

(19)



(11)

EP 4 481 196 A1

(12)

EUROPEAN PATENT APPLICATION

(43) Date of publication:

25.12.2024 Bulletin 2024/52

(51) International Patent Classification (IPC):

F04B 37/02 ^(2006.01) **F04B 37/12** ^(2006.01)

F04B 37/18 ^(2006.01) **F25B 17/00** ^(2006.01)

(21) Application number: **23181241.3**

(52) Cooperative Patent Classification (CPC):

F04B 37/02; F04B 37/12; F04B 37/18; F25B 17/08;

F25B 17/12; F25B 49/046; F25B 2600/11

(22) Date of filing: **23.06.2023**

(84) Designated Contracting States:

**AL AT BE BG CH CY CZ DE DK EE ES FI FR GB
GR HR HU IE IS IT LI LT LU LV MC ME MK MT NL
NO PL PT RO RS SE SI SK SM TR**

Designated Extension States:

BA

Designated Validation States:

KH MA MD TN

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(54) METAL HYDRIDE COMPRESSOR

(57) A metal hydride compressor (1) for compressing hydrogen gas from a state of lower pressure to a state of higher pressure comprises a first pressure vessel (2), said first pressure vessel (2) containing a first metal alloy capable of absorbing hydrogen gas at a first pressure (p1) in an absorption mode of the first pressure vessel (2) to form a first metal hydride. The first metal hydride is capable of desorbing hydrogen gas at a second pressure (p2), higher than the first pressure (p1), in a desorption mode of the first pressure vessel (2) to release hydrogen gas. The metal hydride compressor (1) further comprises a piping system (3) comprising a first inlet line (4) connected to an inlet (5) of the first pressure vessel (2) for receiving hydrogen gas into the first pressure vessel (2), and a first outlet line (6) connected to an outlet (7) of the first pressure vessel (2) for discharging hydrogen gas from the first pressure vessel (2). The piping system (3) further comprises a first cooling loop (8) that is adapted to cool the first metal alloy in the first pressure vessel (2) when hydrogen gas is absorbed at the first pressure (p1) by the first metal alloy to form a first metal hydride. The first cooling loop (8) comprises a first heat exchanger (9). The piping system (3) further comprises a first heating loop (10) that is adapted to heat the first metal hydride in the first pressure vessel (2) when hydrogen gas is desorbed from the first metal hydride at the second pressure (p2), the first heating loop (10) comprising a second heat exchanger (11).

The first cooling loop (8) and the first heating loop

(10) each comprise a blower (12) to circulate hydrogen gas through the first cooling loop (8) and the first heating loop (10). The first cooling loop (8) is fluidically connectable to the outlet (7) and to the inlet (5) of the first pressure vessel (2) during the absorption mode such that hydrogen gas being discharged from the outlet (7) of the first pressure vessel (2) via the first outlet line (6) of the first pressure vessel (2) is cooled via the first heat exchanger (9) and is then supplied to the inlet (5) of the first pressure vessel (2) via the first inlet line (4) to cool the first metal alloy as the first metal hydride is formed. The first heating loop (10) is fluidically connectable to the outlet (7) and to the inlet (5) of the first pressure vessel (2) during the desorption mode such that hydrogen gas being discharged from the outlet (7) of the first pressure vessel (2) via the first outlet line (6) is heated via the second heat exchanger (11) and is then supplied to the inlet (5) of the first pressure vessel (2) to heat the first metal hydride as hydrogen gas is desorbed. The piping system (3) further comprises a plurality of first switching valves (13) adapted to either connect the first cooling loop (8) or the first heating loop (10) to the outlet (7) and the inlet (5) of the first pressure vessel (2). The piping system (3) further comprises a supply line (16) adapted to fluidically connect a hydrogen source with the first inlet line (4), wherein the supply line (16) comprises a check valve (17) adapted to prevent a backflow of the hydrogen gas towards the hydrogen source and adapted to let through hydrogen gas towards the inlet (5) of the first pressure

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vessel (2) at a pressure of at most the first pressure (p_1).
The piping system (3) further comprises a first discharge line (18) fluidically connected to the first outlet line (6) and comprising a first overflow valve (19) adapted to discharge hydrogen gas having a pressure of at least the second pressure (p_2).

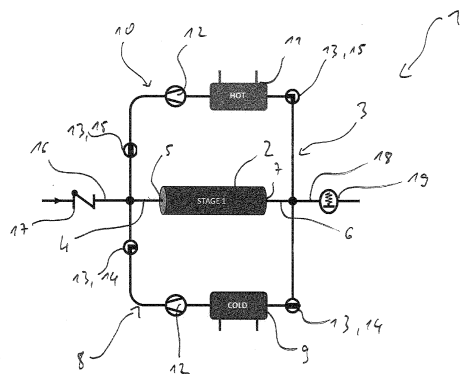


Fig. 1

Description

[0001] The results included in this application were funded by dtcc.bw - Center for Digitization and Technology Research of the German Armed Forces. dtcc.bw is funded by the European Union - NextGenerationEU.

FIELD OF THE INVENTION

[0002] The present invention relates to a metal hydride compressor for compressing hydrogen gas from a state of lower pressure to a state of higher pressure and to a method for compressing hydrogen gas. The compressor comprises a first pressure vessel, said first pressure vessel containing a first metal alloy capable of absorbing hydrogen gas at a first pressure in an absorption mode of the first pressure vessel to form a first metal hydride. The first metal hydride is capable of desorbing hydrogen gas at a second pressure, higher than the first pressure, in a desorption mode of the first pressure vessel to release hydrogen gas.

BACKGROUND OF THE INVENTION

[0003] Hydrogen as a substitute for natural gas, oil and coal is becoming increasingly important when it comes to climate protection and a secure energy supply. Due to its low density at ambient conditions, liquefaction and compression are typically used to increase the energy density and to store hydrogen. Hydrogen, when being used as fuel for cars and commercial vehicles, is for example stored in pressure vessels at a pressure of 35 MPa (350 bar) for passenger cars and 70 MPa (700 bar) for commercial vehicles such as trucks, buses and trains.

[0004] To generate these pressures, for example at hydrogen refueling stations, compressors are needed. Currently mechanical compressors (e.g. piston compressor or ionic compressor) are used. However, the operating costs of the mechanical compressors are rather high due to consumption of electrical energy and high maintenance requirements.

[0005] Metal hydride compressors provide an alternative technology to the mechanical compressors. Metal hydride compressors advantageously do not comprise any moving parts and are operated by heat alone which can be supplied e.g. by industrial waste heat.

[0006] Metal hydride compressors are for example disclosed in the article "Metal hydride hydrogen compressors: A review", M.V. Lototsky a, V.A. Yartys b,c, B.G. Pollet a and R.C. Bowman Jr., International Journal of Hydrogen Energy Vol 39 (2014), pages 5818 - 5851. Metal hydride compressors use metal alloys which are added to a pressure vessel as a powder. The alloys form a bond with hydrogen by absorbing it in their interstitial sites thereby forming metal hydrides during an exothermic reaction. This process must be cooled so that the reaction can continue, and absorption can take place until saturation of the metal hydrides. The arrangement of metal

alloys in a pressure vessel is referred to hereinafter as a metal hydride bed.

[0007] After the absorption reaction has been completed the hydrides are heated until a desired elevated pressure is reached. Due to the application of heat the temperature of the metal hydrides and the pressure of the hydrogen in the pressure vessel increases. Hydrogen is desorbed from the metal hydrides at the elevated pressure and an elevated temperature. As the desorption reaction is an endothermic reaction in which the metal hydrides have to be continuously heated to keep the desorbing reaction running. Metal hydride compressors are used as single stage compressors comprising one pressure vessel but may also be used as multistage compressors comprising a plurality of pressure vessels connected in series.

[0008] The metal hydrides are usually cooled and heated by use of a cooling/heating jacket surrounding the outside wall of the pressure vessel and/or by cooling/heating tubes inside of the pressure vessel. Typically, a heat exchanging fluid, such as a mixture of water and glycol, is used to flow through the cooling/heating jacket and the cooling/heating tubes and to transport heat towards or away from the metal hydrides. The cooling/heating jacket and/or the cooling/heating tubes together with the heat exchanging fluid add complexity to the metal hydride compressor. Moreover, the cooling/heating jacket and/or the cooling/heating tubes increase the inertial thermal mass which has to be heated and cooled in each compression cycle. Finally, the cooling/heating tubes decrease the volume inside the pressure vessel and thus the capacity of the metal hydride compressor.

[0009] It is therefore an object of the present invention to provide a cost effective, efficient and simplified metal hydride compressor with an increased capacity.

SUMMARY OF THE INVENTION

[0010] This object is achieved by a metal hydride compressor comprising the features of claim 1. Preferred embodiments are set out in the dependent claims.

[0011] According to the present invention the first cooling loop and the first heating loop each comprise a blower to circulate hydrogen gas through the first cooling loop and the first heating loop. The first cooling loop is fluidically connectable to the outlet and to the inlet of the first pressure vessel during the absorption mode such that hydrogen gas being discharged from the outlet of the first pressure vessel via the first outlet line of the first pressure vessel is cooled via the first heat exchanger and is then supplied to the inlet of the first pressure vessel via the first inlet line to cool the first metal alloy as the first metal hydride is formed. The first heating loop is fluidically connectable to the outlet and to the inlet of the first pressure vessel during the desorption mode such that hydrogen gas being discharged from the outlet of the first pressure vessel via the first outlet line is heated via the second heat exchanger and is then supplied to the inlet of

the first pressure vessel to heat the first metal hydride as hydrogen gas is desorbed. The piping system further comprises a plurality of first switching valves adapted to either connect the first cooling loop or the first heating loop to the outlet and the inlet of the first pressure vessel. The piping system further comprises a supply line adapted to fluidically connect a hydrogen source with the first inlet line. The supply line comprises a check valve adapted to prevent a backflow of the hydrogen gas towards the hydrogen source and adapted to let through hydrogen gas towards the inlet of the first pressure vessel at a pressure of at most the first pressure. The piping system further comprises a first discharge line fluidically connected to the first outlet line and comprising a first overflow valve adapted to discharge hydrogen gas having a pressure of at least the second pressure. Preferably, a valve such as a ball valve may be used instead of the check valve.

[0012] According to the present invention the metal hydride compressor uses the hydrogen itself as a heat transfer medium. The hydrogen gas is passed through the first or second heat exchanger and then at elevated temperatures (heating for desorption) or low temperatures (cooling for absorption) through the metal hydride bed, where it exchanges heat in direct contact with the metal hydride particles. Compared to solutions known from the prior art in which cooling/heating jackets surrounding the outside wall of the pressure vessel and/or cooling/heating tubes inside of the pressure vessel are used, the inert thermal mass is reduced to the minimum, namely to the metal hydride material itself.

[0013] In addition, the heat exchange between the gaseous hydrogen and the metal hydride particles offers the potential to dynamically adjust the transferred heat flux by means of the flow rate of the hydrogen gas without making changes to the temperature of the hydrogen gas. If the resource efficiency, i.e. the power of the compressor per volume of the metal hydride bed, is considered, the metal hydride compressor according to the present invention offers potential for improvement over compressors with heat transfer fluid.

[0014] In an embodiment of the invention wherein the metal hydride compressor further comprises a second pressure vessel, wherein the first discharge line is formed as a connection line fluidically connecting the outlet of the first pressure vessel with an inlet of the second pressure vessel, wherein the piping system comprises a second inlet line connected to the inlet of the second pressure vessel for receiving hydrogen gas into the second pressure vessel, and a second outlet line connected to an outlet of the second pressure vessel for discharging hydrogen gas from the second pressure vessel and, wherein the second pressure vessel comprises a second metal alloy capable of absorbing hydrogen gas at the second pressure in an absorption mode of the second pressure vessel to form a second metal hydride, and the second metal hydride capable of desorbing hydrogen gas at a third pressure, higher than the second pressure,

in a desorption mode of the second pressure vessel to release hydrogen gas. The use of two pressure vessels instead of one allows the generation of higher pressures. Preferably, the first and second pressure vessel are connected in series. Preferably, each pressure vessel forms one compression stage. Accordingly, using one pressure vessel provides a single compression stage, whereas the use of two pressure vessels connected in series provides two compression stages. Optionally, the metal hydride compressor may comprise more than two compression stages e.g. four compression stages. For example, using two or three pressure vessels allows the generation of pressures of about 35 MPa (350 bar) which may be generated at the outlet of the last pressure vessel.

[0015] In another embodiment of the invention the piping system further comprises a second discharge line fluidically connected to an outlet of the second pressure vessel via the second outlet line for discharging hydrogen gas from the second pressure vessel and, wherein the second discharge line comprises a second overflow valve adapted to discharge hydrogen gas having a pressure of at least the third pressure. The second overflow valve ensures that only hydrogen gas having a pressure of at least the third pressure passes the overflow valve and is discharged from the metal hydride compressor.

[0016] In an embodiment of the invention the first metal alloy of the first pressure vessel is the same or different than that of the second metal alloy of the second pressure vessel. If two different metal alloys are used, the second metal alloy of the second pressure vessel is preferably adapted to adsorb hydrogen at a higher pressure than the first metal alloy of the first pressure vessel. Moreover, the second metal alloy is preferably adapted to desorb hydrogen at a higher pressure than the first metal alloy of the first pressure vessel. Thus, two different metal alloys used in two different pressure vessels arranged in series allows the compression of hydrogen gas to a higher pressure than using one metal alloy in one single pressure vessel.

[0017] In another embodiment of the invention the first cooling loop comprises a first bypass line to bypass the first pressure vessel during absorption mode of the second pressure vessel and, that the first cooling loop is fluidically connectable to the outlet and the inlet of the second pressure vessel during the absorption mode of the second pressure vessel via the first bypass line. The first cooling loop is connectable to the first and the second pressure vessel. Thus, one blower and one heat exchanger are used in the first cooling loop for both compression stages. This reduces the number of components used in the first cooling loop and thus reduces the costs of the metal hydride compressor as well as the maintenance costs as less components must be maintained.

[0018] In an embodiment of the invention the plurality of first switching valves includes a first amount of switching valves arranged at the first cooling loop, wherein the first amount of switching valves are adapted to fluidically connect the outlet and the inlet of the second pressure

vessel during the absorption mode of the second pressure vessel via the first bypass line with the first heat exchanger of the first cooling loop such that hydrogen gas being discharged from the outlet of the second pressure vessel via the second outlet line is cooled via the first heat exchanger and is then supplied to the inlet of the second pressure vessel via the first bypass line and the second inlet line to cool the second metal alloy as the second metal hydride is formed. The first amount of switching valves is preferably formed as 3/2-way valves i.e., the first amount of switching valves each have 3 connections and two switching states.

[0019] In another embodiment of the invention the first heating loop comprises a second bypass line to bypass the first pressure vessel during desorption mode of the second pressure vessel and, that the first heating loop is fluidically connectable to the outlet and the inlet of the second pressure vessel during the desorption mode of the second pressure vessel via the second bypass line. The first heating loop is connectable to the first and the second pressure vessel. Thus, one blower and one heat exchanger are used in the first heating loop for both compression stages. This reduces the number of components used in the first heating loop and thus reduces the costs of the metal hydride compressor as well as the maintenance costs as less components must be maintained.

[0020] In an embodiment of the invention the plurality of first switching valves includes a second amount of switching valves arranged at the first heating loop, wherein the second amount of switching valves are adapted to fluidically connect the outlet and the inlet of the second pressure vessel during the desorption mode of the second pressure vessel with the second heat exchanger of the first heating loop via the second bypass line such that hydrogen gas being discharged from the outlet of the second pressure vessel via the second outlet line is heated via the second heat exchanger and is then supplied to the inlet of the second pressure vessel via the second bypass line and the second inlet line to heat the second metal hydride as hydrogen gas is desorbed. The second amount of switching valves is preferably formed as 3/2-way valves i.e., the second amount of switching valves each have 3 connections and two switching states.

[0021] In another embodiment of the invention the metal hydride compressor further comprises a control unit for controlling the speed of the blowers in the first cooling loop as well as the first heating loop. The control unit allows a dynamic adjustment of the heat transfer between the hydrogen gas and the first and/or second metal hydride bed by changing the flow rate of the hydrogen gas to reduce cycle times and blower energy consumption. The control can be converted into a closed-loop control by incorporating the temperature of the hydrogen gas at the outlet of the first and/or second pressure vessel as a controlled variable.

[0022] In another embodiment of the invention the

5 piping system further comprises a second cooling loop that is adapted to cool the second metal alloy in the second pressure vessel when hydrogen gas is absorbed at the second pressure by the second metal alloy to form a second metal hydride, that the second cooling loop comprises a third heat exchanger and a blower to circulate hydrogen gas through the second cooling loop, that the second cooling loop is fluidically connectable to the outlet and to the inlet of the second pressure vessel during the absorption mode such that hydrogen gas being discharged from the outlet of the second pressure vessel via the second outlet line of the second pressure vessel is cooled via the third heat exchanger and is then supplied to the inlet of the second pressure vessel via the second inlet line to cool the second metal alloy as the second metal hydride is formed. Providing one cooling loop for each pressure vessel i.e., for each compression stage, ensures that the same temperature and pressure conditions during the absorption mode of the first pressure vessel and the second pressure vessel are the same.

[0023] In an embodiment of the invention the piping system further comprises a second heating loop that is adapted to heat the second metal hydride in the second pressure vessel when hydrogen gas is desorbed from the second metal hydride at the third pressure, the second heating loop comprising a fourth heat exchanger and a blower to circulate hydrogen gas through the second heating loop, that the second heating loop is fluidically connectable to the outlet and to the inlet of the second pressure vessel during the desorption mode such that hydrogen gas being discharged from the outlet of the second pressure vessel via the second outlet line is heated via the fourth heat exchanger and is then supplied to the inlet of the second pressure vessel to heat the second metal hydride as hydrogen gas is desorbed and, that the piping system further comprises a plurality of second switching valves adapted to either connect the second cooling loop or the second heating loop to the outlet and the inlet of the second pressure vessel. Providing one heating loop for each pressure vessel i.e., for each compression stage, ensures that the same temperature and pressure conditions during the desorption mode of the first pressure vessel and the second pressure vessel are the same.

[0024] In another embodiment of the invention the metal hydride compressor further comprises a control unit for controlling the speed of the blowers in the second cooling loop as well as the second heating loop. Controlling the blowers in both cooling loops and heating loops allows better control of the heat being transferred between the hydrogen gas and the metal hydride bed and thus an improved control of the conditions during absorption and desorption of hydrogen gas.

[0025] The above object is also achieved by a method for compressing hydrogen gas. The method comprises the steps of:

- a) providing a metal hydride compressor as described above;
- b) operating the first pressure vessel in an absorption mode in which:

- i) hydrogen gas is supplied at a first pressure to the inlet of the first pressure vessel via the first inlet line such that hydrogen gas is absorbed by the first metal alloy to form the first metal hydride and the remaining hydrogen gas not being absorbed by the first metal alloy is discharged from the outlet of the first pressure vessel;
- ii) the plurality of first switching valves are switched to a first switching state in which the first cooling loop is fluidically connected to the outlet and the inlet of the first pressure vessel and
- iii) the hydrogen gas being discharged from the outlet of the first pressure vessel via the first outlet line is conveyed through the first cooling loop such that the hydrogen gas is cooled via the first heat exchanger and is then supplied to the inlet of the first pressure vessel via the first inlet line to cool the first metal alloy as the first metal hydride is formed;

- c) operating the first pressure vessel in a desorption mode in which:

- i) the plurality of first switching valves is switched to a second switching state in which the first cooling loop is fluidically disconnected from the outlet and the inlet of the first pressure vessel and in which the first heating loop is fluidically connected to the outlet and the inlet of the first pressure vessel;
- ii) hydrogen gas is conveyed through the first heating loop such that hydrogen gas being discharged from the outlet of the first pressure vessel via the first outlet line is heated via the second heat exchanger and is then supplied to the inlet of the first pressure vessel to heat the first metal hydride;
- iv) hydrogen gas is desorbed from the first metal hydride at a second pressure which is higher than the first pressure and passes the first overflow valve at the first discharge line,

wherein steps b) and c) are carried out in an alternating manner.

[0026] According to the present invention hydrogen gas is used as a heat transfer medium in the first cooling loop and the first heating loop. While some of the hydrogen gas is absorbed from the first cooling loop in the metal hydride bed, the circulating hydrogen gas cools the exothermic reaction during the absorption mode of the first pressure vessel. The heat is removed from the hydrogen gas in the cooling loop by the first heat exchanger

connected to an external cooling source. As some of the hydrogen gas is absorbed, the pressure in the first cooling loop drops and new hydrogen flows from the hydrogen source via the check valve towards the compressor inlet until the first pressure is restored.

[0027] After absorption is complete, the first switching valves are moved to their second switching state, thereby connecting the first heating loop to the outlet and inlet of the first pressure vessel. The hydrogen gas in the first heating loop is heated by the second heat exchanger connected to an external heat source. The first metal hydride is heated and the desorption reaction is initiated, so that the pressure in the first pressure vessel and in the first heating loop increases. Once the second pressure is reached, hydrogen gas flows through the overflow valve at the discharge line and is discharged via the discharge line.

[0028] In an embodiment of the invention the metal hydride compressor further comprises a second pressure vessel, wherein the first discharge line is formed as a connection line fluidically connecting the outlet of the first pressure vessel with an inlet of the second pressure vessel, wherein the second pressure vessel comprises a second metal alloy, wherein the piping system further comprises a second inlet line connected to the inlet of the second pressure vessel for receiving hydrogen gas into the second pressure vessel and a second outlet line connected to an outlet of the second pressure vessel for discharging hydrogen gas from the second pressure vessel and, wherein simultaneously to step c) the second pressure vessel is operated in an absorption mode in which:

- i) the first cooling loop is connected to the outlet and the inlet of the second pressure vessel by switching the plurality of first switching valves to the second switching state in step c-i);
- ii) hydrogen gas being desorbed in step c-iv) is supplied at the second pressure to the inlet of the second pressure vessel such that hydrogen gas is absorbed by the second metal alloy to form the second metal hydride and;
- iii) remaining hydrogen gas not being absorbed by the second metal alloy being discharged from the outlet of the second pressure vessel via the second outlet line is conveyed through the first cooling loop such that the hydrogen gas is cooled via the first heat exchanger and is then supplied to the inlet of the second pressure vessel via the second inlet line to cool the second metal alloy as the second metal hydride is formed.

[0029] The use of two pressure vessels instead of one allows the generation of higher pressures. Preferably, the desorption of hydrogen gas from the outlet of the first pressure vessel (step c) is always combined with the absorption of hydrogen by the second metal hydride bed of the second pressure vessel. Accordingly, the first cool-

ing loop is connected to the first pressure vessel and the second pressure vessel in an alternating manner.

[0030] In another embodiment of the invention the piping system further comprises a second discharge line fluidically connected to the outlet of the second pressure vessel via the second outlet line for discharging hydrogen gas from the second pressure vessel and, wherein simultaneously to step b) the second pressure vessel is operated in a desorption mode in which:

- i) the plurality of first switching valves is switched to the first switching state in which the first cooling loop is fluidically disconnected from the outlet and the inlet of the second pressure vessel and in which the first heating loop is fluidically connected to the outlet and the inlet of the second pressure vessel;
- ii) hydrogen gas is conveyed through the first heating loop such that hydrogen gas being discharged from the outlet of the second pressure vessel is heated via the second heat exchanger and is then supplied to the inlet of the second pressure vessel to heat the second metal hydride;
- iii) hydrogen gas is desorbed from the second metal hydride at a third pressure which is higher than the second pressure and passes a second over-flow valve at the second discharge line.

[0031] Preferably, the absorption of hydrogen by the first metal hydride bed (step b) is always combined with the desorption of hydrogen gas from the outlet of the second pressure vessel. Accordingly, the first heating loop is connected to the first pressure vessel and the second pressure vessel in an alternating manner.

[0032] In an embodiment of the invention wherein the metal hydride compressor further comprises a control unit connected to the blowers of the first cooling loop as well as the first heating loop and wherein the method comprises the additional step of

e) controlling the speed of the blowers in the first cooling loop as well as the first heating loop.

[0033] The control unit allows a dynamic adjustment of the heat transfer between the hydrogen gas and the first and/or second metal hydride bed by changing the flow rate of the hydrogen gas to reduce cycle times and blower energy consumption. The control can be converted into a closed-loop control by incorporating the temperature of the hydrogen gas at the outlet of the first and/or second pressure vessel as a controlled variable.

[0034] In another embodiment of the invention the metal hydride compressor further comprises a second pressure vessel, wherein the first discharge line is formed as a connection line fluidically connecting the outlet of the first pressure vessel with an inlet of the second pressure vessel, wherein the second pressure vessel comprises a second metal alloy, wherein the piping system further comprises a second inlet line connected to the inlet of the second pressure vessel for receiving hydrogen gas into the second pressure vessel and a second outlet line

connected to an outlet of the second pressure vessel for discharging hydrogen gas from the second pressure vessel, wherein the piping system further comprises a second cooling loop that is adapted to cool the second metal alloy in the second pressure vessel when hydrogen gas is absorbed at the second pressure by the second metal alloy to form a second metal hydride, wherein the piping system further comprises a second heating loop that is adapted to heat the second metal hydride in the second pressure vessel when hydrogen gas is desorbed from the second metal hydride at the third pressure, wherein the piping system further comprises a plurality of second switching valves adapted to either connect the second cooling loop or the second heating loop to the outlet and the inlet of the second pressure vessel and, wherein simultaneously to step c) the second pressure vessel is operated in an absorption mode in which:

- iv) the second cooling loop is connected to the outlet and the inlet of the second pressure vessel by switching the plurality of second switching valves to a first switching state in step c-i);
- v) hydrogen gas being desorbed in step c-iv) is supplied at the second pressure to the inlet of the second pressure vessel such that hydrogen gas is absorbed by the second metal alloy to form the second metal hydride and;
- vi) remaining hydrogen gas not being absorbed by the second metal alloy being discharged from the outlet of the second pressure vessel via the second outlet line is conveyed through the second cooling loop such that the hydrogen gas is cooled via the third heat exchanger and is then supplied to the inlet of the second pressure vessel via the inlet line to cool the second metal alloy as the second metal hydride is formed.

[0035] By providing a second cooling loop the pressure and temperature conditions in the first and second pressure vessel can be adjusted to be the same during the absorption mode of the first and second pressure vessel.

[0036] In an embodiment of the invention the piping system further comprises a second discharge line fluidically connected to the outlet of the second pressure vessel via the second outlet line for discharging hydrogen gas from the second pressure vessel and, wherein simultaneously to step b) the second pressure vessel is operated in a desorption mode in which:

- iv) the plurality of second switching valves is switched to a second switching state in which the second cooling loop is fluidically disconnected from the outlet and the inlet of the second pressure vessel and in which the second heating loop is fluidically connected to the outlet and the inlet of the second pressure vessel;
- v) hydrogen gas is conveyed through the second heating loop such that hydrogen gas being dis-

charged from the outlet of the second pressure vessel is heated via the fourth heat exchanger and is then supplied to the inlet of the second pressure vessel to heat the second metal hydride;

vi) hydrogen gas is desorbed from the second metal hydride at a third pressure which is higher than the second pressure and passes a second over-flow valve at the second discharge line.

[0037] By providing a second heating loop the pressure and temperature conditions in the first and second pressure vessel can be adjusted to be the same during the desorption mode of the first and second pressure vessel.

[0038] In another embodiment of the invention the second cooling loop and the second heating loop each comprises a blower to circulate hydrogen gas through the second cooling loop and the second heating loop, wherein the metal hydride compressor further comprises a control unit connected to the blowers of the first cooling loop as well as the first heating loop and to the blowers of the second cooling loop as well as the second heating loop and wherein the method comprises the additional step of

e) controlling the speed of the blowers in the first cooling loop as well as the first heating loop and controlling the speed of the blowers in the second cooling loop as well as the second heating loop.

[0039] Controlling the blowers in both cooling loops and heating loops allows better control of the heat being transferred between the hydrogen gas and the metal hydride bed and thus an improved control of the conditions during absorption and desorption of hydrogen gas.

BRIEF DESCRIPTION OF THE FIGURES

[0040] The invention will now be described in connection with two exemplary embodiments shown in the figures in which:

- Figure 1 shows a schematic view of a metal hydride compressor according to the present invention and
- Figure 2 shows a schematic view of a second embodiment of a metal hydride compressor,
- Figure 3 shows a schematic view of a third embodiment of a metal hydride compressor and
- Figure 4 shows a schematic view of a fourth embodiment of a metal hydride compressor.

[0041] Figure 1 shows metal hydride compressor 1 for compressing hydrogen gas from a state of lower pressure to a state of higher pressure. The compressor 1 comprises a first pressure vessel 2, said first pressure vessel 2 containing a first metal alloy capable of absorbing hydrogen gas at a first pressure p_1 in an absorption mode of the first pressure vessel 2 to form a first metal hydride. The first metal hydride is capable of desorbing

hydrogen gas at a second pressure p_2 , higher than the first pressure p_1 , in a desorption mode of the first pressure vessel 2 to release hydrogen gas.

[0042] The metal hydride compressor 1 further comprises a piping system 3 comprising a first inlet line 4 connected to an inlet 5 of the first pressure vessel 2 for receiving hydrogen gas into the first pressure vessel, and a first outlet line 6 connected to an outlet 7 of the first pressure vessel 2 for discharging hydrogen gas from the first pressure vessel 2. The piping system 3 further comprises a first cooling loop 8 that is adapted to cool the first metal alloy in the first pressure vessel 2 when hydrogen gas is absorbed at the first pressure p_1 by the first metal alloy to form a first metal hydride. The first cooling loop 8 comprises a first heat exchanger 9. The first cooling loop 8 is fluidically connectable to the outlet 7 and to the inlet 5 of the first pressure vessel 2 during the absorption mode such that hydrogen gas being discharged from the outlet 7 of the first pressure vessel 2 via the first outlet line 6 of the first pressure vessel 2 is cooled via the first heat exchanger 9 and is then supplied to the inlet 5 of the first pressure vessel 2 via the first inlet line 4 to cool the first metal alloy as the first metal hydride is formed.

[0043] The piping system 3 further comprises a first heating loop 10 that is adapted to heat the first metal hydride in the first pressure vessel 2 when hydrogen gas is desorbed from the first metal hydride at the second pressure p_2 . The first heating loop 10 comprises a second heat exchanger 11. The first heating loop 10 is fluidically connectable to the outlet 7 and to the inlet 5 of the first pressure vessel 2 during the desorption mode such that hydrogen gas being discharged from the outlet 7 of the first pressure vessel 2 via the first outlet line 6 is heated via the second heat exchanger 11 and is then supplied to the inlet 5 of the first pressure vessel 2 to heat the first metal hydride as hydrogen gas is desorbed.

[0044] The first cooling loop 8 and the first heating loop 10 each comprise a blower 12 to circulate hydrogen gas through the first cooling loop 8 and the first heating loop 10, respectively.

[0045] The piping system 3 further comprises a plurality of first switching valves 13 adapted to either connect the first cooling loop 8 or the first heating loop 10 to the outlet 7 and the inlet 5 of the first pressure vessel 2. The plurality of first switching valves 13 includes a first amount of switching valves 14 arranged at the first cooling loop 8 and a second amount of switching valves 15 arranged at the first heating loop 10.

[0046] The piping system 3 further comprises a supply line 16 adapted to fluidically connect a hydrogen source (not shown) with the first inlet line 4, wherein the supply line 16 comprises a check valve 17 adapted to prevent a backflow of the hydrogen gas towards the hydrogen source and adapted to let through hydrogen gas towards the inlet 5 of the first pressure vessel 2 at a pressure of at most the first pressure.

[0047] The piping system 3 further comprises a first discharge line 18 fluidically connected to the first outlet

line 6 and comprising a first overflow valve 19 adapted to discharge hydrogen gas having a pressure of at least the second pressure p2.

[0048] The metal hydride compressor 1 further comprises a control unit (not shown) for controlling the speed of the blowers 12 in the first cooling loop 8 as well as the first heating loop 10.

[0049] In the following a method for compressing hydrogen gas is described with reference to Fig. 1.

[0050] In a first step (step a) a metal hydride compressor as described above is provided.

[0051] In a second step (step b) the first pressure vessel 2 is operated in an absorption mode in which hydrogen gas is supplied at a first pressure p1 to the inlet 5 of the first pressure vessel 2 via the first inlet line 4 such that hydrogen gas is absorbed by the first metal alloy to form the first metal hydride. The remaining hydrogen gas not being absorbed by the first metal alloy is discharged from the outlet 7 of the first pressure vessel 2. The plurality of first switching valves 13 is switched to a first switching state in which the first cooling loop 8 is fluidically connected to the outlet and the inlet of the first pressure vessel 2. The hydrogen gas being discharged from the outlet 7 of the first pressure vessel 2 via the first outlet line 6 is conveyed through the first cooling loop 8 such that the hydrogen gas is cooled via the first heat exchanger 9 and is then supplied to the inlet 5 of the first pressure vessel 2 via the first inlet line 4 to cool the first metal alloy as the first metal hydride is formed.

[0052] In a third step (step c) the first pressure vessel 2 is operated in a desorption mode in which the plurality of first switching valves 13 is switched to a second switching state in which the first cooling loop 8 is fluidically disconnected from the outlet 7 and the inlet 5 of the first pressure vessel 2 and in which the first heating loop 10 is fluidically connected to the outlet 7 and the inlet 5 of the first pressure vessel 2. Hydrogen gas is conveyed through the first heating loop 10 such that hydrogen gas being discharged from the outlet 7 of the first pressure vessel 2 via the first outlet line 6 is heated via the second heat exchanger 11 and is then supplied to the inlet 5 of the first pressure vessel 2 to heat the first metal hydride. Hydrogen gas is desorbed from the first metal hydride at a second pressure p2 which is higher than the first pressure p1 and passes the first overflow valve 19 at the first discharge line 18.

[0053] The steps of operating the first pressure vessel 2 in an absorption mode and in a desorption mode are carried out in an alternating manner.

[0054] Figure 2 shows a second embodiment of the metal hydride compressor 1. The metal hydride compressor 1' differs from the one shown in Figure 1 in that the metal hydride compressor 1' further comprises a second pressure vessel 20. The first discharge line 18 is formed as a connection line fluidically connecting the outlet 7 of the first pressure vessel 2 with an inlet 5 of the second pressure vessel 20. The piping system 3 comprises a second inlet line 21 connected to the inlet 5 of the second

pressure vessel 20 for receiving hydrogen gas into the second pressure vessel 20, and a second outlet line 22 connected to an outlet 7 of the second pressure vessel 20 for discharging hydrogen gas from the second pressure vessel 20.

[0055] The second pressure vessel 20 comprises a second metal alloy (not shown) capable of absorbing hydrogen gas at the second pressure p2 in an absorption mode of the second pressure vessel 20 to form a second metal hydride. The second metal hydride is capable of desorbing hydrogen gas at a third pressure p3, higher than the second pressure p2, in a desorption mode of the second pressure vessel 20 to release hydrogen gas. The first metal alloy of the first pressure vessel 2 is the same or different than that of the second metal alloy of the second pressure vessel 20.

[0056] The piping system 3 further comprises a second discharge 23 line fluidically connected to an outlet 7 of the second pressure vessel 20 via the second outlet line 22 for discharging hydrogen gas from the second pressure vessel 20. The second discharge line 23 comprises a second overflow valve 24 adapted to discharge hydrogen gas having a pressure of at least the third pressure p3.

[0057] The first cooling loop 8 comprises a first bypass line 25 to bypass the first pressure vessel 2 during absorption mode of the second pressure vessel 2. The first cooling loop 8 is fluidically connectable to the outlet 7 and the inlet 5 of the second pressure vessel 20 during the absorption mode of the second pressure vessel 20 via the first bypass line 25. The first amount of switching valves 14 are adapted to fluidically connect the outlet 7 and the inlet 5 of the second pressure vessel 20 during the absorption mode of the second pressure vessel 20 via the first bypass line 25 with the first heat exchanger 9 of the first cooling loop 8 such that hydrogen gas being discharged from the outlet 7 of the second pressure vessel 20 via the second outlet line 22 is cooled via the first heat exchanger 9 and is then supplied to the inlet 5 of the second pressure vessel 20 via the first bypass line 25 and the second inlet line 21 to cool the second metal alloy as the second metal hydride is formed.

[0058] The first heating loop 10 comprises a second bypass 26 line to bypass the first pressure vessel 2 during desorption mode of the second pressure vessel 20. The first heating loop 10 is fluidically connectable to the outlet 7 and the inlet 5 of the second pressure vessel 20 during the desorption mode of the second pressure vessel 20 via the second bypass line 26. The second amount of switching valves 15 is adapted to fluidically connect the outlet 7 and the inlet 5 of the second pressure vessel 20 during the desorption mode of the second pressure vessel 20 with the second heat exchanger 11 of the first heating loop 10 via the second bypass line 26 such that hydrogen gas being discharged from the outlet 7 of the second pressure vessel 20 via the second outlet line 22 is heated via the second heat exchanger 11 and is then supplied to the inlet 5 of the second pressure vessel 20 via the second bypass line 26 and the second inlet line 21 to

heat the second metal hydride as hydrogen gas is desorbed.

[0059] In the following a method for compressing hydrogen gas is described with reference to Fig. 2 and the second embodiment of the metal hydride compressor 1'.

[0060] Simultaneously to the third step (step c) as described with reference to the first embodiment of the metal hydride compressor 1 shown in Figure 1, which is the operation of the first pressure vessel 2 in the desorption mode, the second pressure vessel 20 is operated in an absorption mode. This condition is shown in Figure 2 and the corresponding flows of hydrogen gas are highlighted.

[0061] In the absorption mode of the second pressure vessel 20 the first cooling loop 8 is connected to the outlet 7 and the inlet 5 of the second pressure vessel 20 by switching the plurality of first switching valves 13 to the second switching state (third step, step c). The hydrogen gas being desorbed from the first pressure vessel 2 in the third step (step c) is supplied at the second pressure p2 to the inlet 5 of the second pressure vessel 20 such that hydrogen gas is absorbed by the second metal alloy to form the second metal hydride. Remaining hydrogen gas not being absorbed by the second metal alloy and being discharged from the outlet 7 of the second pressure vessel 20 via the second outlet line 22 is conveyed through the first cooling loop 8 such that the hydrogen gas is cooled via the first heat exchanger 9 and is then supplied to the inlet 5 of the second pressure vessel 20 via the second inlet line 4 to cool the second metal alloy as the second metal hydride is formed.

[0062] Simultaneously to the second step (step b) as described with reference to the first embodiment of the metal hydride compressor 1 shown in Figure 1, which is the operation of the first pressure vessel 2 in the absorption mode, the second pressure vessel 20 is operated in a desorption mode. In the desorption mode of the second pressure vessel 20 the plurality of first switching valves 13 is switched to the first switching state in which the first cooling loop 8 is fluidically disconnected from the outlet 7 and the inlet 5 of the second pressure vessel 20 and in which the first heating loop 10 is fluidically connected to the outlet 7 and the inlet 5 of the second pressure vessel 20. Hydrogen gas is conveyed through the first heating loop 10 such that hydrogen gas being discharged from the outlet 7 of the second pressure vessel 20 is heated via the second heat exchanger 11 and is then supplied to the inlet 5 of the second pressure vessel 20 to heat the second metal hydride. Hydrogen gas is desorbed from the second metal hydride at a third pressure p3 which is higher than the second pressure p2 and passes a second overflow valve 24 at the second discharge line 23.

[0063] The metal hydride compressor 1' may further comprise a control unit (not shown) connected to the blowers 12 of the first cooling loop 8 as well as the first heating loop 10. Accordingly, the method comprises the additional step of controlling the speed of the blowers 12 in the first cooling loop 8 as well as the first heating loop

10.

[0064] Figure 3 shows a third embodiment of the metal hydride compressor 1. The metal hydride compressor 1" differs from the one shown in Fig. 2 in that the plurality of first switching valves 13 does not include a first amount of switching valves 14 and a second amount of switching valves 15. As shown in Figure 3 the plurality of first switching valves 13 is formed by two 3/2-way valves which are arranged at the first inlet line 4 and the first outlet line 6 of the first pressure vessel 2. The two 3/2-way valves each have 3 connections and two switching states.

[0065] The metal hydride compressor 1" further differs from the one shown in Fig. 2 in that the piping system further comprises a second cooling loop 27 that is adapted to cool the second metal alloy in the second pressure vessel 20 when hydrogen gas is absorbed at the second pressure p2 by the second metal alloy to form a second metal hydride. The second cooling loop 27 comprises a third heat exchanger 28 and a blower 12 to circulate hydrogen gas through the second cooling loop 27. The second cooling loop 27 is fluidically connectable to the outlet 7 and to the inlet 5 of the second pressure vessel 20 during the absorption mode such that hydrogen gas being discharged from the outlet 7 of the second pressure vessel 20 via the second outlet line 22 of the second pressure vessel 20 is cooled via the third heat exchanger 28 and is then supplied to the inlet 5 of the second pressure vessel 20 via the second inlet line 21 to cool the second metal alloy as the second metal hydride is formed.

[0066] The piping system 3 further comprises a second heating loop 29 that is adapted to heat the second metal hydride in the second pressure vessel 20 when hydrogen gas is desorbed from the second metal hydride at the third pressure p3. The second heating loop 29 comprises a fourth heat exchanger 30 and a blower 12 to circulate hydrogen gas through the second heating loop 29. The second heating loop 29 is fluidically connectable to the outlet 7 and to the inlet 5 of the second pressure vessel 20 during the desorption mode such that hydrogen gas being discharged from the outlet 7 of the second pressure vessel 20 via the second outlet line 22 is heated via the fourth heat exchanger 30 and is then supplied to the inlet 5 of the second pressure vessel 20 to heat the second metal hydride as hydrogen gas is desorbed. The piping system 3 further comprises a plurality of second switching valves 31 adapted to either connect the second cooling loop 27 or the second heating loop 29 to the outlet 7 and the inlet 5 of the second pressure vessel 20.

[0067] The metal hydride compressor 1" further comprises a control unit (not shown) for controlling the speed of the blowers 12 in the second cooling loop 27 as well as the second heating loop 29.

[0068] Optionally, the metal hydride compressor 1" may further comprise multiple first pressure vessels 2 and multiple second pressure vessels 20, each of the first and second pressure vessels 2, 20 comprising an inlet 5

and an outlet 7. The inlets 7 of the multiple first pressure vessels 2 are connected to the first inlet line 4 and the outlets 7 of the first pressure vessels 2 are connected to the first outlet line 6. In other words: the multiple first pressure vessels 2 are arranged in parallel wherein the first inlet line 4 is connected to the inlets 5 of the first pressure vessels 2 and wherein the first outlet line 6 is connected to the outlets 7 of the first pressure vessels 2. The inlets 7 of the multiple second pressure vessels 20 are connected to the second inlet line 21 and the outlets 7 of the multiple second pressure vessels 2 are connected to the second outlet line 22. In other words: the multiple second pressure vessels 2 are arranged in parallel wherein the second inlet line 21 is connected to the inlets 5 of the second pressure vessels 2 and wherein the second outlet line 22 is connected to the outlets 7 of the second pressure vessels 20. The use of multiple first and second pressure vessels 2, 20 arranged in parallel increases the load capacity of the metal hydride compressor 1".

[0069] In the following a method for compression hydrogen gas is described with reference to Fig. 3 and the third embodiment of the metal hydride compressor 1".

[0070] Simultaneously to the third step (step c) as described with reference to the first embodiment of the metal hydride compressor 1 shown in Figure 1, which is the operation of the first pressure vessel 2 in the desorption mode, the second pressure vessel 20 is operated in an absorption mode. In the absorption mode of the second pressure vessel 20 the second cooling loop 27 is connected to the outlet 7 and the inlet 5 of the second pressure vessel 20 by switching the plurality of second switching valves 31 to a first switching state. Hydrogen gas being desorbed in the third step (step c) is supplied at the second pressure p_2 to the inlet 5 of the second pressure vessel 20 such that hydrogen gas is absorbed by the second metal alloy to form the second metal hydride. Remaining hydrogen gas not being absorbed by the second metal alloy being discharged from the outlet 7 of the second pressure vessel 20 via the second outlet line 22 is conveyed through the second cooling loop 27 such that the hydrogen gas is cooled via the third heat exchanger 28 and is then supplied to the inlet 5 of the second pressure vessel 20 via the second inlet line 21 to cool the second metal alloy as the second metal hydride is formed.

[0071] Simultaneously to the second step (step b) as described with reference to the first embodiment of the metal hydride compressor 1 shown in Figure 1, which is the operation of the first pressure vessel 2 in the absorption mode, the second pressure vessel 20 is operated in a desorption mode. In the desorption mode of the second pressure vessel 20 the plurality of second switching valves 31 is switched to a second switching state in which the second cooling loop 27 is fluidically disconnected from the outlet 7 and the inlet 5 of the second pressure vessel 20 and in which the second heating loop 29 is fluidically connected to the outlet 7 and the inlet 5 of the

second pressure vessel 20. Hydrogen gas is conveyed through the second heating loop 29 such that hydrogen gas being discharged from the outlet 7 of the second pressure vessel 20 is heated via the fourth heat exchanger 30 and is then supplied to the inlet 5 of the second pressure vessel 20 to heat the second metal hydride. Hydrogen gas is desorbed from the second metal hydride at a third pressure p_3 which is higher than the second pressure p_2 and passes a second overflow valve 24 at the second discharge line 23.

[0072] The metal hydride compressor 1" may further comprises a control unit (not shown) connected to the blowers 12 of the first cooling loop 8 as well as the first heating loop 10 and to the blowers 12 of the second cooling loop 27 as well as the second heating loop 29. Accordingly, the method comprises the additional step of controlling the speed of the blowers 12 in the first cooling loop 8 as well as the first heating loop 10 and controlling the speed of the blowers 12 in the second cooling loop 27 as well as the second heating loop 29.

[0073] Figure 4 shows a fourth embodiment of the metal hydride compressor 1. The metal hydride compressor 1" differs from the one as shown in Figure 3 in that the metal hydride compressor 1" comprises two first pressure vessels 2 and two second pressure vessels 20. Both first pressure vessels 2 are connectable to the first cooling loop 8 and to the first heating loop 10. Both second pressure vessels 20 are connectable to the second cooling loop 27 and to the second heating loop 29.

[0074] The function of the metal hydride compressor 1" is as follows:

While one of the first pressure vessels 2 is operated in the desorption mode, the other vessel of the first pressure vessels 2 can be operated in the absorption mode and hydrogen gas can be supplied to the other vessel of the first pressure vessels 2 via the first cooling loop 8. The same principle goes with the second pressure vessels 20. While one of the second pressure vessels 20 is operated in the desorption mode, the other vessel of the second pressure vessels 20 can be operated in the absorption mode and hydrogen gas can be supplied to the other vessel of the second pressure vessel 20 via the second cooling loop 27.

[0075] This allows a continuous discharging of compressed hydrogen at the third pressure p_3 via the second pressure vessels (20).

[0076] Instead of doubling the first and second pressure vessels 2, 20 (dual phase), the metal hydride compressor 1" may comprise more than two first pressure vessels 2 and more than two second pressure vessels 20. In order to connect more than two first and second pressure vessels 2, 20 to the corresponding first and second cooling loops 8, 27 as well as to the corresponding first and second heating loops 10, 29 the flow of hydrogen gas coming from each set of blower 12 and heat exchanger 9, 11, 28, 30 is further divided.

[0077] Optionally, in addition to the two or more first pressure vessels 2 each being connectable to the first

cooling loop 8 and the first heating loop 10, the metal hydride compressor 1''' may comprise further first pressure vessels 2 each comprising an inlet 5 and an outlet 7. The two or more first inlet lines 4 are each connected to the inlets 5 of multiple of the further first pressure vessels 2 and the two or more first outlet lines 6 are connected to the outlets 7 of multiple of the further first pressure vessels 2 such that the further first pressure vessels 2 connected to one of the first inlet and outlet lines 4, 6 are arranged in parallel.

[0078] Optionally, in addition to the two or more second pressure vessels 2 each being connectable to the second cooling loop 27 and the second heating loop 29, the metal hydride compressor 1''' may comprise further second pressure vessels 20 each comprising an inlet 5 and an outlet 7. The two or more second inlet lines 21 are each connected to the inlets 5 of multiple of the further second pressure vessels 20 and the two or more second outlet lines 22 are connected to the outlets 7 of multiple of the further second pressure vessels 20 such that the further second pressure vessels 20 connected to one of the second inlet and outlet lines 21, 22 are arranged in parallel.

[0079] The use of multiple first and second pressure vessels 2, 20 arranged in parallel increases the load capacity of the metal hydride compressor 1'''.

Reference numerals

[0080]

1, 1', 1'', 1'''	compressor	30
2	first pressure vessel	
p1	first pressure	
p2	second pressure	35
3	piping system	
4	first inlet line (first pressure vessel)	
5	inlet	
6	first outlet line (first pressure vessel)	
7	outlet	40
8	first cooling loop	
9	first heat exchanger	
10	first heating loop	
11	second heat exchanger	
12	blower	45
13	first switching valves	
14	first amount of switching valves	
15	second amount of switching valves	
16	supply line	
17	check valve	50
18	first discharge line	
19	first overflow valve	
20	second pressure vessel	
21	second inlet line	
22	second outlet line	55
p3	third pressure	
23	second discharge line	
24	second overflow valve	

25
26
27
28
29
30
31

first bypass line
second bypass line
second cooling loop
third heat exchanger
second heating loop
fourth heat exchanger
second switching valves

Claims

1. A metal hydride compressor for compressing hydrogen gas from a state of lower pressure to a state of higher pressure, the compressor (1, 1', 1'', 1''') comprising:

- a first pressure vessel (2), said first pressure vessel containing a first metal alloy capable of absorbing hydrogen gas at a first pressure (p1) in an absorption mode of the first pressure vessel (2) to form a first metal hydride, and the first metal hydride capable of desorbing hydrogen gas at a second pressure (p2), higher than the first pressure (p1), in a desorption mode of the first pressure vessel (2) to release hydrogen gas,

- a piping system (3) comprising a first inlet line (4) connected to an inlet (5) of the first pressure vessel (2) for receiving hydrogen gas into the first pressure vessel (2), and a first outlet line (6) connected to an outlet (7) of the first pressure vessel (2) for discharging hydrogen gas from the first pressure vessel (2),

wherein the piping system (3) further comprises:

- a first cooling loop (8) that is adapted to cool the first metal alloy in the first pressure vessel (2) when hydrogen gas is absorbed at the first pressure (p1) by the first metal alloy to form a first metal hydride, the first cooling loop (8) comprising a first heat exchanger (9), and
- a first heating loop (10) that is adapted to heat the first metal hydride in the first pressure vessel (2) when hydrogen gas is desorbed from the first metal hydride at the second pressure (p2), the first heating loop (10) comprising a second heat exchanger (11),

characterized in

that the first cooling loop (8) and the first heating loop (10) each comprise a blower (12) to circulate hydrogen gas through the first cooling loop (8) and the first heating loop (10),

that the first cooling loop (8) is fluidically connectable to the outlet (7) and to the inlet (5) of the first pressure vessel (2) during the absorption mode such that hydrogen gas being discharged

from the outlet (7) of the first pressure vessel (2) via the first outlet line (6) of the first pressure vessel (2) is cooled via the first heat exchanger (9) and is then supplied to the inlet (5) of the first pressure vessel (2) via the first inlet line (4) to cool the first metal alloy as the first metal hydride is formed,

that the first heating loop (10) is fluidically connectable to the outlet (7) and to the inlet (5) of the first pressure vessel (2) during the desorption mode such that hydrogen gas being discharged from the outlet (7) of the first pressure vessel (2) via the first outlet line (6) is heated via the second heat exchanger (11) and is then supplied to the inlet (5) of the first pressure vessel (2) to heat the first metal hydride as hydrogen gas is desorbed, **that** the piping system further comprises (3) a plurality of first switching valves (13) adapted to either connect the first cooling loop (8) or the first heating loop (10) to the outlet (7) and the inlet (5) of the first pressure vessel (2),

that the piping system (3) further comprises a supply line (16) adapted to fluidically connect a hydrogen source with the first inlet line (4), wherein the supply line (16) comprises a check valve (17) adapted to prevent a backflow of the hydrogen gas towards the hydrogen source and adapted to let through hydrogen gas towards the inlet (5) of the first pressure vessel (2) at a pressure of at most the first pressure (p_1) and, **that** the piping system (3) further comprises a first discharge line (18) fluidically connected to the first outlet line (6) and comprising a first overflow valve (19) adapted to discharge hydrogen gas having a pressure of at least the second pressure (p_2).

2. The metal hydride compressor according to claim 1, wherein the metal hydride compressor further comprises a second pressure vessel (20), wherein the first discharge line (18) is formed as a connection line fluidically connecting the outlet (7) of the first pressure vessel (2) with an inlet (5) of the second pressure vessel (20), wherein the piping system (3) comprises a second inlet line (21) connected to the inlet (5) of the second pressure vessel (20) for receiving hydrogen gas into the second pressure vessel (20), and a second outlet line (22) connected to an outlet (7) of the second pressure vessel (20) for discharging hydrogen gas from the second pressure vessel (20) and, wherein the second pressure vessel (20) comprises a second metal alloy capable of absorbing hydrogen gas at the second pressure (p_2) in an absorption mode of the second pressure vessel (20) to form a second metal hydride, and the second metal hydride capable of desorbing hydrogen gas at a third pressure (p_3), higher than the second pressure (p_2), in a desorption mode of the second

pressure vessel (20) to release hydrogen gas.

3. The metal hydride compressor according to claim 2 wherein the piping system (3) further comprises a second discharge line (23) fluidically connected to an outlet (7) of the second pressure vessel (20) via the second outlet line (22) for discharging hydrogen gas from the second pressure vessel (20) and, wherein the second discharge line (23) comprises a second overflow valve (24) adapted to discharge hydrogen gas having a pressure of at least the third pressure (p_3).
4. The metal hydride compressor according to claim wherein the first metal alloy of the first pressure vessel (2) is the same or different than that of the second metal alloy of the second pressure vessel (20).
5. The metal hydride compressor according to claim 2 wherein the first cooling loop comprises a first bypass line (25) to bypass the first pressure vessel (2) during absorption mode of the second pressure vessel (20) and, that the first cooling loop (8) is fluidically connectable to the outlet (7) and the inlet (5) of the second pressure vessel (20) during the absorption mode of the second pressure vessel (20) via the first bypass line (25).
6. The metal hydride compressor according to claim 5 wherein the plurality of first switching valves (13) includes a first amount of switching valves (14) arranged at the first cooling loop (8), wherein the first amount of switching valves (14) are adapted to fluidically connect the outlet (7) and the inlet (5) of the second pressure vessel (20) during the absorption mode of the second pressure vessel (20) via the first bypass line (25) with the first heat exchanger (9) of the first cooling loop (8) such that hydrogen gas being discharged from the outlet (7) of the second pressure vessel (20) via the second outlet line (22) is cooled via the first heat exchanger (9) and is then supplied to the inlet (5) of the second pressure vessel (20) via the first bypass line (25) and the second inlet line (21) to cool the second metal alloy as the second metal hydride is formed.
7. The metal hydride compressor according to claim 2 wherein the first heating loop (10) comprises a second bypass line (26) to bypass the first pressure vessel (2) during desorption mode of the second pressure vessel (20) and, that the first heating loop (10) is fluidically connectable to the outlet (7) and the inlet (5) of the second pressure vessel (20) during the desorption mode of the second pressure vessel (20) via the second bypass line (26).
8. The metal hydride compressor according to claim 7

- wherein the plurality of first switching valves (13) includes a second amount of switching valves (15) arranged at the first heating loop (10), wherein the second amount of switching valves (15) are adapted to fluidically connect the outlet (7) and the inlet (5) of the second pressure vessel (20) during the desorption mode of the second pressure vessel (20) with the second heat exchanger (11) of the first heating loop (10) via the second bypass line (26) such that hydrogen gas being discharged from the outlet (7) of the second pressure vessel (20) via the second outlet line (22) is heated via the second heat exchanger (11) and is then supplied to the inlet (5) of the second pressure vessel (20) via the second bypass line (26) and the second inlet line (21) to heat the second metal hydride as hydrogen gas is desorbed.
9. The metal hydride compressor according to any of the preceding claims wherein the metal hydride compressor (1, 1', 1", 1''') further comprises a control unit for controlling the speed of the blowers (12) in the first cooling loop (8) as well as the first heating loop (10).
 10. The metal hydride compressor according to claim 2 wherein the piping system (3) further comprises a second cooling loop (27) that is adapted to cool the second metal alloy in the second pressure vessel (20) when hydrogen gas is absorbed at the second pressure (p2) by the second metal alloy to form a second metal hydride, that the second cooling loop (10) comprises a third heat exchanger (28) and a blower (12) to circulate hydrogen gas through the second cooling loop (27), that the second cooling loop (27) is fluidically connectable to the outlet (7) and to the inlet (5) of the second pressure vessel (20) during the absorption mode such that hydrogen gas being discharged from the outlet (7) of the second pressure vessel (20) via the second outlet line (22) of the second pressure vessel (20) is cooled via the third heat exchanger (28) and is then supplied to the inlet (5) of the second pressure vessel (20) via the second inlet line (21) to cool the second metal alloy as the second metal hydride is formed.
 11. The metal hydride compressor according to claim 2 wherein that the piping system (3) further comprises a second heating loop (29) that is adapted to heat the second metal hydride in the second pressure vessel (20) when hydrogen gas is desorbed from the second metal hydride at the third pressure (p3), the second heating loop (29) comprising a fourth heat exchanger (30) and a blower (12) to circulate hydrogen gas through the second heating loop (29), that the second heating loop (29) is fluidically connectable to the outlet (7) and to the inlet (5) of the second pressure vessel (20) during the desorption mode such that hydrogen gas being discharged from the outlet (7) of the second pressure vessel (20) via the second outlet line (22) is heated via the fourth heat exchanger (30) and is then supplied to the inlet (5) of the second pressure vessel (20) to heat the second metal hydride as hydrogen gas is desorbed and, that the piping system (3) further comprises a plurality of second switching valves (31) adapted to either connect the second cooling (27) loop or the second heating loop (29) to the outlet (7) and the inlet (5) of the second pressure vessel (20).
 12. The metal hydride compressor according to any of claims 10 or 11 wherein the metal hydride compressor (1, 1', 1", 1''') further comprises a control unit for controlling the speed of the blowers (12) in the second cooling loop (27) as well as the second heating loop (29).
 13. A method for compressing hydrogen gas comprising the steps of:
 - a) providing a metal hydride compressor (1, 1', 1", 1''') according to any of claims 1 to 12;
 - b) operating the first pressure vessel (2) in an absorption mode in which:
 - i) hydrogen gas is supplied at a first pressure (p1) to the inlet (5) of the first pressure vessel (2) via the first inlet line (4) such that hydrogen gas is absorbed by the first metal alloy to form the first metal hydride and the remaining hydrogen gas not being absorbed by the first metal alloy is discharged from the outlet (7) of the first pressure vessel (2);
 - ii) the plurality of first switching valves (13) are switched to a first switching state in which the first cooling loop (8) is fluidically connected to the outlet (7) and the inlet (5) of the first pressure vessel (2) and
 - iii) the hydrogen gas being discharged from the outlet (7) of the first pressure vessel (2) via the first outlet line (6) is conveyed through the first cooling loop (8) such that the hydrogen gas is cooled via the first heat exchanger (9) and is then supplied to the inlet (5) of the first pressure vessel (2) via the first inlet line (4) to cool the first metal alloy as the first metal hydride is formed;
 - c) operating the first pressure vessel (2) in a desorption mode in which:
 - i) the plurality of first switching valves (13) is switched to a second switching state in which the first cooling loop (8) is fluidically disconnected from the outlet (7) and the inlet (5) of the first pressure vessel (2)

and in which the first heating loop (10) is fluidically connected to the outlet (7) and the inlet (5) of the first pressure vessel (2);

iii) hydrogen gas is conveyed through the first heating loop (10) such that hydrogen gas being discharged from the outlet (7) of the first pressure vessel (2) via the first outlet line (6) is heated via the second heat exchanger (11) and is then supplied to the inlet (5) of the first pressure vessel (2) to heat the first metal hydride;

iv) hydrogen gas is desorbed from the first metal hydride at a second pressure (p2) which is higher than the first pressure (p1) and passes the first overflow valve (19) at the first discharge line (18),

wherein steps b) and c) are carried out in an alternating manner.

14. The method for compressing hydrogen gas according to claim 13, wherein the metal hydride compressor (1', 1'', 1''') further comprises a second pressure vessel (20), wherein the first discharge line (18) is formed as a connection line fluidically connecting the outlet (7) of the first pressure vessel (2) with an inlet (5) of the second pressure vessel (20), wherein the second pressure vessel (20) comprises a second metal alloy, wherein the piping system (3) further comprises a second inlet line (21) connected to the inlet (5) of the second pressure vessel (20) for receiving hydrogen gas into the second pressure vessel (20) and a second outlet line (22) connected to an outlet (7) of the second pressure vessel (20) for discharging hydrogen gas from the second pressure vessel (20) and, wherein simultaneously to step c) the second pressure vessel (20) is operated in an absorption mode in which:

i) the first cooling loop (8) is connected to the outlet (7) and the inlet (5) of the second pressure vessel (20) by switching the plurality of first switching valves (13) to the second switching state in step c-i);

ii) hydrogen gas being desorbed in step c-iv) is supplied at the second pressure (p2) to the inlet (5) of the second pressure vessel (20) such that hydrogen gas is absorbed by the second metal alloy to form the second metal hydride and;

iii) remaining hydrogen gas not being absorbed by the second metal alloy being discharged from the outlet (7) of the second pressure vessel (20) via the second outlet line (22) is conveyed through the first cooling loop (8) such that the hydrogen gas is cooled via the first heat exchanger (9) and is then supplied to the inlet (5) of the second pressure vessel (20) via the second inlet line (21) to cool the second metal alloy as the

second metal hydride is formed.

15. The method for compressing hydrogen gas according to claim 14, wherein the piping system (3) further comprises a second discharge line (23) fluidically connected to the outlet (7) of the second pressure vessel (20) via the second outlet line (22) for discharging hydrogen gas from the second pressure vessel (20) and, wherein simultaneously to step b) the second pressure vessel (20) is operated in a desorption mode in which:

i) the plurality of first switching valves (13) is switched to the first switching state in which the first cooling loop (8) is fluidically disconnected from the outlet (7) and the inlet (5) of the second pressure vessel (20) and in which the first heating loop (10) is fluidically connected to the outlet (7) and the inlet (5) of the second pressure vessel (20);

ii) hydrogen gas is conveyed through the first heating loop (10) such that hydrogen gas being discharged from the outlet (7) of the second pressure vessel (20) is heated via the second heat exchanger (11) and is then supplied to the inlet (5) of the second pressure vessel (20) to heat the second metal hydride;

iii) hydrogen gas is desorbed from the second metal hydride at a third pressure (p3) which is higher than the second pressure (p2) and passes a second over-flow valve (24) at the second discharge line (23).

16. The method for compressing hydrogen gas according to any of claims 13 to 15, wherein the metal hydride compressor (1, 1', 1'', 1''') further comprises a control unit connected to the blowers (12) of the first cooling loop (8) as well as the first heating loop (10) and wherein the method comprises the additional step of
e) controlling the speed of the blowers (12) in the first cooling loop (8) as well as the first heating loop (10).

17. The method for compressing hydrogen gas according to claim 13, wherein the metal hydride compressor (1', 1'', 1''') further comprises a second pressure vessel (20), wherein the first discharge line (18) is formed as a connection line fluidically connecting the outlet (7) of the first pressure vessel (2) with an inlet (5) of the second pressure vessel (20), wherein the second pressure vessel (20) comprises a second metal alloy, wherein the piping system (3) further comprises a second inlet line (21) connected to the inlet (5) of the second pressure vessel (20) for receiving hydrogen gas into the second pressure vessel (20) and a second outlet line (22) connected to an outlet (7) of the second pressure vessel (20) for discharging hydrogen gas from the second pressure

vessel (20), wherein the piping system (3) further comprises a second cooling loop (27) that is adapted to cool the second metal alloy in the second pressure vessel (20) when hydrogen gas is absorbed at the second pressure (p2) by the second metal alloy to form a second metal hydride, wherein the piping system (3) further comprises a second heating loop (29) that is adapted to heat the second metal hydride in the second pressure vessel (20) when hydrogen gas is desorbed from the second metal hydride at the third pressure (p3), wherein the piping system (3) further comprises a plurality of second switching (31) valves adapted to either connect the second cooling loop (27) or the second heating loop (29) to the outlet (7) and the inlet (5) of the second pressure vessel (20) and, wherein simultaneously to step c) the second pressure vessel (20) is operated in an absorption mode in which:

iv) the second cooling loop (29) is connected to the outlet (7) and the inlet (5) of the second pressure vessel (20) by switching the plurality of second switching valves (31) to a first switching state;

v) hydrogen gas being desorbed in step c-iv) is supplied at the second pressure (p2) to the inlet (5) of the second pressure vessel (20) such that hydrogen gas is absorbed by the second metal alloy to form the second metal hydride and;

vi) remaining hydrogen gas not being absorbed by the second metal alloy being discharged from the outlet (7) of the second pressure vessel (20) via the second outlet line (22) is conveyed through the second cooling loop (27) such that the hydrogen gas is cooled via the third heat exchanger (28) and is then supplied to the inlet (5) of the second pressure vessel (20) via the second inlet line (21) to cool the second metal alloy as the second metal hydride is formed.

18. The method for compressing hydrogen gas according to claim 17, wherein the piping system (3) further comprises a second discharge line (23) fluidically connected to the outlet (7) of the second pressure vessel (20) via the second outlet line (22) for discharging hydrogen gas from the second pressure vessel (20) and, wherein simultaneously to step b) the second pressure vessel (20) is operated in a desorption mode in which:

iv) the plurality of second switching valves (31) is switched to a second switching state in which the second cooling loop (27) is fluidically disconnected from the outlet (7) and the inlet (5) of the second pressure vessel (20) and in which the second heating loop (29) is fluidically connected to the outlet (7) and the inlet (5) of the second pressure vessel (20);

v) hydrogen gas is conveyed through the second heating loop (29) such that hydrogen gas being discharged from the outlet (7) of the second pressure vessel (20) is heated via the fourth heat exchanger (30) and is then supplied to the inlet (5) of the second pressure vessel (20) to heat the second metal hydride;

vi) hydrogen gas is desorbed from the second metal hydride at a third pressure (p3) which is higher than the second pressure (p2) and passes a second over-flow valve (24) at the second discharge line (23).

19. The method for compressing hydrogen gas according to claims 17, wherein the second cooling loop (27) and the second heating loop (29) each comprises a blower (12) to circulate hydrogen gas through the second cooling loop (27) and the second heating loop (29), wherein the metal hydride compressor further comprises a control unit connected to the blowers (12) of the first cooling loop (8) as well as the first heating loop (10) and to the blowers (12) of the second cooling loop (27) as well as the second heating loop (29) and wherein the method comprises the additional step of

e) controlling the speed of the blowers (12) in the first cooling loop (8) as well as the first heating loop (10) and controlling the speed of the blowers (12) in the second cooling loop (27) as well as the second heating loop (29).

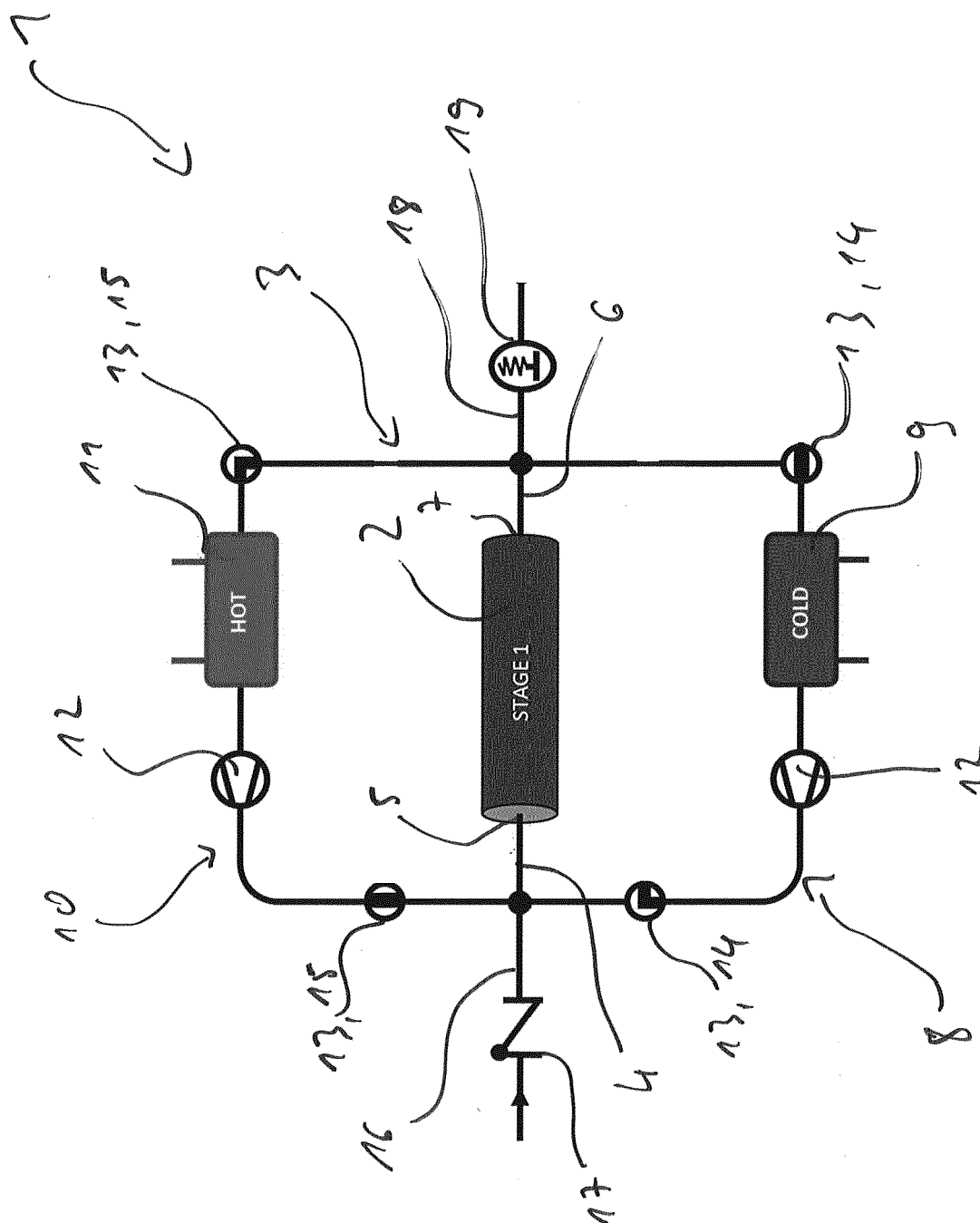


Fig. 1

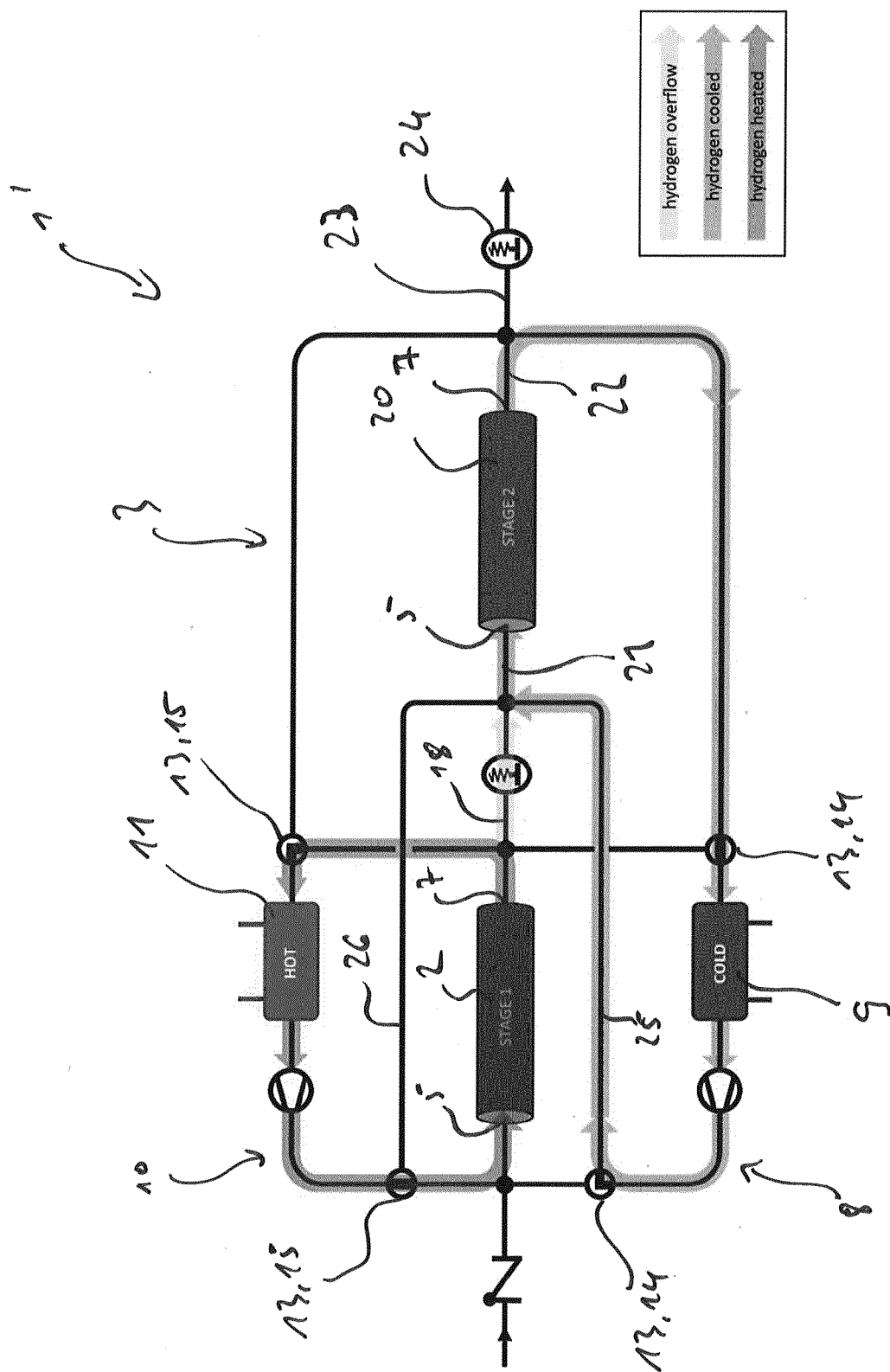


Fig. 2

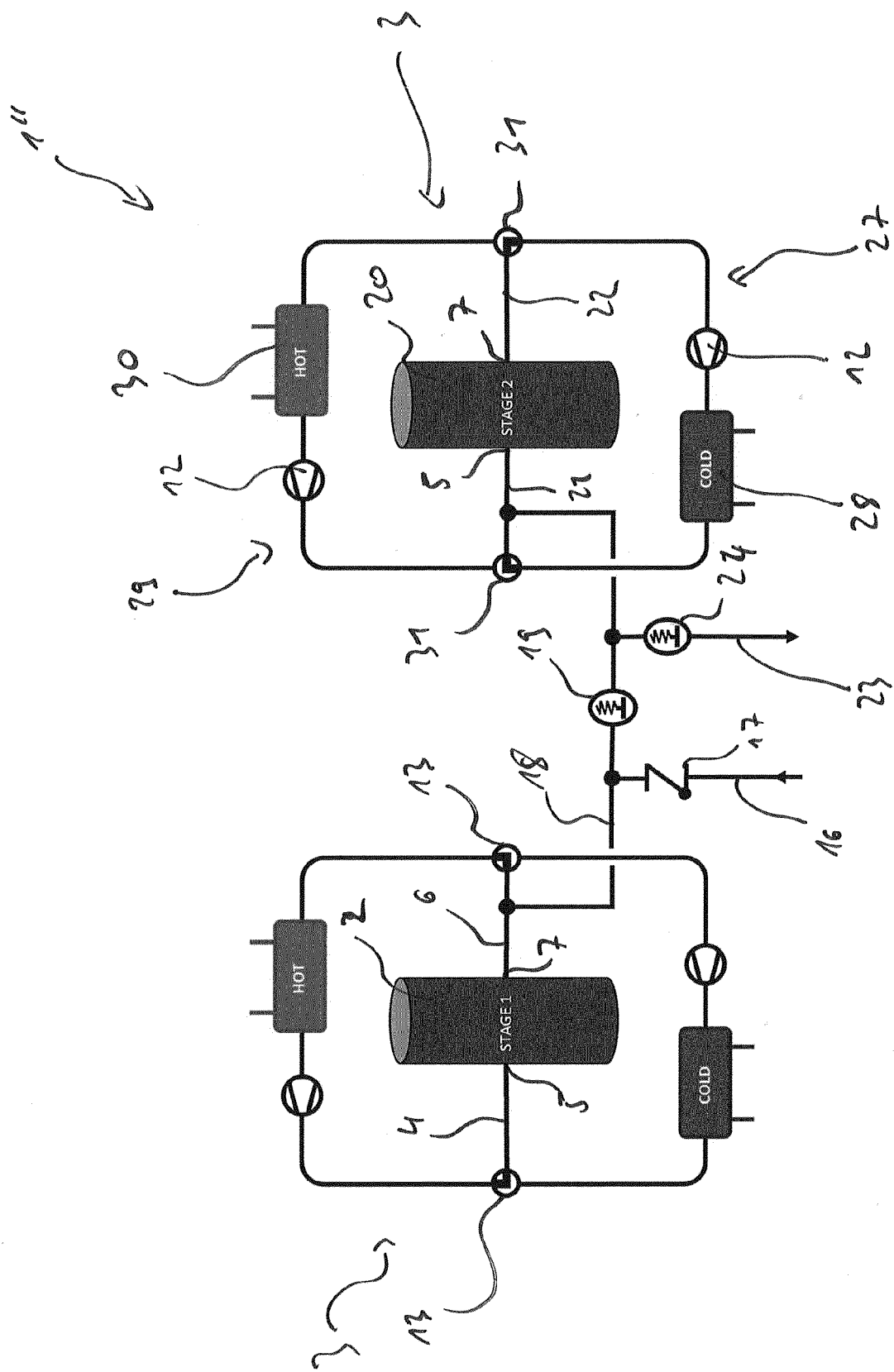


Fig. 3

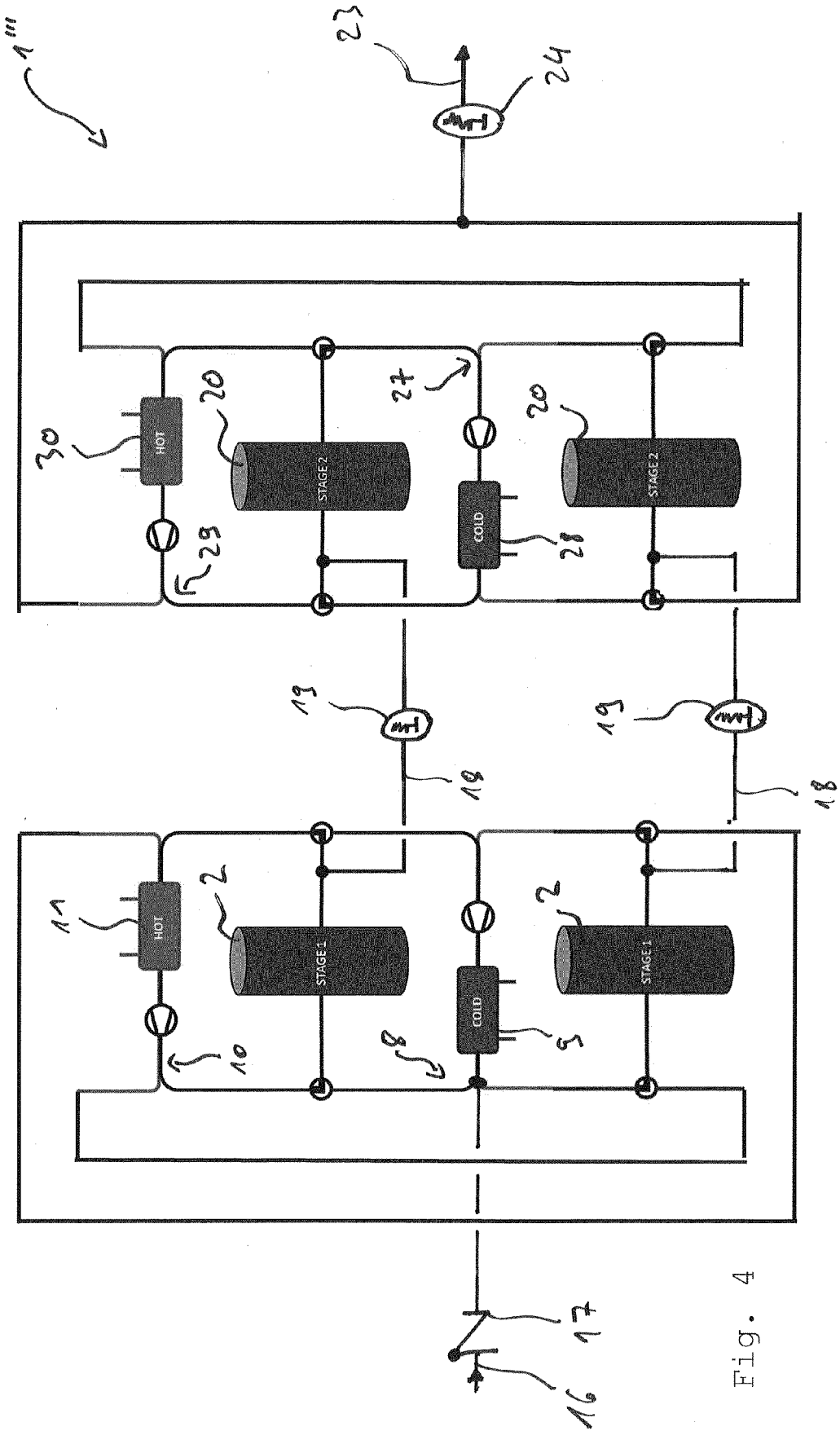


Fig. 4



EUROPEAN SEARCH REPORT

Application Number

EP 23 18 1241

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A	US 2022/364773 A1 (BAHAR BAMDAD [US] ET AL) 17 November 2022 (2022-11-17) * paragraphs [0038], [0091], [0095], [0104] - [0106]; figures 15-19 * -----	1-19	
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The present search report has been drawn up for all claims			TECHNICAL FIELDS SEARCHED (IPC) F04B F25B
Place of search			Examiner
Munich			Pinna, Stefano
Date of completion of the search			
20 October 2023			
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20-10-2023

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[0006]