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(54) **SYSTEM BASED ON INDUCTION ENERGY FOR LIQUID HYDROGEN EVAPORATING AND HEATING INTO GAS HYDROGEN**

(57) System based on induction energy for liquid hydrogen evaporating and heating into gas hydrogen, comprising a module (1) with an inlet (2) for liquid hydrogen and an outlet (3) for gas hydrogen, the inlet (2) and the outlet (3) being joined by a hydrogen pipe (4) that crosses the module (1), in which the induction energy is provided by an induction power supply unit (5), that additionally

comprises a heat station (6) that provides heat to the hydrogen pipe (4) through a heat exchanger (7) and provides energy to the induction power supply unit (5), the liquid hydrogen being the cooling fluid for the heat station (6), such that the induction power supply unit (5) provides induction energy to the hydrogen pipe (4) to heat the liquid hydrogen into gas hydrogen.

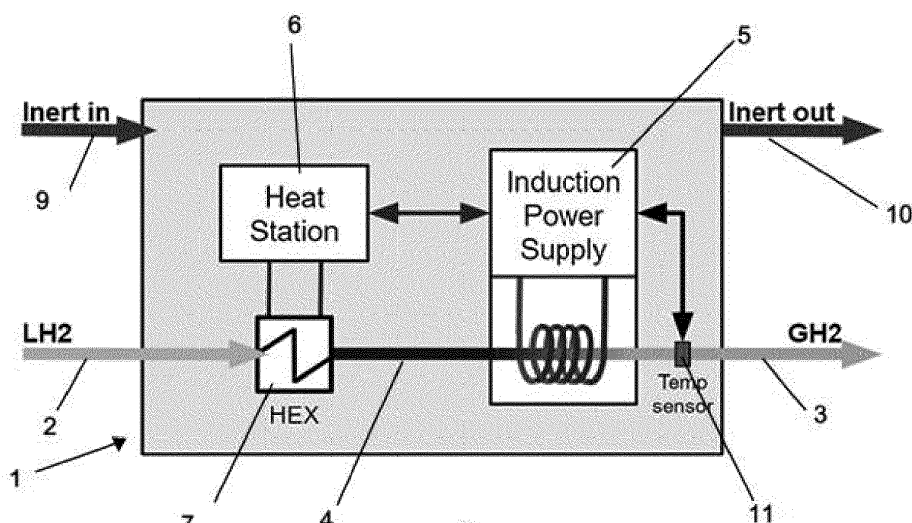


FIG. 1

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F17C 2265/066; F17C 2270/0189;
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Description

Field of the invention

[0001] This invention refers to a system based on induction energy for liquid hydrogen evaporating and heating into gas hydrogen to be used, in particular, in systems that use hydrogen as a fuel in aircraft.

Background of the invention

[0002] The decarbonization path in the aircraft industry includes the use of hydrogen as a fuel in the aircraft. The Auxiliary Power Units (APU) are provided with liquid cryogenic hydrogen (LH2), which must be conditioned to gas at ambient temperature (GH2) in order to be used in the combustion process.

[0003] The process to condition the LH2 during the starting process is very complex and requires the use of different heat exchangers, evaporators, valves and recirculation circuits.

[0004] One of the scenarios study the use of APUs during emergencies, requiring the starting time for the APU to be as short as possible in order to quickly provide electrical and/or pneumatic power to the aircraft.

[0005] The emergency scenarios can occur during flight when the APU is switched off and the H2 condition system is at low temperatures. In this case an external heat source is required to quickly warm up the H2 required to feed the APU during the starting phase until the H2 condition system reaches the nominal conditions.

[0006] As for induction energy, one of its best known uses is induction cooking, which is performed using direct induction heating of cooking vessels, rather than relying on indirect radiation, convection, or thermal conduction. Induction cooking allows high power and very rapid increases in the temperature to be achieved, and changes in heat settings are instantaneous.

[0007] In an induction stove (or "induction hob"), a cooking vessel is placed on top of a coil of copper wire with an alternating electric current passing through it. The resulting oscillating magnetic field wirelessly induces an electrical current in the vessel. This large eddy current flowing through the resistance of the vessel results in resistive heating.

[0008] In emergency situations it is necessary to perform a very fast APU start to provide power to the aircraft. As the H2 is provided at cryogenic temperatures, when the APU is switched off, the H2 condition system is at low temperatures, leading to the need of high energy and time to warm up the system.

[0009] US2007193717A1 discloses a heat exchanger for hydrogen-operated fuel supply systems. A fuel supply system for an internal combustion engine operable using hydrogen and/or for a fuel cell includes a hydrogen tank, which is provided for storing deep-cooled, liquid hydrogen, and a heat exchanger, which is provided for pre-heating the deep-cooled hydrogen. The heat exchanger

is enclosed by a fluid-tight mantle. An intermediate space is provided between the heat exchanger and the mantle, which has a fluid flowing through it, which delivers heat to the heat exchanger and insulates the heat exchanger in relation to the surroundings.

[0010] However, in case of emergency the fluid in the intermediate space that transfers heat cannot do it fast enough.

[0011] Accordingly, there is a need for a system based on induction energy that is able to provide an evaporation of liquid hydrogen and heating into gas hydrogen quick enough to be able to be used in APUs during emergencies.

Summary of the invention

[0012] The object of the present invention is to provide a system based on induction energy for liquid hydrogen evaporating and heating into gas hydrogen that is able to solve the mentioned drawback.

[0013] The invention provides a system based on induction energy for liquid hydrogen evaporating and heating into gas hydrogen, comprising a module with an inlet for liquid hydrogen and an outlet for gas hydrogen, the inlet and the outlet being joined by a hydrogen pipe that crosses the module, in which the induction energy is provided by an induction power supply unit, that additionally comprises a heat station that provides heat to the hydrogen pipe through a heat exchanger and provides energy to the induction power supply unit, the liquid hydrogen being the cooling fluid for the heat station, such that the induction power supply unit provides induction energy to the hydrogen pipe to heat the liquid hydrogen into gas hydrogen.

[0014] In this way it is possible to obtain a very fast heating of the liquid hydrogen thanks to the induction performance.

[0015] The invention offers the following additional advantages:

- Minimum energy losses during induction phase.
- Improves the system performance and efficiency by minimizing losses.
- Lower energy consumption leads to reduction of the battery size and weight.

[0016] Other characteristics and advantages of the present invention will be clear from the following detailed description of several embodiments illustrative of its object in relation to the attached figures.

Brief description of the drawings

[0017]

Figure 1 shows a schematic representation of an em-

bodiment of the system of the invention.

Figure 2 shows a schematic representation of a second embodiment of the system of the invention.

Figure 3 shows an induction heat exchanger used in the second embodiment of the system of the invention.

Figure 4 shows an arrangement of induction means in the induction heat exchanger.

Figure 5 shows a schematic representation of another embodiment of the system of the invention.

Figure 6 shows a schematic representation of another embodiment of the system of the invention.

Detailed description of the invention

[0018] Figure 1 shows a schematic representation of an embodiment of a system of the invention based on induction energy for liquid hydrogen evaporating and heating into gas hydrogen, for instance up to ambient temperatures (about 15°C).

[0019] The system comprises these components: an inlet 2 for liquid hydrogen, an outlet 3 for gas hydrogen, a hydrogen pipe 4, a heat station 6, an induction power supply unit 5 and a heat exchanger 7. A module 1 comprises at least an inlet 2 for liquid hydrogen and an outlet 3 for gas hydrogen, the inlet 2 and the outlet 3 being joined by a hydrogen pipe 4 that crosses the module 1. In the embodiment of the system of Figure 1, the induction power supply unit 5, the heat station 6 and the heat exchanger 7 are inside the module 1.

[0020] The inlet 2 and the outlet 3 are joined by the hydrogen pipe 4 that crosses the module 1. The induction energy is provided by the induction power supply unit 5. The heat station 6 provides heat to the hydrogen pipe 4 through the heat exchanger 7 and provides energy to the induction power supply unit 5. The liquid hydrogen is the cooling fluid for the heat station 6, and the induction power supply unit 5 provides induction energy directly to the hydrogen pipe 4 to heat the liquid hydrogen into gas hydrogen.

[0021] At ambient pressure (101325 Pa) it is required that the induction power supply unit 5 supplies a power of 1 kW per 1 kg/h of H₂ flow in order to evaporate the liquid hydrogen (-253°C) and heat it into gas hydrogen up to ambient temperatures (15°C). The power supply is required to be controlled in the order of milliseconds (ie: 50ms) to be able to adapt the temperature of the H₂ very rapidly and to avoid the H₂ pipe 4 overheating.

[0022] The use of the hydrogen flow at low temperatures as a cooling fluid of the heat station 6 avoids the need of an additional cooling system.

[0023] Figure 2 shows a schematic representation of a second embodiment of a system of the invention based

on induction energy for liquid hydrogen evaporating and heating into gas hydrogen, for instance up to ambient temperatures (about 15°C).

[0024] The system comprises these components: an inlet 2 for liquid hydrogen, an outlet 3 for gas hydrogen, a hydrogen pipe 4, a heat station 6, an induction power supply unit 5, a heat exchanger 7 and an induction heat exchanger 8. A module 1 comprises at least an inlet 2 for liquid hydrogen and an outlet 3 for gas hydrogen, the inlet 2 and the outlet 3 being joined by a hydrogen pipe 4 that crosses the module 1. In the embodiment of the system of Figure 2, the induction power supply unit 5, the heat station 6, the heat exchanger 7 and the induction heat exchanger 8 are inside the module 1.

[0025] The inlet 2 and the outlet 3 are joined by the hydrogen pipe 4 that crosses the module 1. The induction energy is provided by the induction power supply unit 5. The heat station 6 provides heat to the hydrogen pipe 4 through the heat exchanger 7 and provides energy to the induction power supply unit 5. The liquid hydrogen is the cooling fluid for the heat station 6, and the induction power supply unit 5 provides induction energy to the hydrogen pipe 4 to heat the liquid hydrogen into gas hydrogen through the induction heat exchanger 8 comprising integrated induction energy means.

[0026] In both embodiments, the induction heat exchanger 8 can be provided with isolation means to improve induction effectiveness.

[0027] The system can also be provided with an inlet port 9 and an outlet port 10 for an inert flow (as enriched Nitrogen) which will ventilate the internal volume of the component in order to remove any hydrogen leakage and also to keep a low internal temperature. The inert flow will be collected at the inert outlet port 10.

[0028] The system can also be provided with a temperature sensor 11 at the hydrogen outlet port 3 in order to actively control the induction power supply unit 5 to meet the target outlet temperature. The outlet temperature can be a fixed value or variable as demanded by the aircraft system.

[0029] The system can be provided with a built in test function to check the component functional status.

[0030] Figures 3 and 4 refer to the induction heat exchanger 8 used in the second embodiment of the system of the invention.

[0031] Figure 4 shows an arrangement of induction means in the induction heat exchanger 8, with the areas of energy induction.

[0032] The induction energy means can be integrated in the body of the induction heat exchanger 8.

[0033] The induction energy means can also be fixed to the structure of the heat exchanger by adhesive means or welding.

[0034] The pipe and/or induction heat exchanger 8 will be made of, or contain, a ferrous metal such as cast iron or some stainless steel with the minimum dimension to provide enough resistance to current flow.

[0035] The pipe and/or induction heat exchanger 8 will

be provided with the components to provide energy by induction to the metal in contact with the fluid to be heated.

[0036] The pipe and/or induction heat exchanger 8 can incorporate the evaporator process.

[0037] The induction heat exchanger geometry is not limited, so the induction system will be adapted to the geometry.

[0038] New techniques of manufacturing process such as Additive Layer Manufacturing ALM, diffusion bonded, etc. will be used to adapt the induction system to the induction heat exchanger geometry.

[0039] The geometry can be adapted to any type of heat exchanger by integrating the induction elements in the appropriate location to provide the energy directly to the material in contact with the fluid to be heated.

[0040] The system can be designed to heat not only cryogenic hydrogen at liquid state, but also hydrogen at very low temperatures at gas state (ie. H₂ temperatures above 30K). The invention is also not limited to hydrogen and can be applicable to any fluid able to be heated through the described process.

[0041] Figure 5 shows a schematic representation of another embodiment of the system of the invention, in which the induction power supply unit 5 and the heat station 6 are outside the module 1.

[0042] Figure 6 shows a schematic representation of another embodiment of the system of the invention, in which the induction power supply unit 5 is inside the module 1 and the heat station 6 is outside the module 1.

[0043] Although the present invention has been fully described in connection with preferred embodiments, it is evident that modifications may be introduced within the scope thereof, not considering this as limited by these embodiments, but by the contents of the following claims.

Claims

1. System based on induction energy for liquid hydrogen evaporating and heating into gas hydrogen, comprising a module (1) with an inlet (2) for liquid hydrogen and an outlet (3) for gas hydrogen, the inlet (2) and the outlet (3) being joined by a hydrogen pipe (4) that crosses the module (1), in which the induction energy is provided by an induction power supply unit (5), **characterized in that** it additionally comprises a heat station (6) that provides heat to the hydrogen pipe (4) through a heat exchanger (7) and provides energy to the induction power supply unit (5), the liquid hydrogen being the cooling fluid for the heat station (6), such that the induction power supply unit (5) provides induction energy to the hydrogen pipe (4) to heat the liquid hydrogen into gas hydrogen.
2. System based on induction energy for liquid hydrogen evaporating and heating into gas hydrogen according to claim 1, wherein the induction power supply unit (5) provides induction energy directly to the hydrogen pipe (4) to heat the liquid hydrogen into gas hydrogen.
3. System based on induction energy for liquid hydrogen evaporating and heating into gas hydrogen according to claim 1, wherein the induction power supply unit (5) provides induction energy to the hydrogen pipe (4) to heat the liquid hydrogen into gas hydrogen through an induction heat exchanger (8) comprising integrated induction energy means.
4. System based on induction energy for liquid hydrogen evaporating and heating into gas hydrogen according to claim 3, wherein the induction energy means are integrated in the body of the induction heat exchanger (8).
5. System based on induction energy for liquid hydrogen evaporating and heating into gas hydrogen according to claim 3, wherein the induction energy means are fixed to the structure of the induction heat exchanger (8) by adhesive means or welding.
6. System based on induction energy for liquid hydrogen evaporating and heating into gas hydrogen according to claim 3, 4 or 5, wherein the induction heat exchanger (8) is provided with isolation means.
7. System based on induction energy for liquid hydrogen evaporating and heating into gas hydrogen according to any of the previous claims, that additionally comprises an inlet port (9) and an outlet port (10) for an inert flow.
8. System based on induction energy for liquid hydrogen evaporating and heating into gas hydrogen according to any of the previous claims, that additionally comprises a temperature sensor (11) at the outlet for gas hydrogen.
9. System based on induction energy for liquid hydrogen evaporating and heating into gas hydrogen according to any of the previous claims, wherein the hydrogen pipe (4) is, at least partially, made of a ferrous metal.
10. System based on induction energy for liquid hydrogen evaporating and heating into gas hydrogen according to claim 9, wherein the ferrous metal is cast iron or stainless steel.
11. System based on induction energy for liquid hydrogen evaporating and heating into gas hydrogen according to any of claims 3-10, wherein the induction heat exchanger (8) is, at least partially, made of a ferrous metal.

12. System based on induction energy for liquid hydrogen evaporating and heating into gas hydrogen according to claim 11, wherein the ferrous metal is cast iron or stainless steel. 5
13. System based on induction energy for liquid hydrogen evaporating and heating into gas hydrogen according to any of claims 2, 7, 8, 9, 10 or 12, wherein the induction power supply unit (5), the heat station (6) and the heat exchanger (7) are inside the module (1). 10
14. System based on induction energy for liquid hydrogen evaporating and heating into gas hydrogen according to any of claims 2, 7, 8, 9, 10 or 12, wherein the induction power supply unit (5) and the heat station (6) are outside the module (1), and the heat exchanger (7) is inside the module (1). 15
15. System based on induction energy for liquid hydrogen evaporating and heating into gas hydrogen according to any of claims 2, 7, 8, 9, 10 or 12, wherein the induction power supply unit (5) is inside the module (1), the heat station (6) is outside the module (1) and the heat exchanger (7) is inside the module (1). 20
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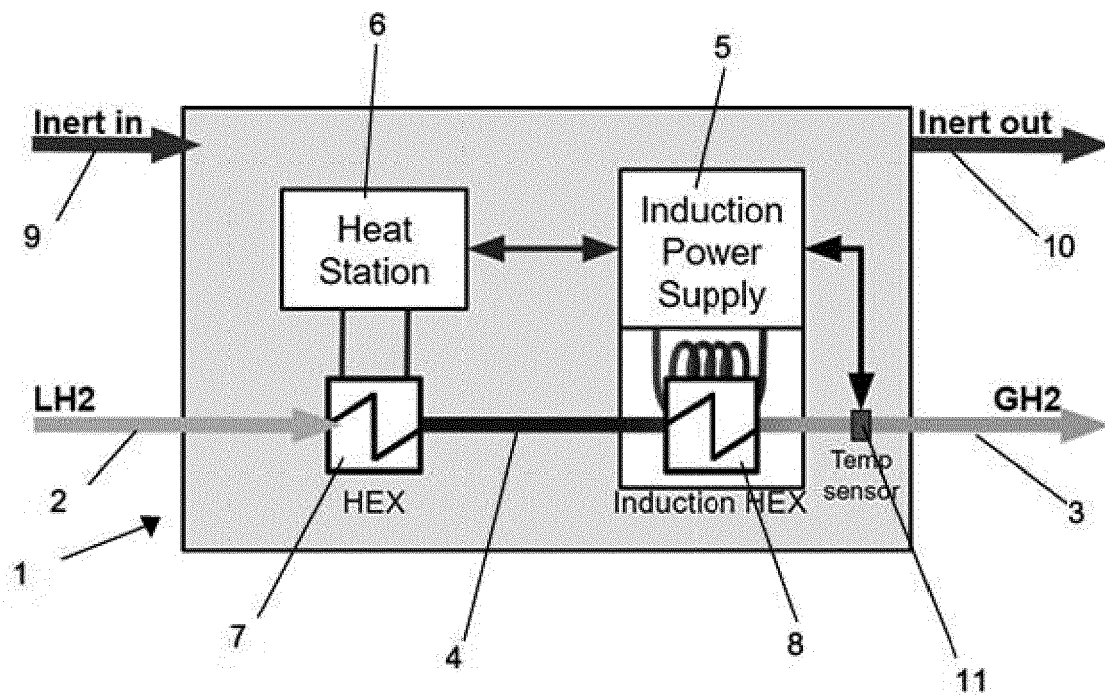
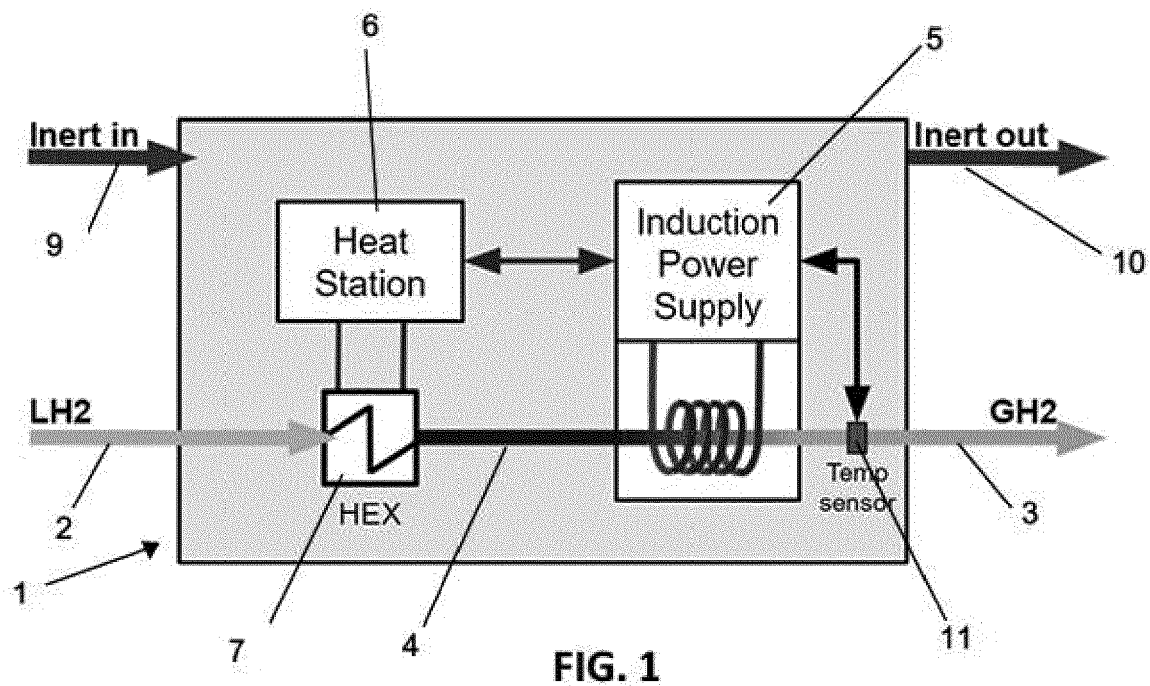


FIG. 2

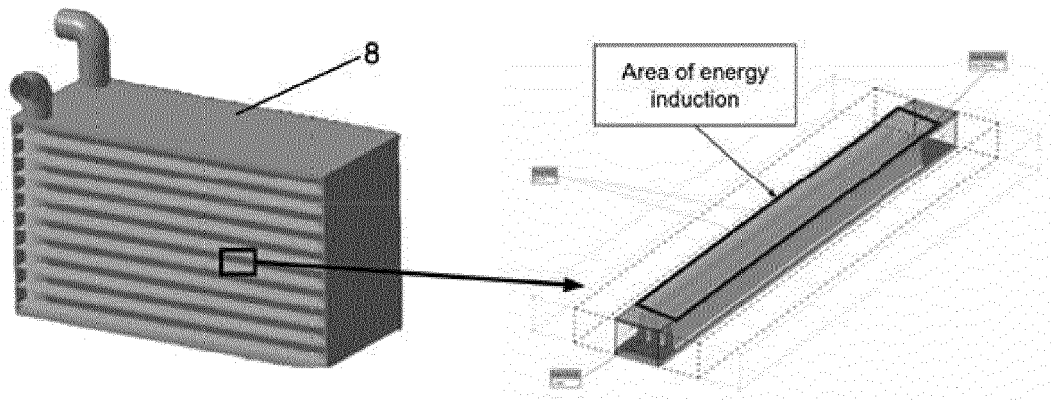


FIG. 3

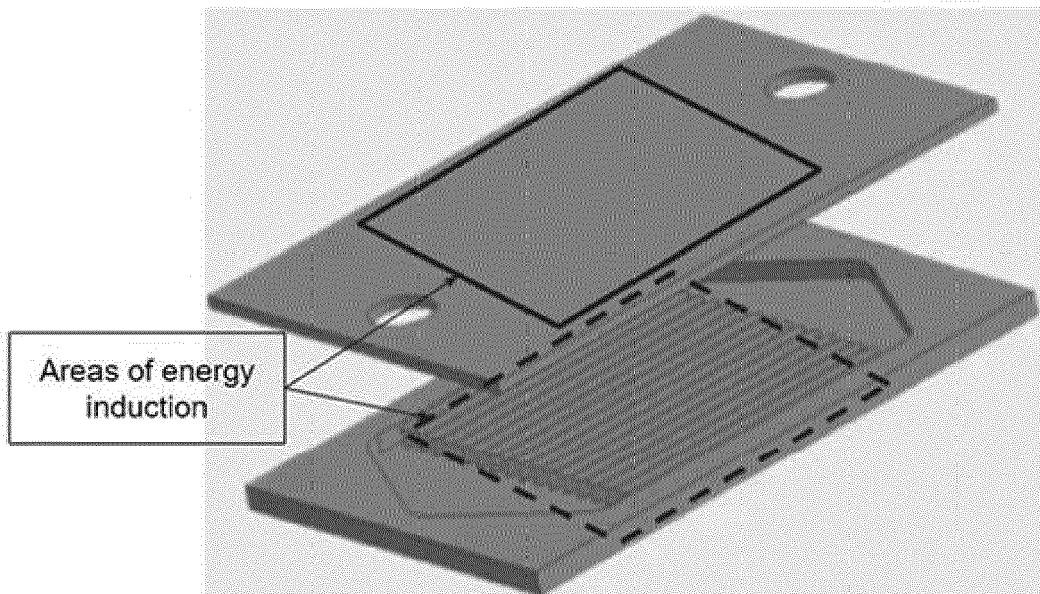
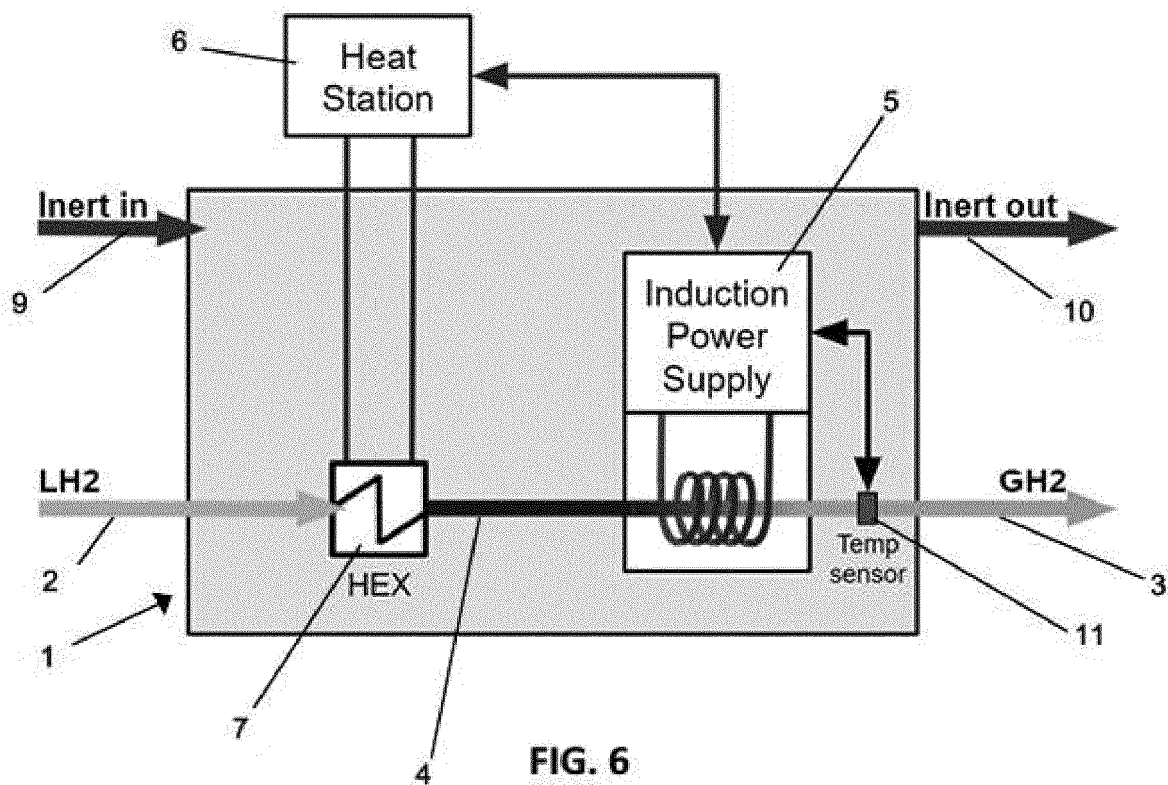
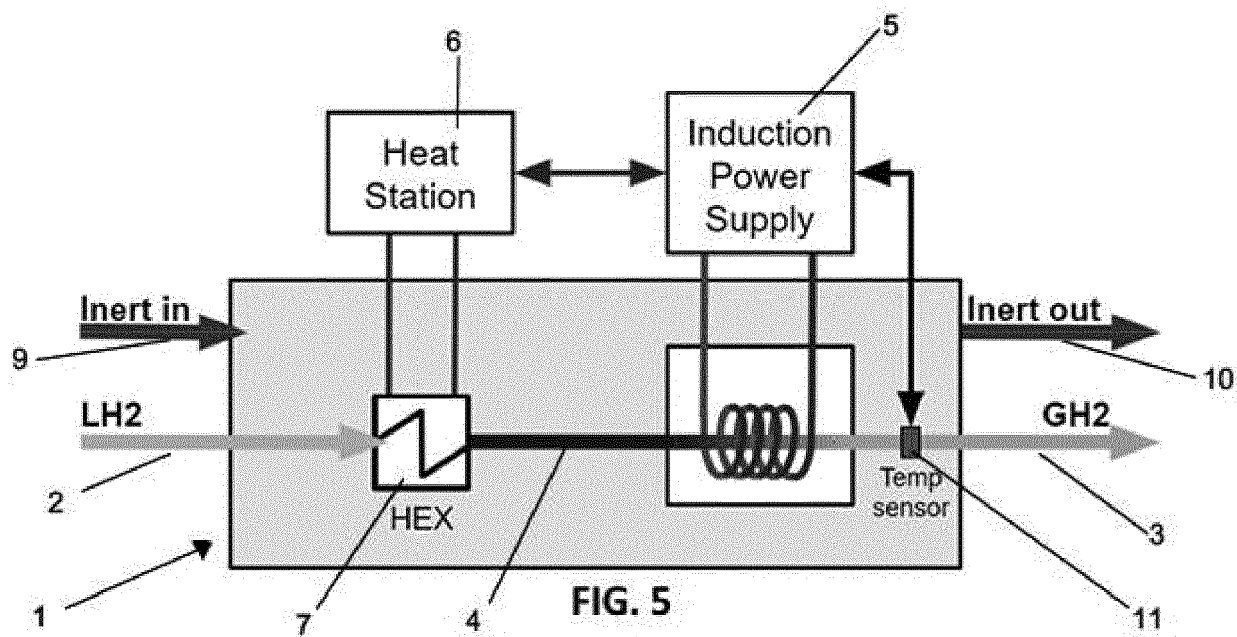


FIG. 4





EUROPEAN SEARCH REPORT

Application Number

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EPO FORM 1503 03.82 (P04C01)

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X	US 2018/180367 A1 (FOLK ROBERT [CA] ET AL) 28 June 2018 (2018-06-28) * abstract; figures * * page 3, paragraphs 59-61, 67-71 * * page 4, paragraph 75-78 * -----	1-15	INV. B01B1/00 F28D9/00 F02M21/02 F02M21/06 F17C7/04
A	US 2018/128211 A1 (PEREZ ALBERTO MARTIN [US]) 10 May 2018 (2018-05-10) * abstract; figures * * page 2, paragraph 32-33 * * page 3, paragraph 36-40 * * page 3, paragraph 48 * * page 4, paragraphs 53, 62 * * page 9, paragraph 149 * * page 10, paragraph 158 * -----	1-15	F17C9/02 F28D21/00 H05B6/10
A	US 2012/118878 A1 (KIM SEONG KYUN [KR] ET AL) 17 May 2012 (2012-05-17) * abstract; figures * * page 1, paragraph 5 * * page 1, paragraph 18 * * page 3, paragraphs 54, 55, 56 * -----	1-15	TECHNICAL FIELDS SEARCHED (IPC) B01B
The present search report has been drawn up for all claims			
Place of search The Hague		Date of completion of the search 15 November 2022	Examiner Lapeyrière, Jean
CATEGORY OF CITED DOCUMENTS X : particularly relevant if taken alone Y : particularly relevant if combined with another document of the same category A : technological background O : non-written disclosure P : intermediate document		T : theory or principle underlying the invention E : earlier patent document, but published on, or after the filing date D : document cited in the application L : document cited for other reasons & : member of the same patent family, corresponding document	

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