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(54) **HIGH EFFICIENCY ELECTROCHEMICAL INSTALLATION AND RELATED PROCESS**

(57) The installation (10), comprises
- an electrochemical unit (12) configured to carry out a high temperature electrochemical reaction, the unit (12) having a purified steam inlet (40), and at least a product outlet (44; 46); and
- a purified steam production unit (14), directly connected to the steam inlet (40), the purified steam production unit (14) comprising a first inlet (80) receiving a heating stream (60) from an industrial latent heat source (16), and a second inlet (82) receiving raw water (72) from a source (70) of raw water.

The purified steam production unit (14) comprises a heat exchange zone (76), configured to place the raw water (72) in heat exchange with the heating stream (60) and to evaporate the raw water (72) to produce the purified steam (24), at a purified steam outlet (84) connected to the purified steam inlet (40) without passing through a steam condensing unit.

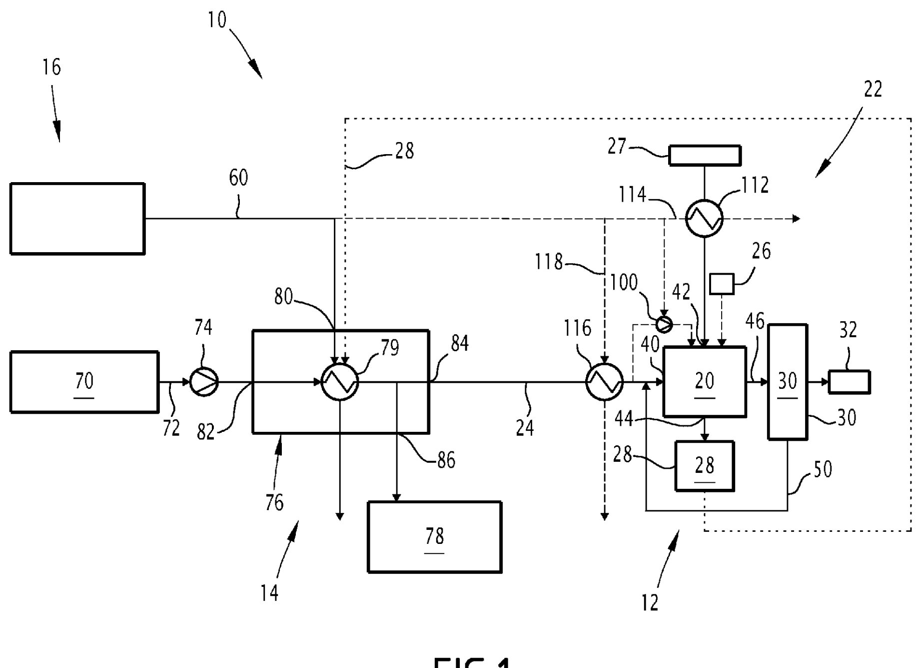

FIG.1

Processed by Luminess, 75001 PARIS (FR)

Description

[0001] The present invention concerns a high temperature electrochemical installation, comprising:

- a high temperature electrochemical unit configured to carry out a high temperature electrochemical reaction in which steam is converted into gaseous reaction products, the electrochemical unit having a purified steam inlet configured to receive purified steam, and at least a product outlet to deliver at least a gaseous reaction product of the electrochemical reaction.

[0002] The installation is intended to carry out a high yield water electrolysis to be able to generate hydrogen with great efficiency from electrical power. The installation is particularly adapted to produce hydrogen when the power produced by carbon-free sources of energy, such as renewable or nuclear sources, is not directly needed by the power grid to which the carbon-free energy source is connected.

[0003] The hydrogen can then be used to produce electrical power, for example in fuel cells, when carbon-free sources of energy do not operate or to complement the electrical power supplied by the carbon-free sources of energy if this power is not sufficient to supply the power grid. The hydrogen can also be used as a feedstock for other chemical processes.

[0004] While water electrolysis has been significantly optimized during the 20^{th} century, the quantity of hydrogen produced by this electrochemical reaction remains very low (4% of the world hydrogen production) as compared to grey hydrogen (96% of the world hydrogen production) mainly produced via steam methane reforming.

[0005] Nevertheless, water electrolysis is now critically needed in view of the development of large renewable power farms (e.g solar and/or wind farms) that are built or projected in order to power large electrolyzer plants.

[0006] The development of such wide scale plants makes possible a production of large amounts of "green" hydrogen. However, the economic viability of such plants requires lower production costs and thus, an improved overall energy efficiency of the process.

[0007] One of the electrolyzer technologies with the best electric efficiency is high-temperature electrolysis (HTE) such as solid-oxide electrolysis (SOEC). It generates hydrogen and oxygen from steam and electricity at high temperatures (generally from 650°C to 850°C).

[0008] The reactions occurring at the electrodes are:

Cathode (reduction): H2O(g) + 4e- = H2(g) + 2O2-
Anode (oxidation): 2 O2- = O2(g) + 4 e-

[0009] The electrolysis cells are assembled in series and form stacks. The stacks are coupled with a balance of plant (BOP) which manages all the incoming fluids (in particular steam, electricity, air/nitrogen) and outgoing fluids (hydrogen and oxygen).

[0010] High temperature electrolyzers operate with a good electric efficiency, for example in the order of 40 kWh/kg of produced hydrogen. This is especially noteworthy when compared to low temperature electrolyzers (alkaline or PEM technologies) for which, the electric energy required by the most efficient electrolyzer stacks ranges from 50 kWh/kg to 60 kWh/kg of produced hydrogen.

[0011] To reach optimized efficiencies, high temperature electrolyzers need to be fed with steam, whereas low temperature electrolyzers are configured to electrolyze liquid water. In the absence of source of "free" steam in the vicinity of the high-temperature electrolyzer, steam must be formed on site and the global energy yield is decreased, because the equivalent of 5kWh/kg of hydrogen is required to vaporize the liquid water into steam.

[0012] In addition, purified water, in particular desalinated water, must be used in the electrolyzers to avoid production issues. In the case of large water electrolysis plants, depending on location, a seawater desalination plant or a dirty water purification plant is required to produce enough purified water with the expected grade.

[0013] Seawater desalinization and more generally, water purification, is an energy extensive process, which requires at least a few kWh per meter cube of water.

[0014] Several water purification processes can be used. For instance, reverse osmosis is configured to convert electricity and seawater into concentrated brines and purified water. Other technologies use thermal energy to convert seawater into concentrated brines and purified water (multi-effect distillation, multi-stage flash distillation, direct contact evaporation, etc.).

[0015] Forming purified water to be used in an electrolysis process from seawater therefore requires desalinating the water, and condensing it for example by distillation. Such a process is also not energy efficient.

[0016] One aim of the invention is therefore to provide an electrochemical installation, in which the yield of electrolysis is further optimized, and which can nevertheless be used very efficiently with a source of raw water, in particular marine water or dirty water.

[0017] To this aim, the subject matter of claim is an electrochemical installation of the above-mentioned type, characterized by a purified steam production unit, directly connected to the steam inlet, the purified steam production unit comprising a first inlet to receive a heating stream transporting heat from an industrial latent heat source, a second inlet to receive raw water from a source of raw water;
the purified steam production unit comprising a raw water heat exchange zone, configured to place the raw water in heat exchange with the heating stream and to at least partially evaporate the raw water to produce the purified steam, at a purified steam outlet, the purified steam outlet being connected to the purified steam inlet without passing through a steam condensing unit.

[0018] The electrochemical installation according to the invention may comprise one or more of the following feature(s), taken solely, or according to any technical feasible combination:

- the heat exchange zone comprises at least a boiler receiving the raw water and the heating stream, the boiler being configured to place the raw water and the heating stream in indirect heat exchange;
- the heat exchange zone comprises at least a direct contact evaporation zone configured to place into direct contact a gaseous stream heated by the heating stream with the raw water, the electrochemical installation comprising an upstream heat exchanger configured to heat the gaseous stream by indirect heat exchange with the heating stream;
- the heat exchange zone comprises a distillation stage of a thermal desalination system chosen among a multi-effect distillation device, heated by the heating stream, a multistage flash distillation device heated by the heating stream, a mechanical vapor compression device, heated by the heating stream, and/or a thermal vapor compression device, heated by the heating stream, the thermal desalination system being without a liquefaction stage;
- the latent heat source comprises a solar concentrator, the heating fluid being a heat transfer fluid heated in the solar concentrator, or being heated by heat exchange with a heat transfer fluid heated in the solar concentrator;
- the latent heat source is a nuclear fuel source and/or an industrial heat source from a metal transforming plant, the heating stream being directly and/or indirectly heated with the latent heat source;
- the latent heat source is a chemical reactor in which an exothermic chemical reaction is carried out, in particular a synthesis of ammonia for example through a Haber-Bosch process and/or a synthesis of methanol, the heating stream being a cooling stream heated by thermal power received from the exothermic chemical reaction;
- the electrochemical installation comprises a thermo-compressor, interposed between the purified stream production unit and the high temperature electrochemical reaction unit to compress the purified steam produced by the purified stream production unit;
- the electrochemical reaction unit comprises an air inlet, the electrochemical installation comprising at least an air heating heat exchanger, configured to place into a heat exchange relationship, a first heating flow derived of the heating stream with air to be introduced into the air inlet;
- the electrochemical installation comprises a supplementary heat exchanger interposed between the purified stream production unit and the high temperature electrochemical reaction unit, configured to place into a heat exchange relationship, a supplementary heating flow derived of the heating stream with purified steam recovered at the steam outlet;
- the electrochemical installation comprises a gas turbine interposed between the purified steam outlet and the purified steam inlet of the high temperature electrochemical reaction unit, the gas turbine being able to produce electricity provided to the high temperature electrochemical unit;
- raw water is marine water, in particular sea water, and/or is dirty water;
- the high temperature electrochemical reaction unit comprises solid oxide electrolysis cells, protonic ceramic electrolysis cells, and/or co-electrolysis cells.

[0019] The invention also concerns a high temperature electrochemical process, comprising the following steps:

- carrying out, in a high temperature electrochemical unit, a high temperature electrochemical reaction converting steam into gaseous reaction products, the electrochemical unit having a purified steam inlet receiving purified steam, and at least a product outlet delivering at least a gaseous reaction product of the electrochemical reaction;

    characterized by receiving, at a first inlet of a purified steam production unit directly connected to the steam inlet, a heating stream transporting heat from an industrial latent heat source, and receiving raw water from a source of raw water at a second inlet;
    placing the raw water in heat exchange with the heating stream at a raw water heat exchange zone of the purified steam production unit, and at least partially evaporating the raw water to produce the purified steam, at a purified steam outlet, the purified steam being conducted from the purified steam outlet to the purified steam inlet without passing through a condensing unit.

[0020] The process according to the invention may comprise one or more of the following features, taken solely or according to any technical feasible combination:

- the temperature of the electrochemical reaction is above 350°C, preferably around 550°C and is optionnally comprised between 650°C and 850°C.

[0021] The invention will be better understood, based on the following description, given solely as an example, and made in reference to the appended drawings, in which:

- [Fig.1] Figure 1 is a schematic flow chart of a first high temperature electrochemical installation according to the invention ;
- [Fig.2] Figure 2 is a view similar to figure 1 of a second electrochemical installation according to the invention ;
- [Fig.3] Figure 3 is a view similar to figure 1 of a third electrochemical installation according to the invention ;
- [Fig.4] Figure 4 is a view similar to figure 1 of a fourth electrochemical installation according to the invention.

[0022] A first electrochemical installation 10 according to the invention is schematically shown in figure 1.

[0023] The installation 10 is for example intended to carry out an electrolysis of steam produced from a source of raw water.

[0024] The installation 10 comprises a high temperature electrochemical unit 12, a purified steam production unit 14 to supply the high temperature electrochemical unit 12 with steam, and a latent heat source 16, to provide heating power to the purified steam production unit 14.

[0025] The high temperature electrochemical unit 12 comprises a high temperature electrolyzer 20 and a balance of plant 22 coupled to the high temperature electrolyzer 20 to provide the incoming utilities such as steam 24, electricity 26, and air 27 to the high temperature electrolyzer 20.

[0026] The balance of plant 22 is also configured to recover all the outgoing products, including an air/oxygen mixture 28 and a hydrogen/water mixture 30 to be separated and purified into hydrogen 32.

[0027] Preferably, the high temperature electrolyzer 20 comprises solid oxide electrolysis cells (SOEC) or proton-conducting ceramic membrane cells which are able to operate at high temperatures. In the present disclosure, "high temperature" generally means temperatures above 350°C, more preferably above 550°C, and generally comprised between 650°C and 850°C.

[0028] The high temperature electrolyzer 20 comprises a plurality of cells which are assembled in series to constitute stacks. All the stacks are coupled with the balance of plant 22.

[0029] The high temperature electrolyzer 20 thus comprises at least a steam inlet 40, connected to the purified steam production unit 14, and at least an air inlet 42, connected to a source of air 27.

[0030] The high temperature electrolyzer 20 further comprises at least an oxygen mixture outlet 44, and a hydrogen mixture outlet 46 to recover the products of the electrolysis carried out into the cells of the electrolyzer 20.

[0031] Advantageously, the high temperature electrochemical unit 12 further comprises a recycling circuit 50, to recycle at least part of the steam separated from the hydrogen water mixture 30 to the steam inlet 40.

[0032] The latent heat source 16 is able to produce a heating stream 60 to be introduced in the purified steam production unit 14 as a source of thermal power.

[0033] The latent heat source 16 is for example a concentrated solar plant (CSP) able to heat a receiver (which is a heat-transfer fluid) to be used directly as a heating stream 60, or to heat exchange with the heating stream 60 to provide the heating stream 60 with thermal power.

[0034] The heat-transfer fluid/receiver acquires heat preferably by circulating into a concentrator of the solar farm, in which solar light is concentrated to heat the heat-fluid transfer fluid/receiver. The concentrator uses mirrors or/and lenses with a tracking system to focus a large area of sunlight into a small concentrated area. Concentrated solar technologies comprise for example parabolic trough, concentrated linear Fresnel reflectors, and/or solar power towers.

[0035] In a variant, the latent heat source is a nuclear power plant. The heating stream 60 is for example a stream that exchanges heat without contact with a primary fluid circulating into a nuclear power plant, the primary fluid being directly heated by a nuclear source.

[0036] In a variant, the heating stream 60 is heated by a secondary fluid of the nuclear plant. The secondary fluid is heated by heat transfer with a primary fluid heated directly by a nuclear source.

[0037] The nuclear plant is for example a small modular reactor (SMR), having an electrical power output of generally less than 1000 MW thermal.

[0038] In another variant, the latent heat source 16 is a chemical plant in which an exothermic reaction takes place. The heating stream 60 is for example directly produced by heat exchange with the reactor in which the exothermic reaction occurs, to cool down the reactor, or/and is produced by indirect heat exchange with a stream which cools down the reactor in which the exothermic reaction occurs.

[0039] An example of exothermic reaction carried out into a chemical plant is the production of methanol or ammonia, in particular with the Haber-Bosch process. The heating stream 60 is for example a water stream used as a cooling stream in the reactor.

[0040] In another variant, the latent heat source is a metal production unit comprised in a metal production plant. The heating stream 60 is produced directly from a cooling stream of the metal production plant, or indirectly by heat exchange with a cooling stream of the metal production plant.

[0041] In all cases, the heating stream 60 fed to the installation 10 has a temperature generally above 120°C and preferably comprised between 375°C and 2000°C.

[0042] The purified steam production unit 14 comprises a source 70 of raw water 72, at least a pump 74, to pump the raw water 72, and at least a heat exchange zone 76 to place in direct or indirect heat exchange the raw water 72 pumped by the pump 74, and the heating stream 60. The heat exchange zone 76 therefore produces purified steam 24, and a concentrate 78, for example brine.

[0043] Raw water 72 is for example marine water from a sea, an ocean or a lake.

[0044] The marine water is saline. It has a salt content greater than 1,000 ppm.

[0045] In a variant, the raw water 72 is dirty water. Dirty water is for example water issuing from waste or from an industrial process, a chemical process, an oil/mining process.

[0046] The dirty water comprises solids and/or liquid impurities. The salinity of the dirty water is for example greater than 1,000 ppm.

[0047] The purified steam produced by the purified steam production unit 14 preferably has a salt content smaller than 10 ppm, in particular smaller than 1,0 ppm.

[0048] The salt content may include NaCl but also other salts.

[0049] In the example of figure 1, the heat exchange zone 76 is an indirect heat exchange zone between the raw water 72 pumped with the pump 74 and the heating stream 60. The heat exchange zone 76 for example comprises a boiler 79, which receives the raw water 72 and which is heated by the heating stream 60. In a variant, it comprises a boiler/condenser/boiler assembly.

[0050] The heat exchange zone 76 comprises at least a first inlet 80, connected to the latent heat source 16 to receive the heating stream 60 and a second inlet 82, connected to the source 70 of raw water 72.

[0051] It further comprises a steam outlet 84 to collect the steam 24 produced by heat exchange from the heating stream 60 into the heat exchange zone 76 and a concentrate outlet 86 to collect the concentrate 78 resulting from the evaporation of steam 24.

[0052] According to the invention, the steam 24 produced at the heat exchange zone 76, and recovered at the steam outlet 84 is not condensed.

[0053] The steam 24 is directly injected without intermediate condensation at the steam inlet 40 of the high temperature electrolyzer 20.

[0054] Thus, the installation 10 does not require a steam condensation stage, as opposed to a traditional desalinating plant in which the steam produced by heating and/or distillation of the raw water is condensed.

[0055] Removing the condensation steps from the purification process and directly using steam 24 into the high temperature electrolyzer 20 makes it possible to directly benefit from the latent heat recovered in the heating stream 60 without having to reheat a purified liquid water which could be produced in a traditional desalinating plant.

[0056] The coupling between the latent heat source 16, and the purified stream production unit 14 according to the invention is hence extremely efficient to yield the high temperature steam 24 which is needed at the inlet 40 of the high temperature electrolyzer 20.

[0057] The high temperature electrolyzer 20 is therefore configured to operate at its optimal temperature, which increases the electrolysis yield and hence production of hydrogen from electrical power provided to the high temperature electrolyzer 20.

[0058] A first high temperature electrolysis process according to the invention, carried out in the electrochemical installation 10 according to the invention will now be described.

[0059] The process comprises the continuous supply of a heating stream 60 from a latent heat source 16, which can be a concentrated solar plant, a nuclear plant, a chemical plant, or a metal production plant, as described above.

[0060] The heating stream 60 is for example formed of pressurized water, glycol, molten salts, fluidized solid particles...

[0061] Its temperature is generally above 120°C and preferably comprised between 375 °C and 2000°C. The heating stream 60 is introduced in the heat exchange zone 76 of the purified steam production unit 14 via the first inlet 80.

[0062] Simultaneously, raw water 72, for example salty water from a marine source, or waste water is pumped via the pump 74 to the second inlet 82 of the heat exchange zone 76. The raw water 72 is heated above its evaporation temperature inside the heat exchange zone 76, which generates purified steam. Purified steam 24 is recovered at the steam outlet 84.

[0063] The temperature of the purified steam 24 recovered at the outlet 84 is for example greater than 100°C and is comprised between 100°C and 800°C. The pressure of the purified steam 24 is for example greater than 1 bar and is comprised between 1,0 bars and 50 bars.

[0064] The purified steam 24 is then directly introduced at the steam inlet 40, without being condensed. It may be mixed with a recycling stream arising from the recycling circuit 50.

[0065] At the concentrate outlet 86, a saline concentrate 78, for example brine, is recovered.

[0066] The purified steam 24 is a pure water stream. It has a salinity smaller than 10 ppm. It is therefore able to be used directly into the electrolyzer 20.

[0067] In the electrolyzer 20, the steam stream 24 is injected in the cathodic compartment while air is injected in the anodic compartment and electrical power is provided by a power source 26.

[0068] The electrolysis reaction is carried out at high temperature, namely above 350°C, more preferably above 550°C, and generally at a temperature comprised between 650°C and 850°C.

[0069] Hydrogen is produced at the cathode, and oxygen is produced at the anode.

[0070] An air/oxygen gaseous mixture 28 is recovered at outlet 44. The hydrogen/water mixture 30 is recovered at outlet 46, and is further separated into hydrogen 32, steam separated from the hydrogen water mixture 30 being recycled to the steam inlet.

[0071] In a variant shown in dotted line in figure 1, the balance of plant 22 further comprises a thermo-compressor 100 which is used to further compress the steam 24 or at least part of the steam 24 before introducing it into the electrolyzer 20.

[0072] The thermo-compressor 100 for example compresses at least part of the steam 24 at a pressure greater than 1.5 bar.

[0073] This helps reaching the required input pressure into the high temperature electrolyzer 20.

[0074] In another variant shown in figure 1, the air/oxygen mixture 28 recovered at the oxygen mixture outlet 44 is placed in heat exchange with the heating steam 60 arising from the latent heat source 16 and with the raw water 72 in the heat exchange zone 76. The air/oxygen mixture 28 transfers calories to the raw water in complement to the calories transferred by the heating stream 60.

[0075] At the inlet of the heat exchange zone 76, the air/oxygen mixture 28 for example has a temperature greater than 600°C and comprised between 650°C and 850°C.

[0076] In a variant, a heating heat exchanger 112 is provided in the balance of plant 22 to place in a heat exchange relationship a heating flux 114 sampled in the heating stream 60 with the flow of air 27 to be introduced in the electrolyzer 20 at the inlet 42.

[0077] The heating flux 114 provides thermal power to the air 27 to increase its temperature to above 250°C, before it is introduced at the inlet 42.

[0078] In a variant, the installation 10 further comprises a supplementary heat exchanger 116, which is interposed between the steam outlet 84 of the purified steam production unit 14 and the steam inlet 40 of the electrolyzer 20. The supplementary heat exchanger 116 places into heat exchange relationship, at least a heating flux 118 sampled in the heating stream 60 with the steam 24 produced at the outlet 84. This helps further heating the steam 24 to reach the required inlet temperature of the electrolyzer 20.

[0079] A second installation 150 according to the invention is shown in figure 2. As opposed to the installation of figure 1, the air/oxygen mixture 28 is preheated in an upstream heat exchanger 110 by heat exchange with the heating stream 60. The temperature of the heated air/oxygen mixture 152 at the outlet of the upstream heat exchanger 110 is for example greater than 400°C and comprised between 650°C and 850°C.

[0080] The heated air/oxygen mixture 152 is directly mixed with the raw water 72 to produce the purified steam from the raw water 72.

[0081] The heat exchange zone 76 is a direct heat exchange zone between the raw water 72 introduced at the second inlet 82, and the heated gaseous air/oxygen mixture 152 introduced at the first inlet 80.

[0082] The direct heat exchange zone 76 for example comprises a mixer 154, able to mix the heated air/oxygen mixture 152 with the raw water 72 to produce the purified steam 24, and the concentrate 78.

[0083] Just as in the installation 10 of figure 1, the purified steam 24 is discharged through the steam outlet 84, to be fed to the steam inlet 40 of the high temperature electrolyzer 20.

[0084] The direct contact heat exchange between the raw water 72 and the heated air/oxygen mixture 152 maximizes the efficiency of the heat exchange and thus, the quantity of steam produced from the raw water 72.

[0085] A third installation 160 according to the invention is shown in figure 3. As a difference from the first installation 10, the heat exchange zone 76 of the purified steam production unit 14 comprises a distillation stage 162 of a thermal desalination system without a liquefaction stage. The distillation stage 162 is for example a multiple-effect distillation (MED) comprising multiple stages or effects. In each stage, the raw water is heated by steam in tubes, usually by spraying saline water onto them. Some of the water evaporates and steam flows into the tubes of the next stage.

[0086] Each stage essentially reduces energy from the previous stage with successively lower temperatures and pressures after each one. In addition, the steam uses some heat to preheat the incoming saline water.

[0087] In a variant, the distillation stage 162 is a multi-stage flash distillation (MSF). The raw water 72 undergoes heat exchange with the heating stream 60, and then enters a succession of stages in which steam is produced at each stage.

[0088] Concentrate 78 is recovered at the last final stage, whereas all the steam 24 is collected, without being condensed. This is opposed to a traditional multi-stage flash desalinator, in which a condensation of the steam is carried out.

[0089] In a variant, the distillation stage is a vapor compression stage (VPC), in which the application of heat is delivered by compressed vapor. The vapor is for example compressed mechanically or thermally, preferentially under vacuum.

[0090] A fourth installation according to the invention 170 is shown in figure 4. The fourth installation 170 differs from any of the installations 10, 150, 160 described above in that it comprises an additional turbine 172 interposed between the steam outlet 84 of the purified steam production unit 14 and the steam inlet 40 of the high temperature electrolyzer 20.

[0091] The purified steam 24 passes through the turbine and drives the turbine 172 in rotation.

[0092] The rotation of the turbine 172 produces electricity, which is sent to the electrolyzer 20 as a complementary source of electrical power to carry out the electrolysis. This improves the global yield of the installation 170.

[0093] Thanks to the installations 10, 150, 160, 170 according to the invention, the coupling between the heat recovered from the latent heat source 16, the purification without condensation of the raw water 72 directly into steam, allows the steam 24 to be directly used into a high temperature electrolyzer 20 with a maximum energy efficiency.

[0094] The installation 10, 150, 160, 170 is operable with raw water made of marine water such as sea water, but also with waste or low-grade water.

[0095] An example of thermal gains obtained with the installations 10, 150, 160, 170 according to the invention is given thereafter. Considering the water splitting chemical reaction: $H_2O \rightarrow H_2 + 1/2\ O_2$ and the respective molar masses of H_2 (2 g/mol) and H_2O (18 g/mol), a mass ratio m(H2O)/m(H2) = 9 is needed. This means that for producing 1kg of H_2, 9kg of H_2O are needed.

[0096] With a latent heat of water vaporization of 2260 kJ/kg(H_2O), up to 2260 kJ/kg x 9= 20,3 MJ/kg(H_2) = 5,65 kWh/kg(H_2) energy is saved, which represents a gain of 12% in the water electrolysis process.

Claims

1. A high temperature electrochemical installation (10; 150; 160; 170), comprising:

   - a high temperature electrochemical unit (12) configured to carry out a high temperature electrochemical reaction in which steam (24) is converted into gaseous reaction products (28, 30), the electrochemical unit (12) having a purified steam inlet (40) configured to receive purified steam (24), and at least a product outlet (44; 46) to deliver at least a gaseous reaction product (28; 30) of the electrochemical reaction;

   characterized by a purified steam production unit (14), directly connected to the steam inlet (40), the purified steam production unit (14) comprising a first inlet (80) to receive a heating stream (60) transporting heat from an industrial latent heat source (16), and a second inlet (82) to receive raw water (72) from a source (70) of raw water;

   the purified steam production unit (14) comprising a raw water heat exchange zone (76), configured to place the raw water (72) in heat exchange with the heating stream (60) and to at least partially evaporate the raw water (72) to produce the purified steam (24), at a purified steam outlet (84), the purified steam outlet (84) being connected to the purified steam inlet (40) without passing through a steam condensing unit.

2. The electrochemical installation (10; 170) according to claim 1, wherein the heat exchange zone (76) comprises at least a boiler (79) receiving the raw water (72) and the heating stream (60), the boiler (79) being configured to place the raw water (72) and the heating stream (60) in indirect heat exchange.

3. The electrochemical installation (150; 170) according to any one of claims 1 or 2, wherein the heat exchange zone (76) comprises at least a direct contact evaporation zone configured to place into direct contact a gaseous stream (152) heated by the heating stream (60) with the raw water (72), the electrochemical installation (10) comprising an upstream heat exchanger (110) configured to heat the gaseous stream by indirect heat exchange with the heating stream (60).

4. The electrochemical installation (160; 170) according to any one of the preceding claims, wherein the heat exchange zone (76) comprises a distillation stage of a thermal desalination system chosen among a multi-effect distillation device, heated by the heating stream (60), a multistage flash distillation device heated by the heating stream (60), a mechanical vapor compression device, heated by the heating stream (60), and/or a thermal vapor compression device, heated by the heating stream (60), the thermal desalination system being without a liquefaction stage.

5. The electrochemical installation (10; 150; 160; 170) according to any one of the preceding claims, wherein the latent heat source (16) comprises a solar concentrator, the heating fluid (60) being a heat transfer fluid heated in the solar concentrator, or being heated by heat exchange with a heat transfer fluid heated in the solar concentrator.

6. The electrochemical installation (10; 150; 160; 170) according to any one of the preceding claims, wherein the latent heat source (16) is a nuclear fuel source and/or an industrial heat source from a metal transforming plant, the heating stream (60) being directly and/or indirectly heated with the latent heat source (16).

7. The electrochemical installation (10; 150; 160; 170) according to any one of the preceding claims, wherein the latent heat source (16) is a chemical reactor in which an exothermic chemical reaction is carried out, in particular a synthesis of ammonia for example through a Haber-Bosch process and/or a synthesis of methanol, the heating stream (60) being a cooling stream heated by thermal power received from the exothermic chemical reaction.

8. The electrochemical installation (10; 150; 160; 170) according to any one of the preceding claims comprising a thermo-compressor (100), interposed between the purified stream production unit (14) and the high temperature electrochemical reaction unit (12) to compress the purified steam (24) produced by the purified stream production unit (12).

9. The electrochemical installation (10; 150; 160; 170) according to any one of the preceding claims, wherein the electrochemical reaction unit (12) comprises an air inlet (42), the electrochemical installation (10; 150; 160; 170) comprising at least an air heating heat exchanger (112), configured to place into a heat exchange relationship, a first heating flow (114) derived of the heating stream (60) with air (27) to be introduced into the air inlet (42).

10. The electrochemical installation (10; 150; 160; 170) according to any one of the preceding claims, comprising a supplementary heat exchanger (116) interposed between the purified stream production unit (14) and the high temperature electrochemical reaction unit (12), configured to place into a heat exchange relationship, a supplementary heating flow (116) derived of the heating stream (60) with purified steam (24) recovered at the steam outlet (84).

11. The electrochemical installation (10; 150; 160; 170) according to any one of the preceding claims, comprising a gas turbine (172) interposed between the purified steam outlet (84) and the purified steam inlet (40) of the high temperature electrochemical reaction unit (12), the gas turbine (172) being able to produce electricity provided to the high temperature electrochemical unit (12).

12. The electrochemical installation (10; 150; 160; 170) according to any one of the preceding claims, wherein raw water (72) is marine water, in particular sea water, and/or is dirty water.

13. The electrochemical installation (10; 150; 160; 170) according to any one of the preceding claims, wherein the high temperature electrochemical reaction unit (12) comprises solid oxide electrolysis cells, protonic ceramic electrolysis cells, and/or co-electrolysis cells.

14. High temperature electrochemical process, comprising the following steps:

- carrying out, in a high temperature electrochemical unit (12), a high temperature electrochemical reaction converting steam (24) into gaseous reaction products (28, 30), the electrochemical unit (12) having a purified steam inlet (40) receiving purified steam (24), and at least a product outlet (44; 46) delivering at least a gaseous reaction product (28; 30) of the electrochemical reaction;

characterized by receiving, at a first inlet (80) of a purified steam production unit (14) directly connected to the steam inlet (40), a heating stream (60) transporting heat from an industrial latent heat source (16), and receiving raw water (72) from a source (70) of raw water at a second inlet (82);
placing the raw water (72) in heat exchange with the heating stream (60) at a raw water heat exchange zone (76) of the purified steam production unit (14), and at least partially evaporating the raw water (72) to produce the purified steam (24), at a purified steam outlet (84), the purified steam (24) being conducted from the purified steam outlet (84) to the purified steam inlet (40) without passing through a condensing unit.

15. The electrochemical process according to claim 14, wherein the temperature of the electrochemical reaction is above 350°C, preferably around 550°C and is optionnally comprised between 650°C and 850°C.

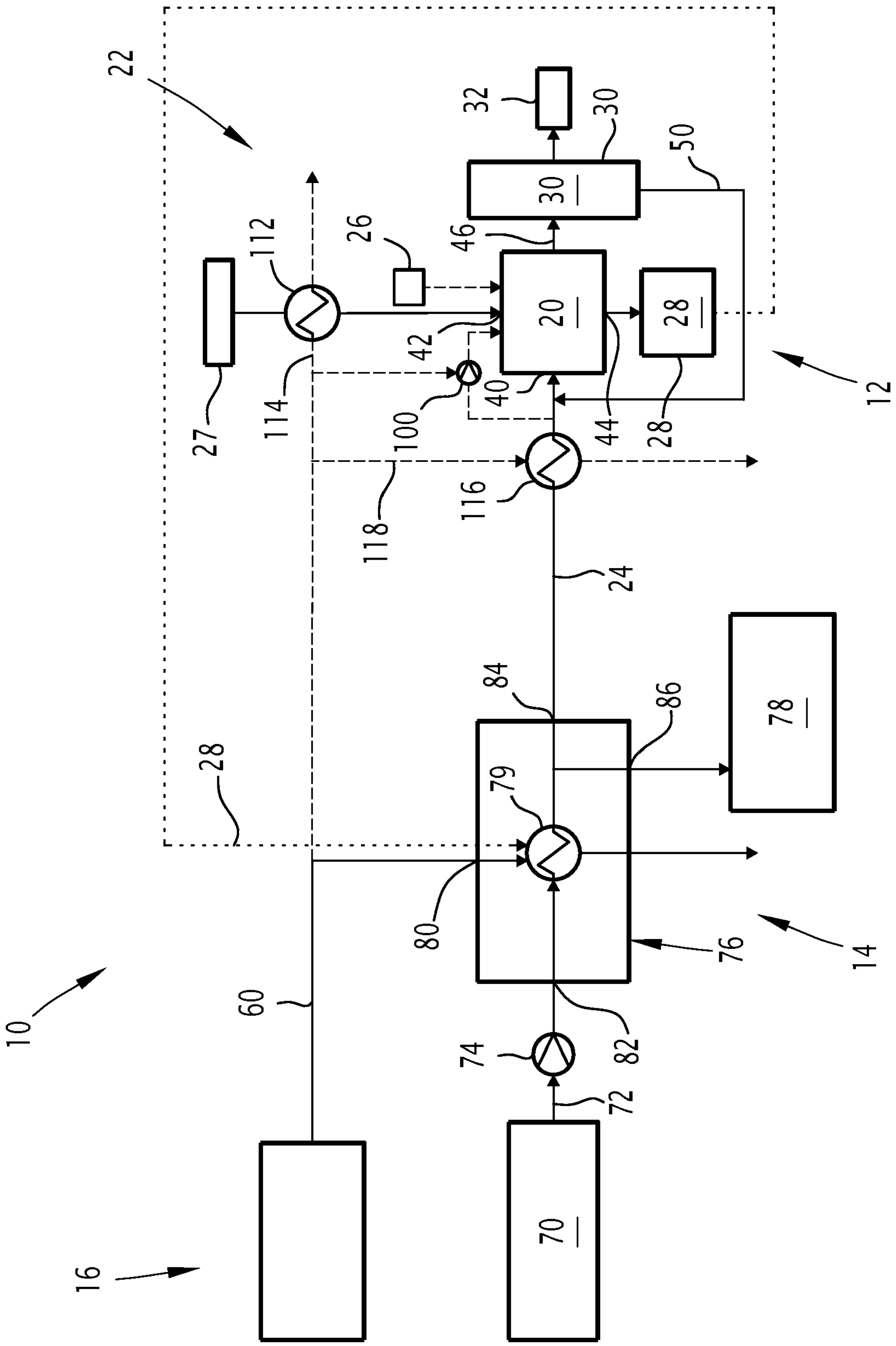
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FIG.1

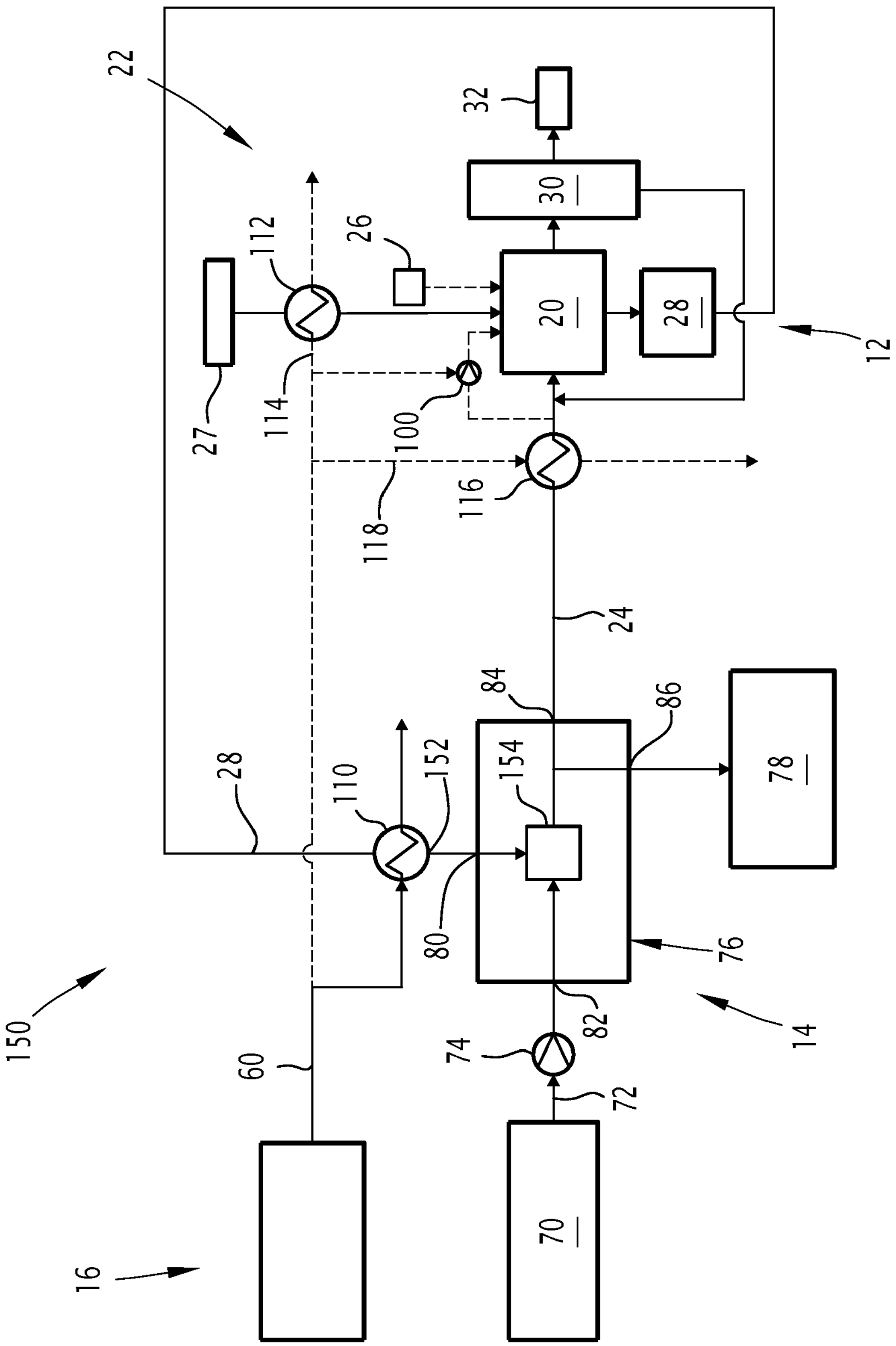
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FIG.2

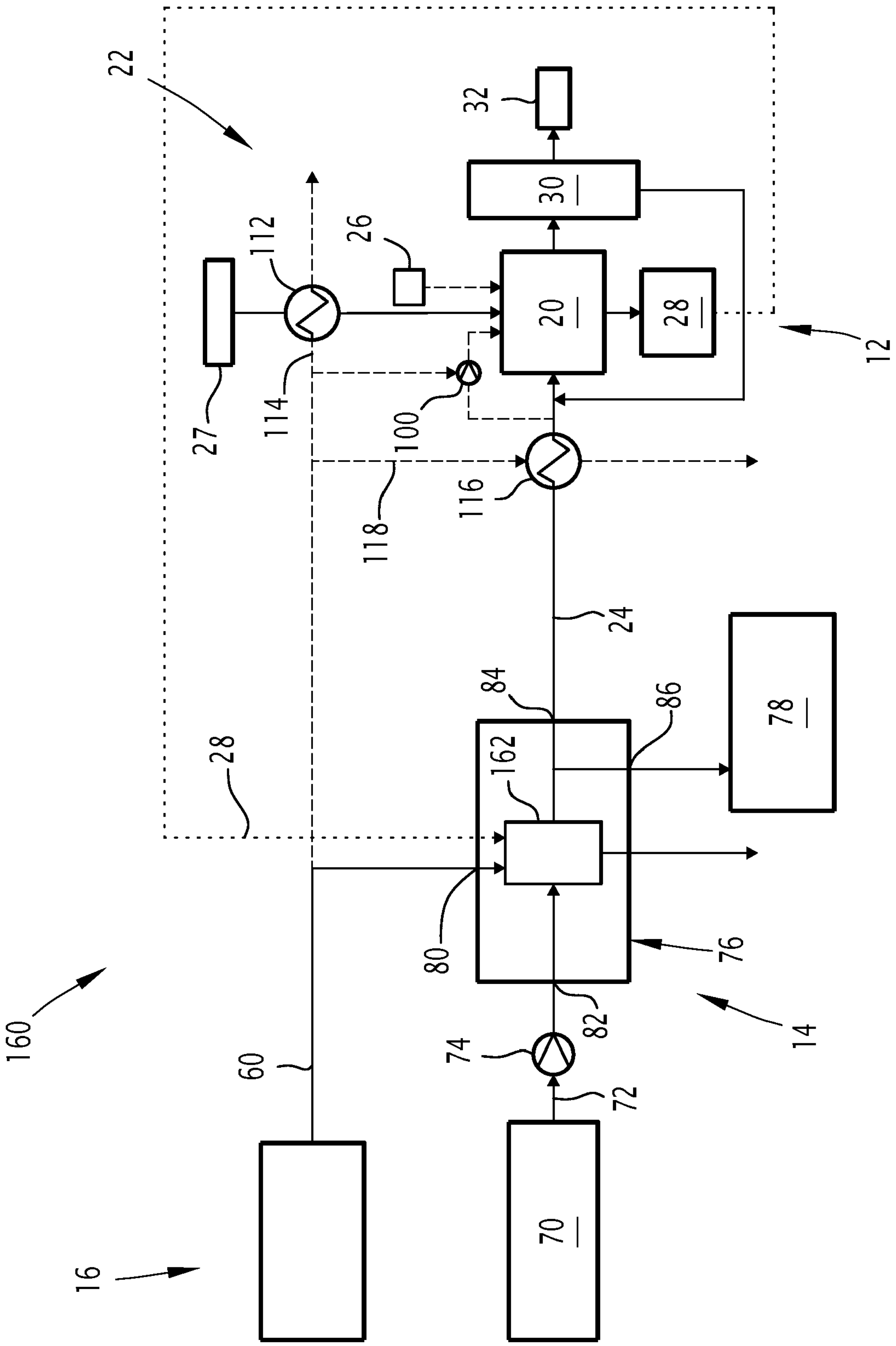
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FIG.3

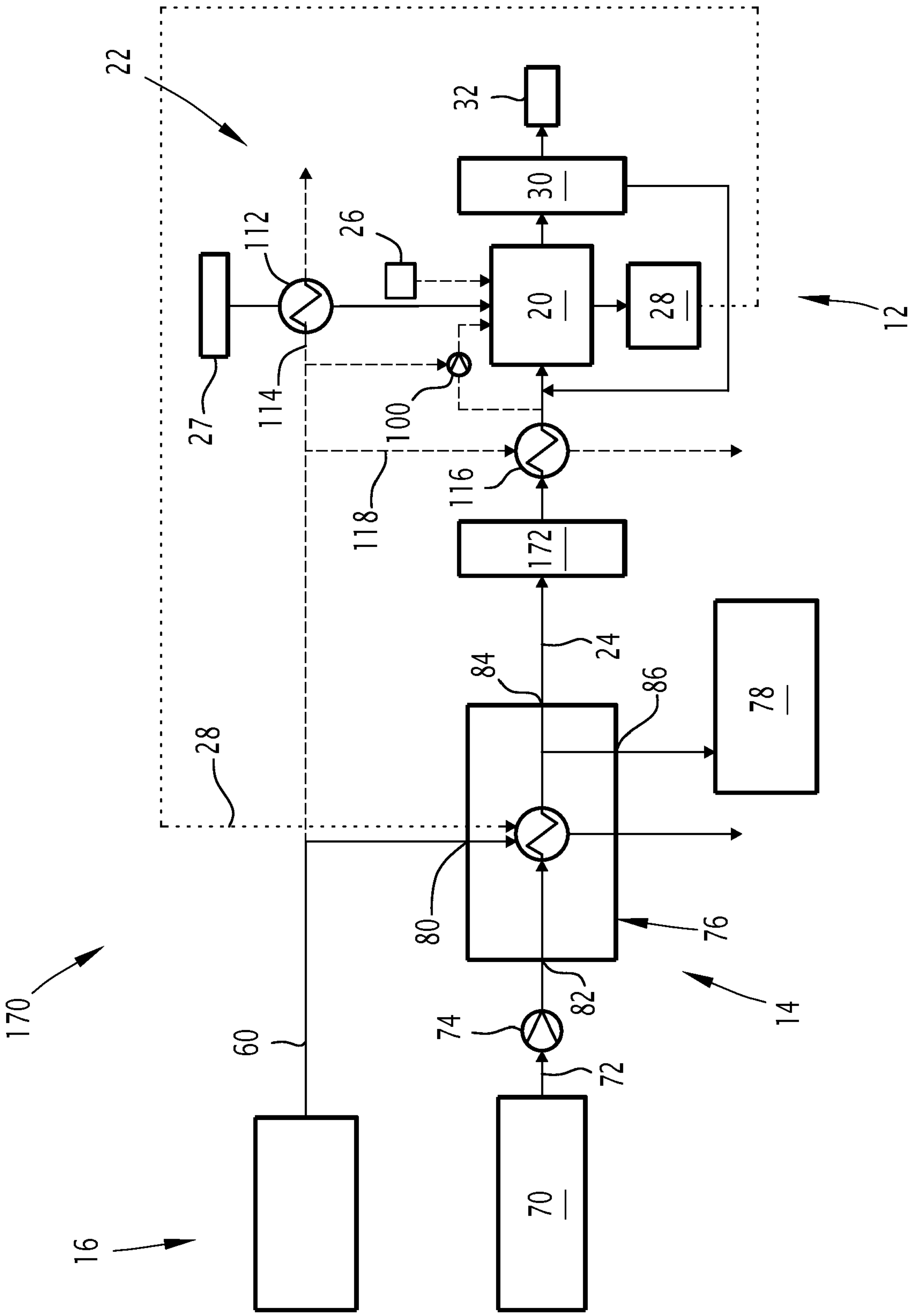
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FIG.4

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EUROPEAN SEARCH REPORT

Application Number
EP 22 30 6761

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Place of search	Date of completion of the search	Examiner
Munich	16 October 2023	Leu, Oana

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