system also comprises a sorbent regenerator in which the sorbent releases CO_2 into a controlled environment so that the CO_2 is not released into the atmosphere. The regenerated sorbent is then re-used to remove CO_2 from gas. The sorbent is therefore moved around the CCS system in a loop.

[0006] The sorbent used for post combustion CO_2 capture can either be any of a number of commercially available aqueous amine solvents or a sorbent-based adsorption technology. An advantage of absorption processes that use amine solvents is the fast kinetics in the absorption reactor. However, disadvantages include high capital and operating costs. The use of amine solvents can also cause environmental problems. The use of solid sorbents for CCS has a number of technical and economic advantages over the use of amine solvents. An example of a solid sorbent for CCS is calcium oxide (CaO).

[0007] For realisation of a solid sorbent-based CCS system, a gas-solid reactor is required for supporting the reaction between a solid sorbent and carbonaceous gas, e.g. a flue gas from a fossil fuel power plant. Three types of beds are typically used in gas-solid reactors. These are fixed beds, fluidized beds, and moving beds.

[0008] When reactors with fixed beds are used in a system that is operated continuously, the reactors require complicated operation and control procedures in which the bed is alternatively saturated and regenerated in a cyclical manner. Another problem with fixed bed reactors, in the specific application of CCS applied to flue gas from fossil fuel fired plant with a CaO sorbent, is that the volume of flue gas is three orders of magnitude larger than the optimum volume flow of solid particles. Due to limitations on gas velocity to prevent the bed from fluidizing, a large number of fixed beds are needed, and this greatly increases the capital cost.

[0009] A fluidised bed of a reactor is a bubbling and circulating bed in which solids and gas are well mixed. The mixing ensures good heat and mass transfer characteristics. The fluidized bed reactor is an effective mixing device for solid particles due to the large flows inside the reactor. However, a problem with fluidised bed reactors is that the retention time of individual solid particles has a very wide probability distribution. Some particles can stay in the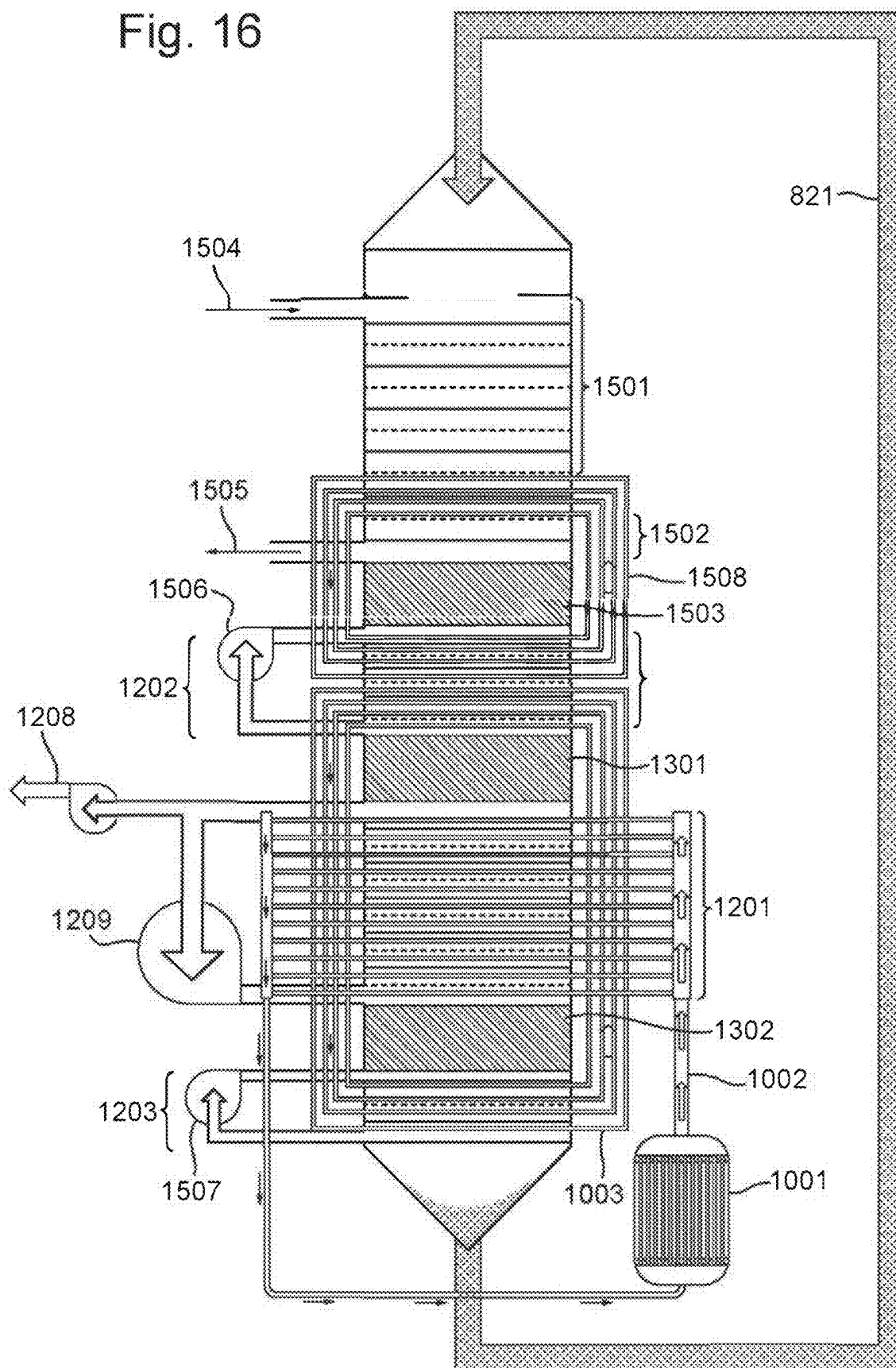 reactor for seconds, whereas other particles may stay in the reactor for minutes. When the optimum retention time for the reaction is in the order of a few minutes, a significant proportion of the solids will be in the reactor for too short a time for the reaction to be effectively completed, and another significant proportion will still be in the reactor long after reaction is completed. This reduces the efficiency of fluidized bed reactors and reduces their economic viability. Another problem with the use of fluidized bed reactors is that there can be significant attrition of sorbent particles and erosion of the reactor vessel and internal components.

[0010] In known designs of moving bed reactor, solid particles are contained in a vertically oriented reactor chamber. Solid particles are continuously fed into the top of the reactor and taken out from the bottom of the reactor in a controlled manner. By the act of gravity, the solid bed inside the reactor moves from the top of the reactor to the bottom of the reactor as a plug. This secures a specific retention time of solid particle passing through the reactor. The solid particles are fairly densely packed in the moving bed, leaving a relatively small volume for the gas phase. Gaseous reactants can pass through the reactor in a co-flow, counter flow, or cross flow manner. Known designs of moving bed reactor are problematic when the gas has a relatively low concentration of reactants such that there is a large proportion of inert gas inside the reactor that needs to be transported through the solid bed. This creates large pressure drops in the gas phase, and in the case of counter flowing gas, the gas may quickly start to fluidize the solid bed so that the system does not possess the characteristics of a moving bed reactor.

[0011] Hydrogen has a number of important uses, often termed the 'hydrogen economy'. In particular, hydrogen may be used as a directly combusted fuel. Advantageously, hydrogen is a clean fuel because the only product of the combustion is water.

[0012] It is known to use reforming processes to generate hydrogen. Reforming processes react methane with steam to generate hydrogen and carbon dioxide. The hydrogen can then be separated from the gas mixture by using a membrane or other techniques.

[0013] There is a general need to provide an improved reactor system for use in large scale CCS applications and for hydrogen production by reforming. There is also a general need to improve the provision of hydrogen as a fuel.

SUMMARY

[0014] Aspects of the invention are set out in the independent claims.

[0015] Preferable aspects are set out in the dependent claims.

BRIEF DESCRIPTION OF DRAWINGS

[0016] FIG. 1 is a cross-section through a reactor design according to an example;

[0017] FIG. 2 is a cross-section through a reactor design according to an example;

[0018] FIG. 3 is a cross-section through a reactor design according to an example;

[0019] FIG. 4 is a cross-section through a reactor design according to an example;

[0020] FIG. 5 is a cross-section through a reactor design according to an example;

[0021] FIG. 6 is a cross-section through a reactor design according to an example;

[0022] FIG. 7A is a cross-section through a reactor design according to an example;

[0023] FIG. 7B is a top down view of a reactor design according to an example;

[0024] FIG. 7C is a cross-section through a reactor design according to an example;

[0025] FIG. 7D is a cross-section through a moving bed of a reactor design according to an example;

[0026] FIG. 7E is a cross-section through part of a flow control mechanism according to an example;

[0027] FIG. 7F is a cross-section through a loop valve of a reactor design according to an example;

[0028] FIG. 8 is a system according to an example;

[0029] FIG. 9 is a system showing first and second reactor designs according to an example;

[0030] FIG. 10 is a system showing first and second reactor designs according to an example;

[0031] FIGS. 11A, 11B, 11C and 11D show flow control mechanisms that may be used to control the flow through the first and/or second reactor designs according to examples;

[0032] FIG. 12 is a system according to an example;

[0033] FIG. 13 is a system according to an example;

[0034] FIG. 14 is a system according to an example;

[0035] FIG. 15 is a system according to an example;

[0036] FIG. 16 is a system according to an example;

[0037] FIG. 17 is a system according to an example;

[0038] FIG. 18 shows a known implementation of a gas turbine; and

[0039] FIG. 19 is a flow diagram of a technique according to an embodiment.

DESCRIPTION OF EXAMPLES

[0040] There are a number of problems with using hydrogen as a combusted fuel in a gas turbine. Hydrogen is highly reactive, and this causes high temperatures. One of the problems experienced by the various attempts to combust hydrogen in air is that the high temperatures cause high NOx concentrations, and this is a strictly regulated pollutant. The high combustion velocity also prevents the use of advanced dry low NOx burner technology.

[0041] A way of using hydrogen as fuel is to use syngas fired gas turbines in IGCC plants. Hydrogen is one of the major fuel constituents of syngas. However, a problem with this approach is that it requires additional processes for the generation of the syngas and large amounts of carbon monoxide may be generated.

[0042] An attempt to solve the problems experienced by pure hydrogen has been to dilute the hydrogen. Nitrogen and steam are both potential diluent candidates. Although steam is demonstrated to be more effective than nitrogen, the latter is preferred because steam significantly affects the heat transfer properties of the hot exhaust gas flow and reduces the use life components in a system. However, the use of nitrogen requires the cost and complication of providing an air separation unit for generating the nitrogen, i.e. depleting oxygen from air.

[0043] There is a need to improve on known technologies for use of hydrogen in a gas turbine. In particular, there is a need provide an efficient hydrogen driven gas turbine in dependence on a supply of natural gas.

[0044] The inventors have found a way of improving the use of hydrogen as a combusted fuel in a gas turbine. The fuel used in the gas turbine is a gas mixture that comprises hydrogen as well as substantially inert gasses, such as nitrogen and carbon dioxide.

[0045] The inventors have also developed a particularly advantageous system for generating hydrogen by reforming processes and realised that the hydrogen generated by such a system may be used as the hydrogen that is combusted in a gas turbine. Hydrogen production may therefore be integrated with the use of the hydrogen in a gas turbine.

[0046] Presented first below is a description of a number of examples of new reactor designs of the inventors.

[0047] Embodiments are then described in which hydrogen generated by a reactor is used to supply the fuel for a gas turbine.

[0048] According to a first example, there is provided a first reactor for supporting a reaction between a sorbent and a gas.

[0049] According to a second example, there is provided a second reactor for supporting a reaction in which a sorbent is regenerated.

[0050] According to a third example, there is provided a system comprising the reactors of the first and second examples.

[0051] According to a fourth example, there is provided another system comprising the reactors of the first and second examples.

[0052] According to a fifth example, there is provided a system for supporting a sorption enhanced reforming process, and optionally a sorption enhanced water gas shift process, in addition to a gas capture process.

[0053] A preferred application of examples is in a CCS system for large scale CCS applications. The CCS system preferably uses metal oxide particles/pellets, such as calcium oxide (CaO) particles/pellets, as a sorbent. The sorbent preferably continuously moves around the CCS system in a loop with the sorbent being used to capture a gas and then being regenerated with each loop of the system.

[0054] In the application of CO_2 capture from flue gas from a natural gas fired combined cycle power plant (NGCC), the concentration of reactant is less than 4% vol. A typical 400 MW class NGCC produces nearly 2000 m^3/s exhaust from the gas turbine. To capture the CO_2 by carbonate looping in a moving bed reactor requires a flow of approximately 400 kg/s of CaO particles. Effective CaO particles would need to be in the form of substantially spherical pellets of diameter 1 mm to 3 mm having a bulk density of about 1000 kg/m^3. This results in a volume flow of circulating solids of 0.4 m^3/s. An acceptable utilization of the CaO pellets requires a retention time in the reactor of approximately 3 minutes. That implies a bulk volume of the solid pellets bed of 72 m^3. It is clearly not possible to pass

2000 m³/s exhaust gas through a known design of moving bed of such volume without causing extreme pressure drops or fluidization of the bed.

[0055] For a coal fired power plant, the CO_2 concentration in the gas may be 12-14% vol. Flue gases from industrial process like a blast furnace for steel production or a cement kiln can have concentrations of CO_2 above 20%. However, the inert gas volume left after the CO_2 has reacted with the solids has practically the same volume. Known moving bed reactor designs therefore experience similar problems to those described above.

[0056] Examples solve the above problems by providing new designs of reactors for supporting gas-solid reactions and the release of gas from a solid in a CCS system. Each reactor comprises a plurality of moving beds for transporting solid sorbent through the reactor. Each reactor also comprises a plurality of gas ducts for gas flows through the reactor. The gas flows are controlled such that gas is forced to flow across one or more moving beds a plurality of times.

[0057] A particularly preferred application of a reactor according to an example is supporting the reaction between a solid sorbent and a carbonaceous gas in a CCS system. The sorbent is preferably CaO particles in the form of substantially spherical pellets/particles with a 1 mm to 3 mm diameter and a bulk density of up to 3000 kg/m³, preferably the bulk density is in the range 1000 to 1500 kg/m³.

[0058] Examples also include other applications for reactors, such as reactors for gas reforming and/or the removal of CO_2 from a mixture of H_2 and CO_2.

[0059] A first example is described in more detail below.

[0060] FIGS. 1 to 6, 7A and 7C show cross-sections through a first reactor according to a first example. FIG. 7B is a top-down view of the first reactor. As shown in FIGS. 1 to 6, 7A and 7C, at the top of the first reactor is an inlet 5 through which sorbent enters the first reactor. At the bottom of the first reactor is an outlet 10 through which the sorbent exits the first reactor. Between the inlet 5 and the outlet 10 is a main body of the first reactor.

[0061] The main body of the first reactor has outer walls 1. At the top of the main body of the first reactor is an upper bed 6. Provided below the upper bed 6 are a plurality of moving beds 7 that extend vertically downwards through the main body of the first reactor to a lower bed 9 at the bottom of the first reactor. The main body of the first reactor also comprises a gas inlet 14, through which gas enters the first reactor, and a gas outlet 13, through which gas exits the first reactor. Between the vertically arranged moving beds 7, as well as the outer walls 1 of the main body, are gas ducts for gas flows through chambers in the main body.

[0062] The walls of the moving beds 7 comprise strainer plates 3. The strainer plates 3 have the property of retaining the solid sorbent within each moving bed 7 but gas is able to pass through the strainer plates 3. A possible design of the strainer plate 3 may be types of wedge wire screens, such as those manufactured by Intamesh, see http://www.intamesh.co.uk/as viewed on 13 Dec. 2017. It is known to use such screens as strainers and filters in other industries than the field of examples, such as in shale shakers for mud and cuttings separation during the drilling of oil and gas wells. FIG. 7D is a cross-section through a moving bed 7 with wedge wire screens as walls according to an example.

[0063] In order to minimise the friction and stress on the particles of sorbent, the strainer plates 3 are preferably orientated vertically. That is to say, the gap between the plates is linear and orientated so that it is parallel to the flow of sorbent through the first reactor. For the same reason, when the strainer plate 3 is a wedge wire screen, the flat side of the wedge should provide the inner surface of the outer wall of the moving beds 7, as shown in FIG. 7D. The wedge should have the property that the openings in the wedge are not so large that particles of the sorbent can pass through the openings, but the openings should be large enough to allow gas to pass through them. The diameter of the sorbent particles/pellets may be about 1 mm to 3 mm and so an appropriate opening distance in the wedge wire screen may be between 0.2 mm to 0.8 mm, preferably 0.5 mm. The width of the flat side of the wedge that provides the inner surface of the outer wall of the moving beds 7, as shown in FIG. 7D, may be 1.5 mm.

[0064] The first reactor is designed so that it can be used with any size of sorbent. The openings in the wedge are always designed to be smaller than the diameter of all, or substantially all, the particles of the sorbent so the particles cannot pass through the openings. For example, if the particles of the sorbent have a diameter of 0.5 mm the openings in the wedge may be reduced to 0.3 mm.

[0065] Alternatively, the strainer plates 3 may be provided by perforated plates, or a thick rigid perforated plate with fairly large diameter perforation (approx. 10 mm) cladded with a thin sheet with very small perforation (<1 mm). In some applications these may be sufficient for retaining particles of solid sorbent in the moving beds 7 and less expensive than wedge wire screens.

[0066] The gas ducts comprise horizontally arranged baffle plates 2 and gas is unable to flow directly through a baffle plate 2. Preferably there is at least one baffle plate 2 in each gas duct 4. The provision of one or more baffle plates 2 in each vertically aligned gas duct divides each gas duct into a plurality of separate and vertically aligned chambers.

[0067] As shown in FIG. 6, when a gas flow in a gas duct 4 reaches a baffle plate 2, the gas is forced by the baffle plate 2 to flow out of its current chamber in the gas duct, through a strainer plate 3 and into a moving bed 7. The gas then flows across the moving bed 7 and into a chamber of a different gas duct. In order for it to be possible for gas to flow from a chamber in a first gas duct 4 to an adjacent chamber in the same first gas duct, via a chamber in a second gas duct, the vertical position of baffle plates 2 in adjacent gas ducts is preferably staggered as shown in FIG. 6. That is to say, in any two adjacent gas ducts 4, all of the baffle pates 2 have different vertical positions. As shown in FIG. 6, a gas path through the first reactor may comprise flowing across the same moving bed 7 plurality of times. Clearly, a gas flow path through the first reactor may additionally, or alternatively, comprise flowing across a plurality of different moving beds 7.

[0068] The gas flow paths from the gas inlet 14 to the gas outlet 13 therefore comprise gas flows through a plurality of chambers, with the gas flowing through one of the moving beds 7 whenever it flows between two chambers.

[0069] Preferably, the main body of the first reactor is substantially a rectangular cuboid. Each of the moving beds 7, gas ducts and chambers in each gas duct are also substantially rectangular cuboids. Two walls of each moving bed 7 are provided by strainer plates 3, two further walls of each moving bed 7 are provided by parts of the outer wall 1 of the main body and the moving beds 7 are open at each end in order for sorbent to enter and exit the moving bed 7.

Each gas duct is also cuboid and is either formed between two moving beds **7** or between a moving bed **7** and the outer wall **1** of the main body. The baffle plates **2** in the gas ducts are also thin rectangular cuboids. Advantageously, the components of the main body of the first reactor all have a rectangular cuboid construction and can therefore be easily made. The construction of the first reactor is also easier when rectangular cuboid components are used.

[0070] Although the main body of the first reactor is preferably rectangular cuboid, examples also include the first reactor being cylindrical, as well as other shapes.

[0071] According to a preferred example, the rate at which sorbent passes through the moving beds **7** can be controlled. At the lower end of each of the moving beds **7** is an exit duct **8**. Each of the exit ducts **8** comprises a flow control mechanism. The flow control mechanism may comprise, for example, one or more loop seals, as shown in FIG. 7F, and/or one or more adjustable baffles, as shown in FIG. 7E, and allows the rate at which the sorbent moves into the lower bed **9** to be controlled. Preferably, some of the gas is fed into a gas inlet of the loop seal. This generates an up-flow of gas that reduces that rate at which sorbent particles move through the moving beds. The flow control mechanism through the first reactor may also be as described later with reference to FIGS. 11A to 11D.

[0072] The reaction between a carbonaceous gas and CaO is an exothermic reaction. It is therefore necessary to remove heat from the first reactor in order to maintain the conditions of the reaction between the gas and the sorbent within a desired temperature range over a long period of use, or continuous use, of the first reactor. In order to remove heat for the first reactor, the first reactor preferably comprises one or more cooling tubes **12**. As shown in FIGS. **4**, **5**, 7A and 7C, a cooling tube **2** has an inlet **15** into the first reactor and outlet **16** from the first reactor. The cooling tube **2** is arranged to pass the through one or more of the gas ducts. Examples include there being one or more cooling tubes **12** for each chamber of a gas duct, one or more cooling tubes **12** for each gas duct or one or more cooling tubes **12** for all of the gas ducts. The cooling tubes are arranged to directly cool the gas in order to remove heat from the system. Since the cooling tubes **12** do not pass through the moving beds **7** they do not impede the movement of the sorbent in the moving beds **7**. Within each cooling tube is a circulated coolant in a heat exchanger arrangement according to known techniques. The coolant may be, for example, one of the noble elements (such as Helium), sodium or any other suitable working fluid.

[0073] FIGS. **3** and **5** show gas inlet ports **312** and gas outlet ports **311** for providing a gas flow into the gas ducts **4** of the first reactor. There is a first manifold between the gas inlet ports **312** and the gas inlet **14**, and a second manifold between the gas outlet ports **311** and the gas outlet **13**. In the shown configuration with the gas inlet **14** below the gas outlet **13**, the relative flows of the gas and sorbent through the first reactor comprise a counter flow component in addition to the cross-flow component. However, examples also include the gas inlet **14** being above the gas outlet **13** and the relative flows of the gas and sorbent through the first reactor comprising a co-flow component in addition to the cross-flow component.

[0074] As shown in FIG. **3**, the first and second manifold are preferably arranged to connect to every second gas duct. Examples also include manifolds being connected to both sides of the first reactor, such that every gas duct is connected to manifolds for gas supply and extraction. This is particularly appropriate when the gas flows are large as it reduces the gas flow velocity into and out of the first reactor.

[0075] Examples include there being any number of baffles **2** in each gas duct. For example, the number of baffles **2** in a gas duct may be between one and ten. The superficial cross flow velocity of gas through the first reactor depends on the vertical spacing of the baffles **2** in gas duct and so the number and spacing of the baffles **2** is preferably designed so that an appropriate cross-flow velocity is achieved for the expected operating conditions of the first reactor.

[0076] In use, solid particles/pellets of sorbent are fed into the inlet **5** at the top of the first reactor. A carbonaceous gas, such as a flue gas, is fed into the gas inlet **14**. The sorbent moves through the upper bed **6** and is split so that it travels into the plurality of parallel moving beds **7**. The baffle plates **2** in the gas ducts **4** force the gas to make a plurality of flows through one or more the moving beds **7**. In each moving bed **7**, the relative flow between the solid and the gas has both a cross-flow component, due to the gas moving across the moving bed **7**, and a vertical component, which is either a counter-flow or co-flow relative to that of the sorbent.

[0077] An advantage of the first reactor design according to examples is that the contact between the gas and sorbent is very effective. The gas is forced to make a plurality of crossings of one or more moving beds **7** as the gas flows from the gas inlet to the gas outlet. This is clearly shown in FIG. **6** in which there is a cross-flow and counter-flow of gas and sorbent. The first reactor has approximate properties to those of a counter flow moving bed reactor in which the solids are distributed over a very large area and there is a low bed thickness. The narrow thickness of the bed allows the gas cross-flow velocity to be low and the gas pressure drop is consequently also low.

[0078] Another advantage of the first reactor according to examples is that the volume of the gas ducts is a lot larger than that of the moving beds **7**. For example, the width of each of the gas ducts may be in the range of 10 cm to 100 cm, whereas the width of each moving bed **7** may be in the range 1 cm to 10 cm. Even when the volume ratio of the gas and solid is greater than a thousand, the first reactor can be easily designed to accommodate gas flow velocities in the preferred range of 10 m/s to 20 m/s, and sorbent velocities in the moving beds **7** that are in the range 1 cm/s to 10 cm/s.

[0079] The first reactor according to examples has the combined advantages of a fluidized bed reactor's large gas flow capacity and a moving bed reactor's specific retention time of a solid sorbent. The mechanical stress on sorbent particles/pellets is also low due to the low velocity of the sorbent through the moving beds **7**.

[0080] FIG. **6** shows gas flow paths **18** between adjacent gas ducts **4** via a moving bed **7**. The average vertical gas flow velocity, UFG, is 19. The superficial cross-flow velocity of the gas, UCF, is 20. The moving bed velocity, UMB, is 17.

[0081] The cooling requirements of the cooling tubes are explained further below.

[0082] The specific surface area of randomly packed spheres of diameter 2 mm is 900 m^2/m^3. The total bulk volume of the solid sorbent pellets in a first reactor, for a CaO looping CCS system for flue gas from a 400 MW class NGCC, is 72 m^3. The results in a total heat surface area between solid sorbent and flue gas of 64800 m^2. For a flue

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gas passing such a bed at a superficial velocity of approximately 1 m/s, the heat exchange coefficient will be in the order of 500 W/m²K. The required heat removal in such a system in order to keep the temperature of the solid sorbent constant is 150 MW. This implies a temperature difference between gas and solid sorbent of:

$$\Delta T = \frac{150 \text{ MW}}{500 \text{ W m}^{-2}\text{K}^{-1} \cdot 64{,}800 \text{ m}^2} = 4.6\text{K}$$

[0083] For a flow velocity of gas in the ducts of 10-20 m/s, the heat exchange coefficients are 75-150 W/m²K. This is for forced convection over typical tube bundles with tube diameter, D, being 20 mm-50 mm. The specific area of a 20 mm diameter tube in a rectangular array with pitch of 2×D is 40 m². Examples include this being increased by use of finned tubes. The required volume of the gas ducts in the carbonator reactor will be 50 times larger than the volume of the solids beds of 72 m³. This gives following required temperature difference between flue gas and tube wall:

$$\Delta T = \frac{150 \text{ MW}}{100 \text{ W m}^{-2}\text{K}^{-1} \cdot 40 \text{ m}^2\text{m}^{-3} \cdot 50 \cdot 72 \text{ m}^3} = 10.4\text{K}$$

[0084] This implies that gas will be efficiently cooled each time it passes the heat exchanger installed in the gas ducts. Therefore, the solid sorbent in the moving bed **7** will be cooled indirectly in an efficient manner. As the number of passes increases, the temperature rise in the gas phase per pass of a moving bed **7** will reduce.

[0085] FIG. **8** shows a CCS system according to an example. A solid sorbent, such as CaO particles/pellets, as described throughout the present document, move around the CCS system in a loop. The CCS system is appropriate for retrofitting to a fossil fuel power plant.

[0086] The CCS system comprises an input of flue gas **801**, a carbonator **803**, a calcinator **809**, a riser **821**, and output of cleaned flue gas **818** and a separate output of substantially pure CO₂.

[0087] The carbonator is preferably a gas-solid reactor of the first example as described with reference to FIGS. **1** to **7F**. In the carbonator **803**, sorbent reacts with the flue gas to thereby substantially reduce the CO₂ concentration in the flue gas. In the calcinator **809**, the sorbent is regenerated by heating the sorbent so that it releases CO₂. The riser then returns the regenerated sorbent to the input of the carbonator **803**.

[0088] The first reactor, according to the first example, may also be integrated with one or more other reactors. In particular, FIGS. **9** and **10** also show an implementation of a CCS system according to an example in which an implementation of the first reactor is integrated with a second reactor, as described in detail below.

[0089] A second example is described below.

[0090] According to the second example, a second reactor **809** is provided. The second reactor **809** is designed to receive solid particles and heat the particles so that the particles release a gas.

[0091] A preferred application of the second reactor **809** may be as the above-described calcinator **809** in which the

same sorbent that was used in the carbonator **803** is regenerated by heating the sorbent so that it releases carbon dioxide gas.

[0092] The second reactor **809** may be used with any type of sorbent. Preferably, the sorbent comprises a metal oxide. More preferably, the sorbent comprises calcium oxide and/or calcium carbonate. Calcium oxide may react in the first reactor **803** with carbon dioxide gas to form calcium carbonate. The sorbent may then be regenerated in the second reactor **809** by heating the calcium carbonate so that it becomes calcium oxide and carbon dioxide gas is released.

[0093] The second reactor **809** is described below in the example application of the second reactor **809** receiving particles of calcium carbonate and regenerating the calcium carbonate so that it becomes particles of calcium oxide and carbon dioxide gas is generated.

[0094] Examples of the second reactor **809** are shown in FIGS. **9** and **10**. The second reactor **809** is shown integrated with an implementation the above-described first reactor **803** and a riser **903**.

[0095] The second reactor **809** has a similar construction and design features to the first reactor **803** in that the structure of the second reactor **809** supports substantial cross-flows of gas across solid particles that are travelling vertically downwards in a moving bed **901** with the solid particles retained within the moving bed.

[0096] The second reactor **809** comprises inlet(s) at the top of the second reactor **809** through which sorbent enters the second reactor **809**. At the bottom of the second reactor **809** are outlet(s) through which sorbent exits the second reactor **809**. Between the inlet(s) and the outlet(s) is a main body of the second reactor **809**. The main body of the second reactor **809** has outer walls. One or more moving beds **901** are provided in the second reactor **809**. Each moving bed **901** extends, from an inlet, vertically downwards through the main body of the second reactor **809** to an outlet of the second reactor **809**. The main body of the second reactor **809** also comprises at least one gas inlet, through which gas enters the second reactor **809**, and at least one gas outlet, through which gas exits the second reactor **809**. Between the vertically arranged moving beds **901**, as well as the outer walls of the main body, are gas ducts for gas flows in the main body. Each gas duct comprises a plurality of vertically staked chambers.

[0097] The walls of the moving beds **901** comprise strainer plates. The strainer plates have the property of retaining the solid sorbent within each moving bed **901** but gas is able to pass through the strainer plates. The strainer plates in the second reactor **809** may be the same as the strainer plates as described earlier for the first reactor **803**.

[0098] The strainer plates in the second reactor **809** may also be arranged in the same way as the strainer plates as described earlier for the first reactor **803**. Accordingly, in order to minimise the friction and stress on the particles of sorbent in the second reactor **809**, the strainer plates are preferably orientated vertically. That is to say, the gap between the plates is linear and orientated so that it is parallel to the flow of sorbent through the second reactor **809**. Similarly, when the strainer plate is a wedge wire screen, the flat side of the wedge should provide the inner surface of the outer wall of the moving beds **901** in the second reactor **809**, as shown in FIG. **7D** for the first reactor **803**. The wedge should have the property that the openings in the wedge are not so large that particles of the sorbent can

pass through the openings, but the openings should be large enough to allow gas to pass through them. The diameter of the sorbent particles/pellets may be about 1 mm to 2 mm and so an appropriate opening distance in the wedge wire screen may be between 0.2 mm to 0.8 mm, preferably 0.5 mm. The width of the flat side of the wedge that provides the inner surface of the outer wall of the moving beds **901** in the second reactor **809**, as shown in FIG. **7D** for the first reactor **803**, may be 1.5 mm

[0099] Alternatively, the strainer plates may be provided by perforated plates, or a thick rigid perforated plate with fairly large diameter perforation (approx. 10 mm) cladded with a thin sheet with very small perforation (<1 mm). In some applications these may be sufficient for retaining particles of solid sorbent in the moving beds **901** and less expensive than wedge wire screens.

[0100] The gas ducts comprise horizontally arranged baffle plates and gas is unable to flow directly through a baffle plate. Preferably, there is at least one baffle plate in each gas duct. The provision of one or more baffle plates in each vertically aligned gas duct divides each gas duct into a plurality of separate and vertically aligned chambers. In any two adjacent gas ducts, all of the baffle plates preferably have different vertical positions.

[0101] The arrangement of the baffle plates, strainer plates and moving beds **901** in the second reactor **809** is as described for the first reactor **803**. Accordingly, gas is forced to flow through from a gas duct, through a strainer plate and into a moving bed, and through a strainer plate and into a gas duct according to the same process as described earlier with reference to FIG. **6**. The gas flow paths from the gas inlet(s) **903** to the gas outlet(s) **904** therefore comprise gas flows through a plurality of chambers, with the gas flowing through one of the moving beds **901** whenever if flows between two chambers.

[0102] The main body of the second reactor **809** is substantially a rectangular cuboid. Each of the moving beds **901**, gas ducts and chambers in each gas duct are also substantially rectangular cuboids. Two walls of each moving bed **901** are provided by strainer plates, two further walls of each moving bed **901** are provided by parts of the outer wall of the main body and the moving beds **901** are open at each end in order for sorbent to enter and exit the moving bed. Each gas duct is also cuboid and is either formed between two moving beds **901** or between a moving bed **901** and the outer wall of the main body. The baffle plates in the gas ducts are also thin rectangular cuboids. Advantageously, the components of the main body of the second reactor **809** all have a rectangular cuboid construction and can therefore be easily made. The construction of the second reactor **809** is also easier when rectangular cuboid components are used.

[0103] Although the main body of the second reactor **809** is preferably rectangular cuboid, examples also include the second reactor **809** being cylindrical, as well as other shapes.

[0104] When the second reactor **809** is used for the application of regenerating a sorbent, the reaction that regenerates the sorbent should be performed at an appropriate temperature for this reaction. For example, the heating of calcium carbonate to generate calcium oxide and carbon dioxide is preferably performed at about 900° C. When the second reactor **809** is used in a sorbent looping system, such as the system shown in FIGS. **8** to **10**, the temperature of the sorbent received by the second reactor **809** is substantially at the temperature that the reaction in the first reactor **803** is

performed at. The reaction between calcium oxide and carbon dioxide in the first reactor **803** is preferably performed at about 600° C. The sorbent received by the second reactor **809** is therefore at a lower temperature than an appropriate temperature for the regeneration of the sorbent. The sorbent output from the second reactor **809** is returned to the input of the first reactor **803** via the riser. The temperature of the sorbent received by the first reactor **803** is preferably appropriate for the reaction in the first reactor **803**. Accordingly, the temperature of the sorbent output from the second reactor **809** is preferably substantially the temperature required by the first reactor **803**.

[0105] The second reactor **809** may therefore receive sorbent at about 600° C. and it is preferable for the second reactor **809** to output sorbent at about 600° C. Within the second reactor **809**, the sorbent is required to be heated to about 900° C. so that regeneration of the sorbent can occur.

[0106] FIG. **9** shows three different regions in the second reactor **809**. Region 1 is a first region, Region 2 is a second region, and Region 3 a third region.

[0107] The first region is provided at the top of the second reactor **809**. In the first region, sorbent received by the second reactor **809** is heated substantially to the temperature required for sorbent regeneration.

[0108] The second region is provided below the first region. In the second region, the received sorbent is heated at a temperature for regenerating the received sorbent.

[0109] The third region is provided at the bottom of the second reactor **809**. In the third region, the sorbent is cooled approximately to a temperature that is appropriate for being input to the first reactor **803**.

[0110] The second region is therefore provided between the first and third regions such that all of the sorbent that flows from the inlet(s) of the second reactor **809** to the outlet(s) of the second reactor **809** is forced to flow through the first region, then through the second region and then then through the third region.

[0111] FIG. **10** shows how heat may be supplied to the second region so that the second region is at an appropriate temperature for regenerating the sorbent. The heat may be generated in an external combustor **1001**. The external combustor **1001** may be a catalytic combustor and is preferably a catalytic total combustor, such as the catalytic total combustor described in WO/2018/162675, the entire contents of which are incorporated herein by reference.

[0112] The heat may be transferred from the external combustor **1001** to the second region by a heat loop/heat exchanger **1002**. As shown in FIG. **10**, the second reactor **809** comprises pipes in the second region for supplying heat to the second region from the external combustor **1001**. As shown in FIG. **10**, a working fluid may flow from the external combustor **1001** through a first manifold so that the working is supplied to a plurality of pipes that pass through the second region. A second manifold receives the working fluid that has flowed through the second region and returns the working fluid to the external combustor **1001**. The working fluid may be any suitable working fluid. For example, the working fluid may be one of the noble elements (such as Helium), sodium or any other suitable working fluid. If sodium is used the system can be operated as a self-circulating loop-heat-pipe system.

[0113] As described above, the first region heats the received sorbent to the temperature required in the second region and the third region cools the sorbent so that the

sorbent output from the third region is approximately the same as the temperature received by the first region. The first and third regions may both be connected heat exchangers such that the heat required in the first region is supplied to the first region by the third region. Heat transfer between the first and third regions both efficiently provides heat to the first region and removes heat from the third region.

[0114] As shown in FIG. **10**, there are preferably a plurality of heat loops/heat exchangers **1003** between the first and third regions. Each of the heat loops **1003** comprises a first part in the first region and a second part in the third region. In each heat loop **1003**, heat is transferred from the second part of the heat loop **1003** to the first part of the heat loop **1003**.

[0115] The symmetry of the second reactor **809** structure results in the sorbent temperature profile from the input of the first region to the output of the first region substantially corresponding to the sorbent temperature profile from the output of the third region to the input of the third region. The efficiency of heat transfer between the first and third regions is highest when the temperature difference between the second part of a heat loop **1003** and the first part of the same heat loop **1003** is small. Accordingly, for each heat loop **1003**, the position of the first part of the heat loop **1003** relative to the input and output of the first region substantially corresponds to the position of the second part of the heat loop **1003** relative to the output and input of the second region. That is to say, a heat loop **1003** with a first part that is close to the input of the first region has a second part that is close to the output of the second region. Similarly, a heat loop **1003** with a first part that is close to the output of the first region has a second part that is close to the input of the second region. The first and second parts of each heat loop **1003** are therefore at similar temperatures and this improves the efficiency of heat transfer.

[0116] As shown in FIG. **10**, the heat loops **1003** that have a first part that is closest to the input of the first region may entirely surround all of the heat loops **1003** with a first part that is further away from the input of the first region. Each heat loop **1003** may be surrounded by another heat loop **1003**, with the surrounding **1003** heat loop having first and second parts that are at respective positions in the first and second regions with a lower temperature than those of the surrounded heat loop **1003**.

[0117] Accordingly, the first, second and third regions of the second reactor **809** all comprise pipes for heat transfer into, or out of, the region. The pipes are preferably not provided in the moving beds **901** of the second reactor **809** and are instead provided only in the chambers of the gas ducts between the moving beds **901**.

[0118] The heat loops **1003** for transferring heat from the third region to the first region, and the external combustor **1001** to the second region, may be any of a number of known heat loop designs. For example, the heat loops **1003** may be any of the heat loops disclosed in: https://www.qats.com/cms/2014/08/04/understanding-loop-heat-pipes/(as viewed on 15 Oct. 2018).

[0119] The heat transfer from the pipes in the second reactor **809** to the sorbent, and vice versa, is via a forced gas flow through the gas ducts/chambers and through the moving beds **901**. A source of the gas that transfers the heat is the gas that is released when the sorbent is regenerated. Gas for the heat transfer may also be supplied into the second reactor **809** via the gas inlet(s) **903** of the second reactor **809**.

Supplying gas into the second reactor **809** via the gas inlet(s) **903** ensures that there is always an appropriate volume of gas for the required heat transfer between the pipes in each region and the sorbent in the moving beds **901**.

[0120] The supplied gas to the second reactor **809** through the gas inlet(s) **903** of the second reactor **809** may be the same gas as the gas released by the sorbent. For example, if the gas released when the sorbent is regenerated is carbon dioxide then the supplied gas through the gas inlet(s) **903** of the second region may also be carbon dioxide. By supplying the same gas as that released through the gas inlet(s) **903** the purity of the released gas by the sorbent is not reduced.

[0121] FIG. **10** shows how some of the gas flow through the gas outlet(s) **904** of the second reactor **809** can be fed to the gas inlet(s) **903** of the second reactor **809**. The proportion of the gas that is fed to the gas inlet(s) **903** may be controlled by a fan **1004** and/or other gas flow control mechanisms. The gas that is not fed to the gas inlets of the second reactor **809** flows out of the system through the gas outlet **1005** and can be stored or used in commercial applications.

[0122] Preferably, the gas inlet(s) **903** of the second reactor **809** are at the top of the second reactor **809** and the gas outlet(s) **904** of the second reactor **809** are at the bottom of the second reactor **809**. The pressure of the gas at the top of the second reactor **809** can therefore be accurately controlled by controlling the flow of gas into the second reactor **809**.

[0123] As shown in FIG. **9**, a flow control mechanism **905** for controlling the flow of sorbent through each moving bed **901** may be provided at the bottom of the second reactor **809**. The flow control mechanism **905** may comprise a loop seal or adjustable baffles as described for the first reactor **803** and shown in FIGS. **7**E and **7**F. Implementations of a flow control mechanism **905** that may be used are also shown in FIGS. **11**A to **11**D.

[0124] The flow control mechanism **905** shown in FIGS. **11**A to **11**C are all activated by a gas flow. The flow control mechanism **905** shown in FIG. **11**A is a loop seal. The flow control mechanism **905** shown in FIG. **11**B is an L-seal. The flow control mechanism **905** shown in FIG. **11**C is a J-seal.

[0125] The flow control mechanism **905** shown in FIG. **11**D is a vibration activated seal. When the vibrator is not vibrating, the friction between the sorbent particles prevents the sorbent from flowing out of the moving bed. When the vibrator is activated, the vibrator causes the end of the duct comprising the sorbent vibrate. This reduces the friction between the sorbent particles and the sorbent flows out of the duct, and consequently the moving bed.

[0126] The second example includes the second reactor **809** being used in any application. Although the second reactor **809** is shown in FIGS. **9** and **10** integrated with the first reactor **803** according to the first example, the second reactor **809** may not be integrated with the first reactor **803** and may be a separate reactor as shown in FIG. **8**. The second reactor **809** can be used on its own or in conjunction with any other type of reactor.

[0127] According to a third example, the first reactor **803**, as described above for the first example, and the second reactor **809**, as described above for the second example, are integrated together.

[0128] The integration of the first and second reactors is particularly advantageous for the specific application of looping a sorbent of a gas. The sorbent captures gas in the first reactor **803** and then releases the gas in the second reactor **809**.

[0129] The first reactor **803** may be provided directly above the second reactor **809** as shown in FIGS. **9** and **10**. The first reactor **803** is thermally insulated from the second reactor **809** by the insulating section **902**. Each of the moving beds **901** pass unobstructed from the first reactor **803**, through the insulating section **902** and to the second reactor **809**. The walls of the moving beds **901** in the part of the moving bed **901** in the insulating section **902** are a solid wall and not a sintered plate.

[0130] Sorbent travels vertically downwards in the moving beds **901** from the inlet(s) of the moving beds **901** in the first reactor **803**, through the first reactor **803**, through the insulating section **902**, through the second reactor **809** and through the outlet(s) of the moving beds **901** in the second reactor **809**.

[0131] There may be no flow control mechanism at the bottom of the first reactor **803** and only a flow control mechanism **905** at the bottom of the second reactor **809**, as described above for the second example.

[0132] The third example is particularly preferable in a sorbent looping system in which sorbent that has passed through the first and second reactors is returned to the sorbent inlet(s) of the first reactor **803**.

[0133] The sorbent that flows out of the flow control mechanism **905** is returned to the top of the first reactor **803** by the riser **821**. The riser may be any type of riser. For example, the riser may be a gas driven riser as described in WO/2018/162675, the entire contents of which are incorporated herein by reference. The riser may alternatively be a spiral elevator. The spiral elevator may be vibration driven. A demonstration of the operation of a vibration driven elevator is provided here: https://www.youtube.com/watch?v=Foi_J1sJ0wI (as viewed on 15 Oct. 2018). Particles are transported from the bottom of the spiral elevator to the top of the spiral elevator by vibrating the elevator. The riser may alternatively be a mechanical conveyor system.

[0134] Sensors may measure the temperatures and pressures throughout the system. There may also be sensors that measure the concentration of the gas to be captured by the sorbent, such as carbon dioxide, in the gas mixture received by the first reactor **803** and the gas flowing out of the first reactor **803**. The measurements may be automatically provided to a computing system. The flow of gas into the first reactor **803**, the flow of sorbent through the first and second reactors, the flow of gas into the second reactor **809**, the cooling of the first reactor **803** and the heating of the second reactor **809** are preferably all automatically controlled by the computer system. The computing system may automatically control the processes in order to efficiently capture a gas, such as carbon dioxide, from the gas mixture received by the first reactor **803**. The computing system may also automatically detect operational errors/faults of the system in dependence on the automatic feedback of data from the sensors.

[0135] In a preferred implementation of the third example, the gas inlet(s) of the first reactor **803** are at the bottom the first reactor **803** and the gas outlet(s) from the first reactor **803** are at the top of the first reactor **803**. The gas inlet(s) **903** of the second reactor **809** are at the top the second reactor **809** and the gas outlet(s) **904** the second reactor **809** are at the bottom of the second reactor **809**. This arrangement allows the pressure difference between the bottom of the first reactor **803** and the top of the second reactor **809** to be accurately controlled by controlling the gas flows into the first and second reactors. The pressure difference is prefer-

ably controlled such that the gas pressure at the top of the second reactor **809** is slightly larger than the gas pressure at the bottom of the first reactor **803**. This prevents any flow of the gas in the first reactor **803** into the second reactor **809** and the consequent reduction of the purity of the captured gas. The pressure difference is preferably controlled such that it is not substantially larger than necessary to prevent gas flow from the first reactor **803** to the second reactor **809** so that a substantial flow of gas from the second reactor **809** to the first reactor **803** does not occur. Appropriate control of the pressure difference also avoids any requirement for a gas solid lock to be provided between the first and second reactors.

[0136] The above-described sorbent loping system comprising integrated first and second reactors according to the third example may be used for the application of capturing carbon dioxide from a flue gas. A sorbent captures carbon dioxide in the first reactor **803** and the sorbent is regenerated, with the carbon dioxide being released, in the second reactor **809**. The released carbon dioxide can then be used in commercial applications or stored.

[0137] The above-described sorbent loping system according to examples comprises:

[0138] A carbonation region in which a sorbent removes CO_2 from a gas mixture comprising CO_2;

[0139] A heating region in which the sorbent is heated from the carbonation temperature to the sorbent regeneration temperature;

[0140] A sorbent regeneration region in which the sorbent is heated at temperature that causes the sorbent to release CO_2; and

[0141] A cooling region in which the sorbent is cooled from the sorbent regeneration temperature to the carbonation temperature.

[0142] The system may comprise any of number of possible implementations of each of the above regions.

[0143] The processes in the carbonation region may be the earlier described processes in the reactor according to the first example. The heating region, sorbent regeneration region and cooling region may respectively be the first region, second region and third region as described earlier in the second and third examples.

[0144] Each of the four regions may be provided by a separate apparatus or two or more of the regions may be provided within different parts of the same apparatus.

[0145] Two or more of the regions may be coupled with each other, for example by using heat exchangers between heating region and the cooling region as described above. However, examples also include each of the regions being operated independently from the other regions. That is to say, the heating region may comprise a separate heat source from the heat source that provides heat to the sorbent regeneration region and the cooling region may comprise a heat sink that is not coupled to the heat source of the heating region.

[0146] The system may also comprise any of number of possible implementations of techniques for moving the sorbent between the different regions.

[0147] An implementation of a sorbent loping system according a fourth example is shown in FIG. **12**. The system comprises a carbonation region **1204**, a heating region **1202**, a sorbent regeneration region **1201** and a cooling region **1203**. There is a gas input **1206** for a carbonaceous gas, such as a flue gas, and a first gas output **1205** of the cleaned gas.

There is a second gas output **1208** for the released gas in the sorbent regeneration region **1201**. There is a riser **821** for returning the sorbent to the sorbent input of the carbonation region **1204**. The riser may be the riser **821** as described earlier in at least the first and third examples.

[0148] Each of the carbonation region **1204**, heating region **1202**, sorbent regeneration region **1201** and cooling region **1203** may be provided by separate reactors or as different parts of one or more reactors. Each of the carbonation region **1204**, heating region **1202**, sorbent regeneration region **1201** and cooling region **1203** may be operated independently from each of the other regions, or two or more of the regions may be coupled together.

[0149] The carbonation region **1204** may be provided by the first reactor **803** as described in the first and third examples. The heating region **1202**, sorbent regeneration region **1201** and cooling region **1203** may be respectively provided by the first region, second region and third region as described in the second and third examples. There may be heat loops/heat exchangers **1003** between the heating region **1202** and cooling region **1203** as described of the first and third regions in the second and third examples.

[0150] The heat source of the sorbent regeneration region **1201** may be an external combustor **1001** that transfers heat to the sorbent regeneration region **1201** as described earlier for the second and third examples.

[0151] In each of the carbonation region **1204**, heating region **1202**, sorbent regeneration region **1201** and cooling region **1203**, there is contact between particles of solid sorbent and a gas. The one or more reactors for providing each of these regions may have the reactor design as described in the first to third examples in which the reactors support substantial cross-flows of gas across solid particles that are travelling vertically downwards in a moving bed.

[0152] In the implementation of a sorbent loping system **1207** according to the fourth example shown in FIG. **12**, the heating region **1202** and cooling region **1203** are coupled together by the heat loops **1003** as described earlier for the second and third examples.

[0153] A first gas circulation system **1207** circulates a gas between the heating region **1202** and cooling region **1203**. The gas is used in each region to transfer heat between the heat loops **1003** and the sorbent. The first gas circulation system **1207** may comprise one or more fans, with variable frequency drives, valves, and other components for controlling the amount of gas in the first gas circulation system **1207** and the rate at which gas flows around the first gas circulation system **1207**.

[0154] A second gas circulation system **1209** circulates a gas within the sorbent regeneration region **1201**. The gas is used in the sorbent regeneration region **1209** to transfer heat between the heat loops **1002** and the sorbent. The second gas circulation system may comprise one or more fans, with variable frequency drives, valves, and other components for controlling the amount of gas in the second gas circulation system **1209** and rate at which gas flows around the second gas circulation system **1209**. The second gas circulation system **1209** comprises the second gas output **1208** for outputting substantially pure CO_2.

[0155] In the fourth example, the first gas circulation system **1207** is separate from the second gas circulation system **1209**. The gas used in the first gas circulation system **1207** may therefore be different from the gas used in the second gas circulation system **1209**.

[0156] The gas used in the first gas circulation system **1207** may be, for example, air, nitrogen, clean flue gas or an inert gas. It is preferable for the gas in the first gas circulation system **1207** to be a gas that does not substantially react with the sorbent so that the reactions with the sorbent substantially only occur in the carbonation region **1204** and sorbent regeneration region **1201**.

[0157] The gas used in the second gas circulation system **1209** is preferably the same gas released by the sorbent, i.e. CO_2, so that substantially pure CO_2 is output and an additional process to obtain substantially pure CO_2 is not required.

[0158] FIGS. **13** and **14** show orthogonal cross-sections of an implementation of a system according to the fourth example. The carbonation and sorbent regeneration processes are integrated within a single reactor of the system.

[0159] The reactor of the system comprises a carbonation region **1204**, a heating region **1202**, a sorbent regeneration region **1201** and a cooling region **1203**.

[0160] The reactor has a similar design to the reactors as described in the previous examples. The reactor comprises inlet(s) at the top of the reactor through which sorbent enters the carbonation region **1204** of the reactor. At the bottom of the cooling region **1203** of the reactor are outlet(s) through which sorbent exits the cooling region **1203**. Between the inlet(s) and the outlet(s) is a main body of the reactor. The main body of the reactor has outer walls. One or more moving beds are provided in the reactor. Each moving bed extends, from an inlet, vertically downwards through the main body of the reactor to an outlet of the reactor. Between the vertically arranged moving beds, as well as the outer walls of the main body, are gas ducts for gas flows in the main body. Each gas duct comprises a plurality of vertically stacked chambers. The walls of the moving beds comprise strainer plates and the gas ducts comprise baffle plates, for providing a substantial cross-flow of sorbent and gas, as described for the first to third examples. The main body of the reactor is preferably rectangular cuboid, but examples also include the reactor being cylindrical, as well as other shapes.

[0161] At the bottom of the reactor is a flow control mechanism **905** for controlling the flow of sorbent through the reactor. The flow control mechanism **905** may be the same as described earlier for the first and second examples with reference to FIGS. **7E**, **7F**, **11A**, **11B**, **11C** and **11D**.

[0162] The carbonation region **1204** comprises at least one gas inlet **1206**, through which gas enters the carbonation region **1204**, and at least one gas outlet **1205**, through which gas exits the carbonation region **1204**. The at least one gas inlet **1206** may be provided at the bottom of carbonation region **1204** and the at least one gas outlet **1205** may be provided at the bottom of carbonation region **1204**. The carbonation region **1204** may be separated from the heating region **1202** by a gas barrier **1309** that comprises plates across the gas ducts with all of the plates being in the same plane. The carbonation region **1204** comprises a coolant input **1401** and a coolant output **1402**. In use, a coolant flows through the carbonation region **1204** to maintain the carbonation region **1204** at an appropriate temperature for the carbonation reaction.

[0163] The heating region **1202** is separated from the sorbent regeneration region **1201** by a first barrier **1301** that allows the sorbent to flow between the heating region **1202** and the sorbent regeneration region **1201** but substantially

prevents gas flow between these regions. The heating region **1202** comprises one or more gas inputs **1303** and one or more gas outputs **1304**. The one or more gas inputs **1303** may be provided at the top of the heating region **1202** and the one or more gas outputs **1304** may be provided at the bottom of the heating region **1202**.

[0164] The sorbent regeneration region **1201** is separated from the cooling region **1203** by a second barrier **1302** that allows the sorbent to flow between the sorbent regeneration region **1201** and the cooling region **1203** but substantially prevents gas flow between these regions. The sorbent regeneration region **1201** comprises at least one gas input **1307** and at least one gas output **1308**. The at least one gas input **1307** may be provided at the top of the sorbent regeneration region **1201** and the and at least one gas output **1308** at the bottom of the sorbent regeneration region **1201**. The heat source of the sorbent regeneration region **1201** may be an external combustor **1001** that transfers heat to the sorbent regeneration region **1201** as described earlier for the second example. The sorbent regeneration region **1201** comprises a second gas circulation system **1209** as described above. The gas used in the second gas circulation system **1209** is preferably the same gas released by the sorbent, i.e. CO_2.

[0165] The cooling region **1203** comprises one or more gas inputs **1305** and one or more gas outputs **1306**. The one or more gas inputs **1305** may be provided at the top of the cooling region **1203** and the one or more gas outputs **1305** may be provided at the bottom of the cooling region **1203**.

[0166] The heating region **1202** and cooling region **1203** are coupled together by heat loops **1003**, as described above and earlier for the second and third examples, as well as a first gas circulation system **1207** as described above. The gas used in the first gas circulation system **1207** may be, for example, air, nitrogen, clean flue gas or an inert gas.

[0167] The temperature profile through the reactor is substantially as described for the third example. The temperature of the sorbent in the carbonation region **1204** may be about 600° C. The temperature of the sorbent at the output of the heating region **1202** may be about 850° C. In the sorbent regeneration region **1201**, the received sorbent may be heated to about 900° C. The temperature of the sorbent at the output of the cooling region **1203** may be about 600° C. to 650° C.

[0168] In the fourth example, sensors may measure the temperatures and pressures throughout the reactor/system. There may also be sensors that measure the concentration of the gas to be captured by the sorbent, such as carbon dioxide, in the gas mixture received by the carbonation region **1204** and the gas flowing out of the carbonation region **1204**. The measurements may be automatically provided to a computing system. The flow of gas into the carbonation region **1204**, the flow of sorbent through the reactor, the flow of gas into and around the first and second gas circulation systems, the cooling in the carbonation region **1204**, the heating of the sorbent regeneration region **1201** and the heat exchange between the heating region **1202** and cooling region **1203** are preferably all automatically controlled by the computer system. The computing system may automatically control the processes in order to efficiently capture a gas, such as carbon dioxide from a gas mixture. The computing system may also automatically detect operational errors/faults of the system in dependence on the automatic feedback of data from the sensors.

[0169] Preferably, the pressures throughout the system are controlled so that there is substantially no pressure difference across the gas barrier **1309**, the first barrier **1301** and the second barrier **1302** in the reactor so there is substantially no gas flow across the interfaces between the different regions within the reactor.

[0170] The fourth example also includes alternative implementations in which two or more of the carbonation region **1204**, heating region **1202**, sorbent regeneration region **1201** and cooling region **1203** are provided by separate reactors and not integrated together in a single reactor.

[0171] The above-described implementation of sorbent loping system of the fourth example may be used for the application of capturing carbon dioxide from a flue gas. A sorbent captures carbon dioxide in the carbonation region **1204** and the sorbent is regenerated, with the carbon dioxide being released, in the sorbent regeneration region **1201**. The released carbon dioxide can then be used in commercial applications or stored.

[0172] According to a fifth example, the system is designed for the application of hydrogen, H_2, production. H_2 production by reforming processes generates a gas mixture comprising H_2 and CO_2. The system of the fifth example uses similar processes to those described for the fourth example to remove the CO_2 from the gas mixture to thereby generate substantially pure H_2. The sorbent used in the fifth example may be the same sorbent of CO_2 as described in the first to fourth examples.

[0173] A known process is sorption enhanced reforming, SER. In an SER reaction, methane is reacted with H_2O to generate CO, CO_2 and H_2. An SER reaction may be performed at approximately 575° C.

[0174] Another known process is a sorption enhanced water gas shift, SEWGS, reaction. In an SEWGS reaction, CO is reacted with H_2O to generate CO_2 and H_2. An SEWGS reaction may be performed at approximately 400° C. to 450° C.

[0175] In the fifth example, one or more reactors are provided for performing SER and SEWGS reactions. Generated CO_2 by the SER and SEWGS reactions is removed by a moving bed of a sorbent of CO_2. The sorbent is then regenerated and returned to a sorbent input of the moving bed.

[0176] Implementations of the fifth example are shown in FIGS. **15**, **16** and **17**. FIGS. **15**, **16**, and **17** show cross-sections of implementations of a system according to the fifth example. The SER, SEWGS, carbonation and sorbent regeneration processes are all integrated within a single reactor of the system.

[0177] FIG. **15** shows a first implementation of a system according to the fifth example in which pipes for heating and cooling pass through moving beds of the reactor system. FIGS. **16** and **17** show a second implementation of a system according to the fifth example. In the second implementation, the pipes are orthogonal to how they are shown in FIG. **15**. The pipes of the second implantation only pass through gas ducts and not the moving beds. All of the other features of the first and second implementations of the fifth example may be the same as each other.

[0178] The system comprises a riser **821** for moving sorbent from the sorbent input of the reactor to the sorbent out of the reactor. The riser may be substantially as described for the previous examples. However, for gas driven imple-

mentations of the riser, the gas should be one of the gasses input to the SER and SEWGS regions of the reactor, such as methane.

[0179] The reactor of the system comprises an SER region **1501**, an SEWGS region **1502**, a heating region **1202**, a sorbent regeneration region **1201** and a cooling region **1203**. The SER region **1501** and SEWGS region **1502** together provide a carbonation region in which sorbent removes the CO_2 that is generated by the reaction processes.

[0180] The reactor has a similar construction to the reactor as described for the fourth example. The reactor comprises inlet(s) at the top of the reactor through which sorbent enters the SER region **1501** of the reactor. At the bottom of the cooling region **1203** of the reactor are outlet(s) through which sorbent exits the cooling region **1203**. Between the inlet(s) and the outlet(s) is a main body of the reactor. The main body of the reactor has outer walls. One or more moving beds are provided in the reactor. Each moving bed extends, from an inlet, vertically downwards through the main body of the reactor to an outlet of the reactor. Between the vertically arranged moving beds, as well as the outer walls of the main body, are gas ducts for gas flows in the main body. Each gas duct comprises a plurality of vertically stacked chambers. The walls of the moving beds comprise strainer plates and the gas ducts comprise baffle plates, for providing a substantial cross-flow of sorbent and gas, as described for the first to fourth examples. The main body, and/or moving beds, of the reactor are preferably rectangular cuboid, but examples also include the reactor being cylindrical, as well as other shapes.

[0181] At the bottom of the reactor is a flow control mechanism **905** for controlling the flow of sorbent through the reactor. The flow control mechanism **905** may be the same as described earlier for at least the first and second examples with reference to FIGS. 7E, 7F, 11A, 11B, 11C and 11D.

[0182] The SER region **1501** comprises at least one gas inlet **1504**, through which gas enters the SER region **1501**. In use, CH_4 and H_2O are input into the SER region **1501** and the above-described SER reaction is performed at about 575° C.

[0183] Another reaction that occurs in the SER region **1501** is a carbonation reaction with sorbent in the moving bed. The carbonation reaction removes from the gas mixture in the SER region some, or all, of the CO_2 generated by the SER reaction. There may be no need for a cooling, or heating, system in the SER region because the SER reaction is endothermic and the carbonation reaction is exothermic. The reaction temperature may therefore remain approximately constant at about 575° C. to 600° C. so long as both the SER reaction and the carbonation reaction are occurring. The reaction temperature may fall when the CO_2 concentration falls and less carbonation is occurring.

[0184] In an alternative implementation of the present example, the SER region may comprise a heating system and/or cooling system for controlling the reaction temperature.

[0185] The SEWGS region **1502** is located below the SER region **1501** and there may be no barrier separating the SER region **1501** and SEWGS region **1502**. A SEWGS reaction is performed in the SEWGS region. The temperature at which the SEWGS reaction is performed may be about 450° C. The sorbent and/or gas temperature may fall from 575° C. to 450° C. as the amount of carbonation decreases. However,

as described in more detail below, the sorbent and/or gas temperature may be actively decreased by a cooling system. The CO_2 generated by the SEWGS reaction is removed by the sorbent and so substantially the only gas remaining is the H_2 product of the SER and SEWGS reactions. The SEWGS region **1502** comprises at least one gas outlet **1505**, through which gas exits the SEWGS region **1502**.

[0186] The SEWGS region **1502** may be separated from the heating region **1202** by a third gas barrier **1503** that allows the sorbent to flow between the SEWGS region **1502** and the heating region **1201** but substantially prevents gas flow between these regions.

[0187] Heat loops/heat exchangers **1508** may be provided between the SEWGS region **1502** and the heating region **1202**. The heat loops/heat exchangers **1508** cool the gas and/or sorbent so that it is at an appropriate temperature for the SEWGS reaction. The heat loops/heat exchangers **1508** may have the same arrangement of loops as the previously described heat loops in the second to fourth examples. That is to say, a first loop may be surrounded by a second loop with the second loop having parts in higher temperature zones than the first loop.

[0188] In an alternative implementation of the present example, there is no heat exchanger between the SEWGS region **1502** and the heating region **1202**. An independent heating and/or cooling system may be provided between the SER region **1501** and the SEWGS region **1502** for controlling the temperature of the gas and/or sorbent as it enters the SEWGS region. Similarly, an independent heating and/or cooling system may be provided in the heating region **1202** for controlling the temperature of the gas and/or sorbent therein.

[0189] The heating region **1202** is separated from the sorbent regeneration region **1201** by a first barrier **1301**, as described for the fourth example. A difference between the implementation of the heating region **1202** as shown in FIGS. **15** to **17** and that shown in FIGS. **12** to **14** is that the heating region **1202** in FIGS. **15** to **17** has its own gas circulation system that is not coupled to the gas circulation system of the cooling region **1203**. The heating region **1202** may otherwise be substantially the same as the heating region **1202** as described for the fourth example.

[0190] The sorbent regeneration region **1201** is separated from the cooling region **1203** by a second barrier **1302** as described for the fourth example. The sorbent regeneration region **1201** may be substantially the same as that of the fourth example. The heat source of the sorbent regeneration region **1201** may be an external combustor **1001** that transfers heat to the sorbent regeneration region **1201** via heat loop/heat exchanger **1002** as described for the second and fourth examples. The sorbent regeneration region **1201** comprises its own gas circulation system **1209** as described for the fourth example. The gas used in the second gas circulation system **1209** is preferably the same gas released by the sorbent, i.e. CO_2.

[0191] A difference between the implementation of the cooling region **1203** as shown in FIGS. **15** to **17** and that shown in FIGS. **12** to **14** is that the cooling region **1203** in FIGS. **15** to **17** has its own gas circulation system that is not coupled to the gas circulation system of the heating region **1202**. The cooling region **1203** may otherwise be substantially as described for the fourth example.

[0192] The gas used in each of the heating region **1202** and cooling region **1203** may be, for example, air, nitrogen, H_2 or an inert gas.

[0193] In the fifth example, sensors may measure the temperatures and pressures throughout the reactor/system. There may also be sensors that measure the concentration of the gasses, such as hydrogen and carbon dioxide. The measurements may be automatically provided to a computing system. All of the gas flows, the flow of sorbent through the reactor, the heating and any cooling are preferably automatically controlled by the computer system. The computing system may also automatically detect operational errors/faults of the system in dependence on the automatic feedback of data from the sensors.

[0194] Preferably, the pressures throughout the system are controlled so that there is substantially no pressure difference across the third gas barrier **1503**, the first barrier **1301** and the second barrier **1302** in the reactor. Such pressure control helps to ensure that there is substantially no gas flow across the interfaces between the different regions within the reactor.

[0195] The fifth example also includes alternative implementations in which two or more of the SER region **1501**, SEWGS region **1502**, heating region **1202**, sorbent regeneration region **1201**, and cooling region **1203** are provided by separate reactors and not integrated together in a single reactor.

[0196] The above-described implementation of sorbent loping system of the fifth example may be used for the application of hydrogen generation by reforming processes. Advantageously, the CO_2 biproduct of the H_2 production process is captured.

[0197] In an alternative implementation of the fifth example, there is an SER region but no SEWGS region. This allows a simpler reactor design because there is no need for a cooling system to cool the gas and/or sorbent between the SER region and the heating region **1202**. A single gas circulation system may circulate gas between the heating region **1202** and cooling region **1203** as described above for the fourth example. The present implementation of the fifth example may otherwise be substantially as described above with reference to FIGS. **15** to **17**.

[0198] In the present implementation, an SEWGS reaction is not performed and so the produced gas may comprise CO, and/or other gasses, in addition to the main H_2 product. The main H_2 product may be polished, i.e. purified, by passing it through a membrane or using other techniques. Alternatively, for applications in which the purity of the H_2 is not critical, the main H_2 product may be used directly. For example, the main H_2 product may be combusted in a gas turbine.

[0199] Other techniques may be used to heat the sorbent up the temperature required in the sorbent regeneration region **1201**. For example, exhaust gas may be injected from a catalytic combustor that will both heat the sorbent directly, and also indirectly due the carbonation occurring. A heat exchanger with any suitably high temperature source may also be used.

[0200] The sorbent regeneration region may alternatively be heated directly by injecting oxygen and CH_4, and/or CO, from gas reforming.

[0201] The sorbent output from the sorbent regeneration region may alternatively be cooled directly the riser **821**, that is a gas riser, by using cold CH_4 to lift the gas and then using the CH_4 as a reactant in the SER region.

[0202] The fifth example has been described with reference to the use of methane as a reactant in a reforming process. Examples also include natural gas, and other hydrocarbon containing gasses, being used instead of methane.

[0203] Implementation of the fifth example also includes the use of a catalyst for accelerating the SER reaction and/or SEWGS reaction. The catalyst may be any known catalyst for SER and/or SEWGS processes. The catalyst may be, for example, a reforming catalyst of Pd—Ni/Co supported on a hydrotalcite-derived material, i.e. a Pd—Ni/Co HT catalyst.

[0204] The pellets/particles of catalyst may be added to those of the sorbent so that the looped particles around the entire system comprise both sorbent particles and separate catalyst particles.

[0205] Alternatively, pellets/particles may be used that are a combined sorbent and catalyst. For example, the catalyst may be deposited on some, or all, of the outer surfaces of the sorbent pellets/particles during the production process of the sorbent. Advantages of such a combined sorbent and catalyst over separate particles of sorbent and catalyst may include the diffusional limitations being decreased, easier circulation around the entire system and lower total cost.

[0206] Alternatively, the supply of the catalyst to the SER and SEWGS regions may be independent from that of the sorbent. For example, the SER and SEWGS regions may comprise fixed beds of catalyst. The fixed beds may be arranged in parallel to the moving beds of sorbent with gas being able to pass through both beds. An advantage of this implementation is that if the sorbent is discarded, and replaced with a new sorbent, the catalyst, that may comprise expensive metals, is not also discarded.

[0207] Examples also include the use of known SER and/or SEWGS processes to generate an H_2 and CO_2 gas mixture. The H_2 and CO_2 gas mixture is then used as the gas input to the system according the third or fourth examples that is used to separate the CO_2 and H_2 gasses.

[0208] The sorbent that may be used in examples is described in more detail below.

[0209] A particularly advantageous sorbent for carbon dioxide is a mixed oxide, in particular CaO, MgO, and NaO-based mixed oxide forms. Particularly preferred sorbents are the sorbents as disclosed in international patent applications with application numbers PCT/EP2006/003507 and PCT/EP2018/055828, the entire contents of which are incorporated herein by reference.

[0210] The sorbent may be comprised of solid particles. The particles may be small and substantially spherical balls and/or pellets (e.g., substantially cylindrical). The active component of the sorbent, for example calcium oxide/calcium carbonate, is preferably combined with a binding agent.

[0211] The capture and release of the gas by the sorbent is due to reaction of the sorbent with the gas. The reactions may be adsorption and/or desorption processes or by other processes that result in the capturing and/or release of a gas.

[0212] Examples also include the capture of other gasses than carbon dioxide, in particular examples include the capture of hydrogen sulphide from sour gas. The sorbent may be one or more of MnO, CuO, and ZnO.

[0213] Examples also include the use of a mixture of different sorbents so that more than one gas is captured by the gas capture system. For example, different sorbent

particles for carbon dioxide and hydrogen sulphide could be mixed and then used together. The gas capture system may then capture both carbon dioxide and hydrogen sulphide from a gas stream.

[0214] The sorbent changes between a used form and a regenerated form as it is recirculated about the system. The term sorbent refers generally to particles of the sorbent at any point in the sorbent cycle and may refer to the sorbent when it is in either its used form or regenerated form. In addition, the sorbent at any point in the sorbent cycle may always be a mixture of particles of the sorbent in the used form and in the regenerated form. The gas capturing and sorbent regenerating processes change the relative concentrations of the forms of the sorbent at a particular point in the sorbent cycle.

[0215] FIG. 18 shows the basic components of a known design of gas turbine. The gas turbine comprises a compressor 1802 with a gas intake system 1801, a combustor 1803 and a fuel feed system 1804. The gas, typically air, passes from the gas intake system 1801 into the compressor 1802 where it is compressed. The compressed gas is then fed into the combustor 1803 where fuel provided by the fuel feed system 1804 is burnt. The gaseous combustion products are fed into the turbine 1805 and are expanded to a lower pressure, that may be close to atmospheric pressure, and are then exhausted through an exhaust unit 1806. Some of the power from the turbine 1805 is used to drive the compressor 1802 as well as to drive any auxiliary units of the gas turbine (pumps, electric generators, mechanisms etc.) and to overcome hydraulic resistance in the gas turbine unit. The remaining power from the turbine 1805 is used to drive a load mounted on the turbine shaft 1807. The load may be, for example, an electric generator.

[0216] According to embodiments, a fuel comprising hydrogen is used in the combustor of a gas turbine. The gas turbine may be a known gas turbine as described with reference to FIG. 18.

[0217] Embodiments do not use pure hydrogen as the fuel in the combustor of a gas turbine. The fuel according to embodiments is a gas mixture that comprises hydrogen. The fuel according to embodiments may comprises hydrogen and one or more of at least CH_4, CO_2, CO, H_2O, O_2 and N_2.

[0218] Preferably, 30% vol to 55% vol of the fuel is hydrogen. More preferably, 40% vol to 50% vol of the fuel is hydrogen. Further preferably, approximately 40% vol of the fuel is hydrogen. It is preferable for the amount of hydrogen to be less than 50% vol of the fuel.

[0219] Preferably, most of the rest of the fuel is N_2. The fuel may also comprise a relatively small amount of CO_2. The fuel may also comprise a relatively small amount of H_2O. Small, or trace, amounts of any of CH_4, CO and O_2 may also be present in the fuel.

[0220] The fuel according to embodiments may be generated by combining the constituent gasses or of the fuel by any known means. For example, a fuel according to embodiments may be generated by combining substantially pure hydrogen with substantially pure nitrogen and substantially pure CO_2.

[0221] The gasses that are combined to generate the fuel may have any source. For example, the hydrogen in the fuel according to embodiments may have been generated by an electrolysis process.

[0222] In a particularly preferred embodiment, the source of hydrogen in the fuel is a reactor according to the above-described fifth example. A source of other gasses in the fuel according to embodiments is preferably at least the exhaust gas of a combustor for generating the heat required for the sorbent regeneration process.

[0223] FIG. 19 is a flow diagram of a gas turbine system according to an embodiment. The flow diagram in FIG. 19 shows how a gas turbine may be integrated with a hydrogen producing reactor according the above-described fifth example. However, embodiments also include the gas turbine being integrated with other designs of reactor for producing hydrogen by reforming, electrolysis or other processes.

[0224] As shown in FIG. 19, the gas turbine system comprises a first input 1901 that is an input of air to the compressor. The air may be at atmospheric pressure.

[0225] The gas turbine system comprises a second input 1902 that is a input of water, that may be in the form of water vapour or steam.

[0226] The gas turbine system comprises a third input 1903 that is a input of carbonaceous gas that may be, for example, methane, natural gas or biogas.

[0227] The gas turbine system comprises a mixer 1904 for mixing the reactants that are input to the hydrogen producing reactor 1906. The hydrogen producing reactor may be the SER reactor, or combined SER and SEWGS reactor, according to the above-described fifth example. A catalyst for the reforming process in the hydrogen producing reactor may be Pd—Ni—Co.

[0228] The gas turbine system comprises a heat exchanger 1905 for heating the reactants that are input to the hydrogen producing reactor 1906 and cooling the reformate that is output from the hydrogen producing reactor 1906.

[0229] The gas turbine system comprises a pipe 1907 that comprises the reformate that is output from the hydrogen producing reactor 1906. The temperature of the output reformate may be 550-600° C. The reformate may comprise about 90% vol to 95% vol hydrogen and small amounts, or traces, of any of CH_4, CO_2, CO and H_2O.

[0230] The gas turbine system comprises a compressor 1908 of the reformate arranged to pressurise it to the pressure of the combustor 1922 of the gas turbine. This may be approximately 20 bar.

[0231] The gas turbine system comprises a compressor 1909 that is arranged to compress air for use in the combustor 1922 of the gas turbine and also for use a combustor 1917 for the sorbent regeneration process. The compressor 1909 may be arranged to operate in a similar way to the compressor 1802 shown in FIG. 18.

[0232] The gas turbine system comprises a pipe 1910 that comprises some of the compressed air that is output from the compressor 1909. The compressed air is for use in the combustor 1917 for the sorbent regeneration process.

[0233] The gas turbine system comprises a pump/compressor 1911 for compressing some of the carbonaceous gas that is received through the third input 1903.

[0234] The gas turbine system comprises a mixer 1912 that is arranged to mix the carbonaceous gas that is output from the pump/compressor 1911 with compressed air that is output from the compressor 1909.

[0235] The gas turbine system comprises a heat exchanger 1913 that is arranged to heat the reactants that are output from the mixer 1912 and cool carbon dioxide that is output from the sorbent regeneration process.

[0236] The gas turbine system comprises a sorbent regeneration reactor **1914** arranged to regenerate the sorbent. The sorbent regeneration reactor **1914** may be the reactor for regenerating the sorbent according to any of the above-described second to fifth examples.

[0237] The gas turbine system comprises a pipe **1915** that comprises carbon dioxide that is output from the sorbent regeneration reactor **1914**. The temperature of output the carbon dioxide may be 800° C. to 900° C.

[0238] The gas turbine system comprises an output **1916** of carbon dioxide. This may be used as an input to a steam turbine cycle, or its heat may be used in other ways. The carbon dioxide may, for example, be input into a compression and liquefaction plant so that the carbon dioxide is not released into the atmosphere.

[0239] The gas turbine system comprises combustor **1917** for generating the heat required for regenerating the sorbent. The combustor **1917** may be the same combustor for generating the heat required for regenerating the sorbent according to any of the above-described second to fifth examples. Accordingly, the combustor **1917** may be a catalytic combustor and is preferably a total catalytic combustor, such as the total catalytic combustor described in WO/2018/162675, the entire contents of which are incorporated herein by reference.

[0240] The combustor **1917** may be integrated within the sorbent regeneration reactor **1914** or it may be separated from the sorbent regeneration reactor **1914** with the heat transferred from the combustor **1917** to the sorbent regeneration reactor **1914** by heat loops/heat exchangers, according to the techniques described in any of the above-described second to fifth examples. In the combustor **1917**, carbonaceous gas is combusted in air at a temperature of about 900° C. to 1000° C. with the aid of a catalyst. The combustor **1917** may be operated at a pressure of 20 bar. Preferably, the combustor **1917** is operated at a pressure that is greater than 20 bar. Although the combustor **1917** is preferably a total combustor, traces of O_2 may remain in the exhaust gasses output from the combustor **1917**.

[0241] The carbonaceous gas may alternatively be combusted in the combustor **1917** with flue gas in addition to, or instead of, air. Flue gas comprises oxygen and so combustion can occur without air being supplied. Advantageously, it is not necessary to supply pure oxygen to the combustor **1917**.

[0242] The catalyst used in the combustion process in combustor **1917** preferably comprises one or more of nickel, cobalt, Ru, Rh, Pd and Pt. The catalyst is preferably a Ni—Co mixed oxide. The catalyst is preferably any of the catalysts as disclosed in the international patent application with publication number WO/2013/150271, the entire contents of which are incorporated herein by reference.

[0243] The gas turbine system comprises means for moving sorbent from the hydrogen producing reactor **1906** to the sorbent regeneration reactor **1914**. This may be according to the techniques described in any of the above-described second to fifth examples.

[0244] The gas turbine system comprises means **1919** for moving sorbent from the sorbent regeneration reactor **1914** to the hydrogen producing reactor **1906**. The means **1919** for moving sorbent may be according to the techniques as described in any of the above-described second to fifth examples. Accordingly, the means **1919** for moving sorbent may be a riser.

[0245] The gas turbine system comprises a pipe **1920** that comprises exhaust gas from the combustor **1917**. The exhaust gas is a gas mixture that may comprise mostly nitrogen, H_2O and carbon dioxide with trace amounts of methane and oxygen. Approximate concentrations of gasses in the exhaust gas may be 71% vol to 73% vol N_2, 17% vol to 19% vol H_2O, 8% vol to 9% vol CO_2, less than 1% vol CH_4 and less than 1% vol O_2.

[0246] The gas turbine system comprises a mixer **1921** that is arranged to receive hot pressurised gas that is output from the combustor **1917** and hot pressurised reformate from the compressor **1908**. The mixer mixes the received gasses and outputs a gas mixture that is the fuel that is supplied to the combustor **1922** of the gas turbine. The gas mixture output from the mixer **1921** is a hydrogen comprising fuel according to embodiments.

[0247] Preferably, 30% vol to 55% vol of the gas mixture output from the mixer **1921** is hydrogen. More preferably, 40% vol to 50% vol of the fuel is hydrogen. Further preferably, approximately 40% vol of the fuel is hydrogen. It is preferable for the amount of hydrogen to be less than 50% vol of the fuel.

[0248] Preferably, most of the rest of the fuel is N_2. The fuel may also comprise a relatively small amount of CO_2. The fuel may also comprise a relatively small amount of H_2O. Small, or trace, amounts of any of CH_4, CO and O_2 may also be present in the fuel supplied to the combustor **1922**.

[0249] The gas turbine system comprises a combustor **1922** of the gas turbine. The combustor may be similar to the combustor **1803** as described with reference to FIG. **18**.

[0250] The gas turbine system comprises a gas turbine **1924**. The gas turbine **1924** may be similar to the gas turbine **1805** as described with reference to FIG. **18**.

[0251] The gas turbine system comprises air supply **1923**. The air supply **1923** provides a slip stream of compressed air that can be used for cooling blades of the gas turbine **1924**.

[0252] The gas turbine system comprises a generator **1925** of electrical power that is driven by a shaft of the gas turbine.

[0253] The gas turbine system comprises a output **126** of exhaust gas from the combustor **1922** of the gas turbine. This may be used as an input to a steam turbine cycle, or its heat may be used in other ways. The exhaust gas will mostly comprise N_2 and H_2O.

[0254] Advantageously, embodiments allow a hydrogen-based fuel to be used in a gas turbine.

[0255] The gas turbine is preferably part of a combined cycle power plant. The gas turbine is preferably part of a natural gas fired combined cycle power plant (NGCC).

[0256] The gas turbine is preferably integrated with a system for producing the hydrogen that is itself integrated with a carbon capture system. The release of CO_2 into the atmosphere is therefore greatly reduced from if natural gas is used as a fuel in a gas turbine.

[0257] Embodiments provide a system in which hydrogen fuel is intrinsically mixed with CO_2. The CO_2 has a higher damping effect on the reactivity and combustion properties of hydrogen than steam or nitrogen.

[0258] Embodiments do not require the use of syngas, and this avoids the problems caused by high concentrations of CO. Embodiments also do not require the expense and complications resulting from providing equipment for depleting the concentration of O_2 in the air that is used in a combustor.

[0259] Embodiments may include the above-described first to fifth examples.

[0260] Embodiments, and the examples that embodiments may include, include a number of modifications and variations to the above-described techniques.

[0261] In particular, embodiments include other techniques for integrating a hydrogen production system with a gas turbine, with the fuel for the gas turbine comprising the produced hydrogen. Embodiments do not require all of the components of the system as shown in FIG. 19. For example, embodiments include implementations of the gas turbine system that do not include one, or both, of the heat exchangers 1905 and 1913. Separate heating and cooling systems may instead be provided, or no heating and cooling of the gasses may occur at one, or both, of these stages.

[0262] Embodiments also include additional components being provided in the system from those shown in FIG. 19. For example, embodiments include the hydrogen comprising gas mixture that is output from the hydrogen producing reactor 1906 and/or the exhaust gas that is output from the combustor 1917 being passed through a heat exchanger, cooler, or other equipment, to reduce, or remove, the amount of H_2O in the gas mixture before it is supplied to the combustor 1922.

[0263] Embodiments may also include a system for controlling the relative amounts of the gasses in the fuel. For example, the concentration of hydrogen in the reformate may be measured and the amount of exhaust that is mixed with the reformate controlled so as to provide a desired concentration of hydrogen in the fuel. The fuel and air supplies to the combustor 1922 of the gas turbine may be controlled so that the amount of oxygen in the air is at least half that of the amount of hydrogen in the fuel. Preferably, the fuel and air supplies to the combustor 1922 of the gas turbine are controlled so that the amount of oxygen is substantially more than half that of the amount of hydrogen in the fuel. Using excess air in the combustor 1922 reduces the flame temperature.

[0264] Embodiments also include controlling the supply of hydrogen comprising gas that is output from the hydrogen producing reactor 1906 so that some of the hydrogen is used to generate fuel for use by a gas turbine, as described with reference to FIG. 19, and some the hydrogen is stored or used for another application. The amount of fuel supplied to the gas turbine can thereby be controlled by controlling the proportion of the generated hydrogen that is supplied to the gas turbine. This would allow the hydrogen producing reactor 1906 to continue operating if the gas turbine was not operational (e.g. it was being serviced) or if, for example, the amount of fuel supplied to the gas turbine was controlled in dependence on the demand for electrical power produced by the generator 1925.

[0265] Embodiments include supplying flue gas to the combustor 1922 of the gas turbine instead of, or in addition to, the supply of air.

[0266] Examples are not restricted to the use of a solid sorbent and the solid used in the first and second reactors according to examples may be any type of solid reactant.

[0267] Examples are not restricted to the use of reactor designs as specifically shown in the figures and the reactor designs according to examples may be any type of mass transfer system.

[0268] The openings in the sidewalls of each moving bed are all preferably less than 500 μm, more preferably less than 400 μm and further preferably less than 200 μm.

[0269] The first and second reactors according to examples can be made with a wide range of dimensions depending on the application.

[0270] The walls of lower bed 9 of the first reactor may be sloped at an angle between about 60 and 70 degrees in order to facilitate the movement of sorbent out of the first reactor due to gravity.

[0271] Examples include the lower bed 9 of the first reactor comprising one or more space consuming structures that may be hollow. These assist the movement of the sorbent out of the first reactor.

[0272] The baffle plates are preferably substantially rigid so that they help to strengthen the structure of the first and second reactors, in particular the walls of the moving beds 7, 901.

[0273] In the second to fifth examples, the combustor 1001 that provides heat for the sorbent regeneration process is not restricted to being external from the second reactor 809 and examples include the combustor 1001 being integrated in the second reactor 809. The heat source for the sorbent regeneration is preferably a catalytic combustor, and more preferably a catalytic total combustor. The heat source may be provided by any known technique in sorbent regeneration processes. In particular, the heat source may comprise the combustion of a carbonaceous fuel in the presence of air and/or pure oxygen. The heat source for the sorbent regeneration may be, for example, a gas stream, such as a flue gas stream, from another process, and/or excess heat from a furnace, such as in the metal production industry.

[0274] In the second to fourth examples, heat is transferred between the first and third regions of the second reactor 809 by heat loops 1003. Examples include the first and third regions of the second reactor 809 alternatively having independent respective heating and cooling systems and the first and third regions not being connected to each other by heat loops.

[0275] In the second to fifth examples, the supplied gas to the second reactor 809 through the gas inlet(s) 903 of the second reactor 809 is not restricted to being the same gas as the gas that is released during the regeneration of the sorbent and examples include the supplied gas to the second reactor 809 being a different gas as the gas released by the sorbent.

[0276] In at least the fourth example, some of the gas in the carbonation region 1204 may be used as the circulated gas by the first gas circulation system. There may be no gas barrier 1309 and no gas input(s) 1303. Gas from the gas output(s) 1304 is supplied to the cooling region 1203. Gas output(s) 1306 from the cooling region may supply gas to a gas stream comprising the main flow of gas out of the system through the gas outlet 1205.

[0277] It will be understood that the implementation of examples may comprise a number of standard components that are not explicitly described herein. For example, the system may comprise one more fans and valves for controlling the flows of gas and sorbent around the system.

[0278] The first and second reactors both comprise gas ducts with chambers in the gas ducts separated by baffles. The number of baffles, and consequent number of chambers, in the gas ducts of each reactor may be different. The spacing between the baffles in each reactor may or may not be constant. In particular, the baffles may have a variable

vertical spacing between each other. The length of the gas chambers may therefore increase, or decrease, along the vertical length of the reactor.

[0279] Throughout examples the use of moving beds is described. The moving beds according to examples are generally mass transfer regions.

[0280] Examples have been described with reference to a solid sorbent based on CaO. However, examples include the first and second reactors being used with other types of solid sorbent for use in CCS.

[0281] Examples include the first and second reactors being used in other applications than CCS. In particular, the sorbent may, for example, be a sorbent of SO_2 or other gasses.

[0282] Although examples have been presented with the gas to be cleaned being flue gas, examples may be used with any gas and are not restricted to being a flue gas from a combustion process. The gas to be cleaned may be referred to as a dirty gas. The dirty gas may be sour gas directly output from a well head. The sour gas would be cleaned by capturing the hydrogen sulphide content.

[0283] Examples also include cleaning gasses (by removing CO_2 and/or other gasses) in industries such as the power generation industry, the metal production industry, cement production industry and mineral processing industry. In particular, examples can be used to clean gasses from cement production processes, blast furnace processes, steel production processes and reforming processes for hydrogen production.

[0284] Examples are appropriate for industrial scale processes. In particular, examples are particularly appropriate for providing a gas capture system that captures carbon dioxide gas generated by a power station/plant. This includes all types of power plant that generate carbon dioxide gas, such as power plants that generate power by combusting a carbonaceous fuel. The gas capture system according to examples is arranged to receive flue gas output from the power plant and remove carbon dioxide from the flue gas. The power plant may be a natural gas combined cycle plant. A heat exchanger may be used to pre-heat air used in the power plant using heat generated in gas capture system.

[0285] All of the components of the gas capture system of examples are scalable such that the gas capture system is suitable for both capturing gas from the power stations that are the largest generators of carbon dioxide gas as well a power stations that are relatively small generators of carbon dioxide gas.

[0286] Embodiments may include all of the techniques as described in patent applications GB1721034.5, GB1817072. 0, and PCT/EP2018/085300, the entire contents of all of which are incorporated herein by reference.

[0287] Embodiments include the following numbered clauses:

[0288] 1. A gas capture system comprising:

[0289] a gas inlet arranged to receive a gas flow into the system;

[0290] a gas outlet arranged to provide a gas flow out of the system;

[0291] a gas capture region for mass transfer between a gas and a sorbent of the gas; and

[0292] a sorbent regeneration region for regenerating the sorbent by heating the sorbent so that the sorbent releases a gas;

[0293] wherein:

[0294] the gas capture region is arranged to receive sorbent from the sorbent regeneration region;

[0295] the sorbent regeneration region is arranged to receive sorbent for regeneration from the gas capture region;

[0296] the sorbent is a solid sorbent of carbon dioxide gas; and

[0297] the gas capture region comprises:

[0298] a sorbent inlet arranged to receive an input of sorbent into the gas capture region;

[0299] a sorbent outlet arranged to provide an output of sorbent from the gas capture region;

[0300] one or more mass transfer regions arranged between the sorbent inlet and the sorbent outlet such that, in use, the sorbent is retained within the one or more mass transfer regions as the sorbent moves through the mass transfer regions and the mass transfer between the gas and the sorbent occurs in the one or more mass transfer regions;

[0301] a first gas chamber; and

[0302] a second gas chamber, that is different from the first gas chamber;

[0303] wherein the first gas chamber, second gas chamber and one or more mass transfer regions are arranged such that, in use, there is a flow path for gas that comprises gas flowing from the first gas chamber into one of the one or more mass transfer regions, the gas then flowing from said one of the mass transfer regions into the second gas chamber and the gas then flowing from the second gas chamber back into said one of the mass transfer regions.

[0304] 2. The gas capture system according to clause 1, wherein the sorbent regeneration region comprises:

[0305] a sorbent inlet arranged to receive an input of sorbent for regeneration;

[0306] a sorbent outlet arranged to provide an output of regenerated sorbent;

[0307] one or more mass transfer regions arranged between the sorbent inlet and the sorbent outlet such that, in use, the sorbent is retained within the one or more mass transfer regions as the sorbent moves through the mass transfer regions and, in use, heating the sorbent to generate a gas occurs in the one or more mass transfer regions;

[0308] a first gas chamber; and

[0309] a second gas chamber, that is different from the first gas chamber;

[0310] wherein the first gas chamber, second gas chamber and one or more mass transfer regions are arranged such that, in use, there is a flow path for gas from the gas inlet to the gas outlet that comprises gas flowing from the first gas chamber into one of the one or more mass transfer regions, the gas then flowing from said one of the mass transfer regions into the second gas chamber and the gas then flowing from the second gas chamber back into said one of the mass transfer regions.

[0311] 3. The gas capture system according to clause 1 or 2, wherein:

[0312] the number of mass transfer regions in the gas capture region is the same as the number of mass transfer regions in the sorbent regeneration region;

[0313] there are a plurality of mass transfer regions; and

[0314] the number of mass transfer regions is optionally between 2 and 20.

[0315] 4. The gas capture system according to any preceding clause, wherein:

[0316] the gas capture region and/or the sorbent regeneration region are provided by one or more substantially cuboid reactors; and

[0317] one or more of the mass transfer regions are substantially cuboid.

[0318] 5. The gas capture system according to any preceding clause, wherein:

[0319] each mass transfer region is a moving bed; and

[0320] each mass transfer region is arranged such that, in use, the flow path of the sorbent through each mass transfer region is vertically downwards.

[0321] 6. The gas capture system according to any preceding clause, wherein one or more of the mass transfer regions comprises sidewalls that separate the mass transfer region from a gas chamber;

[0322] wherein each of the sidewalls is configured such that, in use, gas is able to flow through the sidewall and substantially no sorbent can pass through the sidewall.

[0323] 7. The gas capture system according to any preceding clause, wherein:

[0324] one or more gas ducts are provided between each two adjacent mass transfer regions; each of the one or more gas ducts comprises a plurality of gas chambers, wherein the gas chambers in each of the one or more gas ducts are separated by one or more baffle plates that gas is unable to flow through; and

[0325] the gas chambers in each gas duct are aligned vertically, with vertically adjacent gas chambers separated by a substantially horizontal baffle plate.

[0326] 8. The gas capture system according to any preceding clause, further comprising a flow control mechanism at an end of each mass transfer region for controlling the rate at which sorbent can move through the mass transfer region.

[0327] 9. The gas capture system according to any preceding clause, wherein the gas capture region comprises cooling tubes in one or more of the gas chambers; and in use, the cooling tubes are arranged to cool gas in the gas chambers.

[0328] 10. The gas capture system according to any preceding clause, wherein the sorbent regeneration region comprises a heat source for supplying heat to the sorbent regeneration region.

[0329] 11. The gas capture system according to clause 10, wherein the heat source in the sorbent regeneration region receives heat from a heat source that is external from the gas capture system;

[0330] wherein the heat source that is external from the mass transfer system is optionally a catalytic combustor, preferably a catalytic total combustor.

[0331] 12. The gas capture system according to any of clauses 2 to 11, wherein the gas capture system comprises:

[0332] a heating region comprising a heating system for heating sorbent in the heating region, one or more moving beds, one or more gas inlets, one or more gas outlets and one or more gas chambers, wherein, in use, the sorbent is retained within the one or more moving beds of the heating region when the sorbent moves between the sorbent outlet of the gas capture region and the sorbent inlet of the sorbent regeneration region; and

[0333] a cooling region comprising a cooling system for cooling sorbent in the cooling region, one or more moving beds, one or more gas inlets, one or more gas outlets and one or more gas chambers, wherein, in use, the one or more moving beds of the cooling region receive the sorbent output from the sorbent outlet of the sorbent regeneration region and, when in the cooling region, the sorbent is retained within the moving beds of the cooling region.

[0334] 13. The gas capture system according to clause 12, further comprising:

[0335] one or more heat loops;

[0336] wherein the heating system comprises a first part of each heat loop arranged in one of the one or more gas chambers of the heating region; and

[0337] wherein the cooling system comprises a second part of each heat loop arranged in one of the one or more gas chambers of the cooling region.

[0338] 14. The gas capture system according to clause 12 or 13, further comprising a gas circulation system, wherein the gas circulation system is arranged to:

[0339] supply gas output from the gas outlet of the heating region to the gas inlet of the cooling region; and

[0340] supply gas output from the gas outlet of the cooling region to the gas inlet of the heating region.

[0341] 15. The gas capture system according to clause 12 or 13, further comprising a first gas circulation system and a second gas circulation system, wherein:

[0342] the first gas circulation system is arranged to supply gas output from the gas outlet of the heating region to the gas inlet of the heating region; and

[0343] the second gas circulation supply gas output from the gas outlet of the cooling region to the gas inlet of the cooling region.

[0344] 16. The gas capture system according to clause 14 or 15, wherein the gas circulated in each gas circulation system for a heating and/or cooling region comprises one or more of air, nitrogen, clean flue gas, hydrogen and an inert gas.

[0345] 17. The gas capture system according to any preceding clause, further comprising a gas circulation system for gas in the sorbent regeneration region, wherein the gas circulation system is arranged to:

[0346] supply gas output from a gas outlet of the sorbent regeneration region to a gas inlet of the sorbent regeneration region.

[0347] 18. The gas capture system according to clause 17, wherein the gas circulated by the gas circulation system for the sorbent regeneration region is substantially pure carbon dioxide.

[0348] 19. The gas capture system according to any of clauses 12 to 18, wherein the gas capture region, heating region, sorbent regeneration region and cooling region are comprised by different parts of a single reactor.

[0349] 20. The gas capture system according to any of clauses 12 to 18, wherein the gas capture region is comprised by a first reactor; and the heating region, sorbent regeneration region and cooling region are comprised by second reactor.

[0350] 21. The gas capture system according to any of clauses 12 to 18, wherein any two, any three or all of the gas capture region, heating region, sorbent regeneration region and cooling region are comprised by different reactors.

[0351] 22. The gas capture system according to any of clauses 12 to 21, further comprising:

[0352] a first barrier that substantially prevents direct gas flow from a gas chamber in the gas capture region to a gas chamber in the heating region;

[0353] a second barrier that substantially prevents direct gas flow from a gas chamber in the heating region to a gas chamber in the sorbent regeneration region; and

[0354] a third barrier that substantially prevents direct gas flow from a gas chamber in the sorbent regeneration region to a gas chamber in the cooling region.

[0355] 23. The gas capture system according to any of clauses 1 to 22, wherein, in use, the gas supplied through the a gas inlet of the gas capture system comprises CH_4 and H_2O; and

[0356] a sorption enhanced reforming process is performed in the gas capture region.

[0357] 24. The gas capture system according to clause 23, wherein, in use, a sorption enhanced water gas shift process is performed in the gas capture region.

[0358] 25. The gas capture system according to clause 24, wherein the gas capture region comprises:

[0359] a first region in which a sorption enhanced reforming process is performed;

[0360] a second region in which a sorption enhanced water gas shift process is performed; and

[0361] one or more pipes for cooling sorbent;

[0362] wherein:

[0363] the first region comprises the gas inlet of the gas capture region;

[0364] the second region comprises the gas outlet of the gas capture region;

[0365] the one or more pipes for cooling sorbent are arranged between the first region and the second region.

[0366] 26. The gas capture system according to clause 25, wherein the one or more pipes for cooling sorbent are part of a heat exchanger arranged to transfer heat between the heating region and the gas capture region.

[0367] 27. The gas capture system according to any of clauses 23 to 26, wherein, in use, the gas capture region comprises a catalyst for accelerating the sorption enhanced reforming process and/or the sorption enhanced water gas shift process.

[0368] 28. The gas capture system according to clause 27, wherein, in use:

[0369] particles are circulated around the gas capture system with each particle comprising both the catalyst and the sorbent;

[0370] separate particles of sorbent and catalyst are circulated around the gas capture system; and/or

[0371] a fixed bed of catalyst is provided in the gas capture region.

[0372] 29. The gas capture system according to any preceding clause, wherein the sorbent comprises a metal carbonate, such as calcium carbonate; and

[0373] in use, the gas captured in the gas capture region is carbon dioxide.

[0374] 30. A gas turbine system comprising:

[0375] a gas turbine; and

[0376] hydrogen producing system that comprises the gas capture system according to any preceding clause;

[0377] wherein, in use, hydrogen is generated by the hydrogen producing system and supplied to a combustor of the gas turbine.

[0378] 31. The gas turbine system according to clause 30, wherein the gas turbine system comprises a total combustor; and

[0379] exhaust gas from the total combustor is supplied to the combustor of the gas turbine.

[0380] The flow charts and descriptions thereof herein should not be understood to prescribe a fixed order of performing the method steps described therein. Rather, the method steps may be performed in any order that is practicable. Although the present invention has been described in connection with specific exemplary examples, it should be understood that various changes, substitutions, and alterations apparent to those skilled in the art can be made to the disclosed examples without departing from the spirit and scope of the invention as set forth in the appended claims.

What is claimed is:

1. A method of generating fuel for use in a combustor of a gas turbine, the method comprising:

generating an exhaust gas by a first combustor;

generating reformate, wherein the reformate comprises hydrogen; and

generating a fuel, that is a gas mixture, by mixing at least part of the reformate with at least part of the exhaust gas from the first combustor, wherein the fuel is for use in a second combustor that is the combustor of the gas turbine.

2. The method according to claim 1, wherein the reformate is generated in dependence on at least some of the heat generated by the first combustor.

3. The method according to claim 1, wherein the exhaust gas comprises nitrogen and carbon dioxide.

4. The method according to claim 3, wherein the exhaust gas comprises water (H_2O), methane (CH_4), and oxygen (O_2).

5. The method according to claim 1, wherein:

the exhaust gas comprises 71% vol. to 73% vol. of nitrogen; and

the exhaust gas comprises 17% vol. to 19% vol. of water.

6. The method according to claim 1, wherein the reformate comprises about 90% vol. to 95% vol. hydrogen (H_2).

7. The method according to claim 6, wherein the reformate further comprises any of methane (CH_4), carbon dioxide (CO_2), carbon monoxide (CO) and water (H_2O).

8. The method according to claim 1, wherein the first combustor is a total combustor.

9. The method according to claim 1, wherein the fuel comprises 30% vol. to 55% vol. of hydrogen.

10. The method according to claim 1, wherein the mixing the at least part of the reformate creates a reformate component in the fuel and the mixing the at least part of the exhaust gas creates an exhaust gas component in the fuel, the fuel comprising:

about 32% to about 56% of the reformate component, wherein the reformate component comprises about 90% vol. to about 95% vol. hydrogen, so that the fuel comprises 30% vol. to 55% vol. hydrogen; and

a balance of the fuel is the exhaust gas component, wherein the exhaust gas component comprises 71% vol. to 73% vol. nitrogen, 17% vol. to 19% vol. water (H_2O), and 8% vol. to 9% vol. carbon dioxide (CO_2).

11. The method according to claim **1**, wherein the generating the reformate occurs by performing a reforming process; and

wherein the reforming process comprises a sorption enhanced reforming (SER) process.

12. The method according to claim **11**, wherein the reforming process comprises a sorption enhanced water gas shift (SEWGS) process.

13. The method according to claim **1**, wherein the generating the exhaust gas further comprises performing a combustion process of a carbonaceous gas at a pressure of at least 20 bar.

14. The method according to claim **1**, further comprising reducing an amount of water in the reformate and/or the exhaust gas before the generating the fuel.

15. The method according to claim **1**, further comprising:

measuring a concentration of hydrogen in the reformate; and

controlling, in dependence on a measured concentration of hydrogen, relative amounts of the exhaust gas and the reformate that are mixed to generate the fuel.

16. A method of operating a combustor of a gas turbine, the method comprising:

supplying air and a fuel comprising an exhaust gas component and a reformate component comprising hydrogen to a combustor of a gas turbine, wherein the supplied air has not been oxygen depleted, wherein the fuel is generated according to the method of claim **1**; and

combusting the supplied air and fuel in the combustor of the gas turbine.

17. The method according to claim **16**, wherein a pressure during the combusting in the combustor of the gas turbine is at least 20 bar.

18. A gas turbine system comprising:

a gas turbine comprising a second combustor that, in use, receives a fuel that is a gas mixture that comprises hydrogen and an exhaust gas;

a hydrogen producing system;

a first combustor, wherein the first combustor is separate from the second combustor; and

an air intake for receiving air;

wherein:

the first combustor is arranged to generate heat and an exhaust gas;

the hydrogen producing system is arranged to use the heat from the first combustor to perform a reforming process on a carbonaceous gas, wherein the reforming process generates a reformate that comprises hydrogen; and

the second combustor is arranged to receive reformate output from the hydrogen producing system, exhaust gas from the first combustor, and air from the air intake.

19. The gas turbine system according to claim **18**, wherein the first combustor is a total combustor.

20. The gas turbine system according to claim **18**, wherein the hydrogen producing system comprises arrangement for capturing, by a sorbent, carbon dioxide generated by the reforming process; and

at least some of the heat generated by the first combustor is used to regenerate sorbent that has captured carbon dioxide in the hydrogen producing system.

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