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- (73) Patenthaver: **WS Reformer GmbH, Dornierstrasse 14, 71272 Renningen, Tyskland**
- (72) Opfinder: **WÜNNING, Joachim, A., Berghalde 20, 71229 Leonberg, Tyskland**  
**SCHMID, Hans-Peter, Eichenweg 16, 73666 Hohengehren, Tyskland**
- (74) Fuldmægtig i Danmark: **PLOUGMANN & VINGTOFT A/S, Rued Langgaards Vej 8, 2300 København S, Danmark**
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### Fuel Cell System

Fuel cell systems are used for the conversion of energy from liquid and gaseous fuels into electrical current and heat. The conversion of energy takes place quietly in the fuel cell and at an efficiency ratio of between 50% and 60% during the conversion of chemical into electrical energy, depending on the selected current density in the cell. The advantages over an engine-driven current generator are particularly effective in the kW range in the case of small outputs as are required for the net-remote power supply and for decentralized power-heat coupling. Consequently, work to develop fuel cell systems is done worldwide, however, until now without any break-through on the market.

The reasons therefor are mainly the high manufacturing costs for the complete, highly complex system. This system comprises fuel processing (using a so-called fuel processor) with a reformer and the fuel cell stack as well as with peripheral components such as heat exchangers, pumps, valves and electrical apparatus for automatic operation.

The PEM fuel cells that are equipped with polymer membranes and designed for operating temperatures up to approximately 80°C require CO fine-scrubbing of the reformat up into the ppm range and expensive water management for the humidification of the cathode air. In this case, the process water for the steam reformer may not be evaporated with the exhaust heat of the stack, because the temperature is too low for this.

Document WO 2005/084771 A2 describes a compact reformer with an integral evaporator. This can be used for reformation with an efficiency ratio of up to 80%. The resultant electrical efficiency ratio for the entire system is 35 to 40% if losses of 10 to 15% of the gross power generation due to auxiliary assemblies such as pumps, blowers and current transducers are taken into account.

Considering high-temperature PEM cells (publication by PEMEAS und Pat) that have recently become available and that operate at temperatures of 120 to 200°C, the CO fine-scrubbing and the water management may be omitted, thus permitting a considerable simplification of the process. In addition, the exhaust heat of the stack may be used for the evaporation of the process water.

The object of the invention is to further simplify the overall process on the basis of high-temperature cells in order to lower the manufacturing costs and to provide a safer automatic operation. In so doing, the electrical efficiency ratio of the total system should not drop below the level of 35 to 40% and, if possible, be even higher.

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This object is achieved with the fuel cell system in accordance with the features of Claim 1.

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The high-temperature stack and preferably also the shift stage or the shift reactor are cooled in direct contact with evaporation channels and are thermostatically controlled with the aid of the steam pressure. Thus, the exhaust heat of at least the stack and, optionally, also that of the shift reactor is utilized, thus improving the efficiency ratio.

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The size and complexity of the apparatus is reduced. In addition to the stack and the reformer, essentially only an air blower, a water pump, a condenser as well as a few valves and fittings are required. A separately heated steam generator is unnecessary.

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Process control and process monitoring are particularly simple. There is only one control circuit for the temperature of the reformer. As regards the mass flows of fuel, air and water, a roughly proportional control is sufficient.

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The electrical efficiency ratios for the total system are higher than in prior-art systems. In combination with a steam generator, it is possible to achieve an electrical efficiency ratio greater than 40% and, with the use of an autothermic reformer, up to 35%. In both cases, the total efficiency ratio for current and heat is at approximately 100%.

The figures of the drawings show exemplary embodiments of the invention. The drawings are intended to supplement the description. They show in

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Figure 1 a schematic representation of an exemplary embodiment of the system in accordance with the invention, and

Figure 2 a modified embodiment of a system in accordance with the invention.

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**Example in accordance with Fig. 1**

For the generation of electrical energy, a fuel cell stack 1 is provided, said stack operating at a temperature above 100°C, preferably at about 120°C. The steam for the reformer is generated with the exhaust heat of the stack 1, said stack being thermostatically controlled with the steam pressure at the desired temperature. This is accomplished by  
5 evaporation channels 2, e.g., in the form of one (or more) evaporator tubes, e.g., configured as tube coils, arranged directly on the stack 1, as well as by a pressure valve 16 at the outlet of the thusly created evaporator. In the simplest case, e.g., in the case of constant output, the pressure valve is an adjustable valve. In the case of changing loads, said valve is, e.g., a spring-biased pressure-maintaining valve. Alternatively, the thusly constructed pressure-  
10 maintaining device may also be represented by a controlled valve with an electronic controller.

Inasmuch as the automatic control of the stack temperature works only via the steam pressure in the wet steam region, a pump 8 provided for supplying the evaporation channel 2 feeds more water into the evaporator, i.e., into the evaporation channels 2 necessary for  
15 evaporation cooling. A water/steam mixture is formed. The excess water is separated in a separator 15 that is located downstream of the pressure-maintaining valve 16. The water separated in the separator 15 is returned to a buffer container 9.

The amount of steam generated by the stack is proportional to the power converted in  
20 the stack (and thus also proportional to the generated electrical power) and results in an S/C (steam/carbon) ratio of approximately five. The high steam excess compared with a usual ratio of 3 positively affects process safety, and does not negatively affect the efficiency ratio.

The evaporation of the water requires that the stack 1 have a minimum temperature.  
25 Therefore, the stack 1 is preferably kept at temperature in standby mode. This is accomplished by a vacuum-insulated vessel 3 in which the stack is arranged together with a heater 4.

Following the reformation, the CO content of the reformate must be lowered in high-  
30 temperature stacks from 8 to 12 vol.% to approximately 1 vol.%, which is achieved with the exothermic shift reaction on catalysts in the temperature range around 200°C. Normally, the shift reactor is an integral part of the reformer (see WO 2005/084771). The present invention departs from this principle. This temperature range overlaps with the temperature range of the stack 1. Said temperature range is at 160° to 200°, for example. Therefore, it is preferred that a shift reactor 5 communicating with the evaporation channels 6 be built into the thermo-  
35 container of the stack 1. In this way, it may also be ready for operation at operating

temperature with the heater 4 in standby mode. In addition, the evaporator tubes 2 and 6 may be connected in series, so that water/steam may sequentially flow through them.

5 A steam jet pump 17 may be connected to the pressure-maintaining valve 16 in order to feed said pump. With the use of this pump and via a valve 15 connected to said pump's suction connector, fuel is taken in, thus making a fuel pump unnecessary. The steam jet pump ejects a steam/fuel mixture at its outlet. This mixture is fed to a reformer 23 via a heat exchanger 20, where it is heated further. The heat exchanger 20 is heated with the heat of the produced reformat.

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Referring to the steam reformer in accordance with Fig. 1, the following components are located in a thermally insulated vessel 21:

15 - the reforming reactor 23 that is indirectly heated and filled with catalyst,

- the combustion chamber 24 that operates expediently in accordance with the principle of flameless oxidation (FLOX) in order to avoid thermal NOX formation,

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- a heat exchanger 20, in which fuel/steam mixture ejected by the jet pump 17 is preheated, preferably counter-current to the out-flowing reformat, and

- a heat exchanger 19, which is used to preheat the combustion air conveyed by a blower 13 and the heating gas that essentially consists of residual gas of the fuel cell 1, preferably counter-current to the exhaust gas of the combustion chamber 24.

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If high-efficiency counter-current apparatus are used for the heat exchangers 19 and 20, the efficiency ratio of the reformer is above 90% and is thus 10% higher than in the case of a reformer with an integrated evaporator for low-temperature stacks.

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The reformat is directed into the shift reactor 5 and then into the stack 1. The residual gas exiting from the stack still contains 15 to 25% of the energy content of the reformat. This is not quite sufficient for heating the reformat, which is why the reformat can be returned to the combustion chamber 24 via the valve 18.

The exhaust gas of the combustion chamber 24 and the exhaust air of the stack 1 are cooled in a condenser 11 to the condensation temperature in order to close the water circuit. This results in a total efficiency ratio of the system for current and heat of approximately 100%, with respect to the lower heating value (so-called heating value operation). Connected to the condenser 11 is a heat uncoupler that can be used for tapping the heat output, e.g., in order to heat a building.

The automatic control of the total system with the controller device 25 is particularly simple. Depending on whether the system is to work with current or heat as a carrier, the signal of current tapping 7 or for heat uncoupling 12 is used to vary, approximately proportionally, the

- fuel supply with the valve 14,

- the air with the blower 13, and/or

- the quantity of water with the pump 8.

The exact ratio of the mass flows does not impair the safety of the process because water is conveyed in excess, and the air number, likewise, is not critical. The electrical efficiency ratio of the system is only insubstantially affected. Also, because the exhaust gases are cooled to condensation, the total efficiency ratio is very good.

The temperature control of the steam reformer comprising the temperature sensor 22 and the valve 18 represents the only required control circuit.

### **Example in accordance with Fig. 2**

It is also possible to couple the fuel cell system in accordance with the invention with an autothermic reformer. Using the same reference signs as basis, the previous description is applicable. In addition, the following is applicable. The autothermic reformation of fuels has certain advantages over steam reformation such as:

- the compact design because there is no indirect heat transfer,

- short start-up times, and

- carbonless operation, even with higher (longer chain) hydrocarbons as the fuel such as, e.g., oil.

5 However, there is the disadvantage that the residual gas of the stack 1 having an energy content of 15 to 25% cannot be utilized for reformation. To the same extent, the electrical efficiency ratio drops. However, the total efficiency ratio remains at 100%, because operation takes place in condensation mode.

10 The descriptions in Fig. 2 correspond to those of Fig. 1, with the following differences:

The autothermic reformer comprises a reaction chamber 26 and a heat exchanger 27 for preheating the steam/fuel mixture and the air with the out-flowing reformat. The temperature in the reactor 26 is controlled with the sensor 22 and the air valve 28. The high steam excess that is delivered by the stack cooler contributes to process safety, in particular when difficult fuels (oil, etc.) are being used. The efficiency ratio of the reformer is above 90% when the heat exchanger 27 is a high-efficiency counter-current apparatus. The residual gas that is not reacted in the stack is combusted with air in a secondary combustion chamber 29 and then conveyed into the condenser 11.

20 The most important advantages are:

- The high-temperature stack, and expediently also the shift stage, are thermostatically controlled in direct contact with the evaporation channels and with the aid of steam pressure.

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- The size of the apparatus is reduced. In addition to the stack and the reformer, only an air blower, a water pump, a condenser and a few valves and fittings are required.

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- Process control and process monitoring are particularly simple. There is only one control circuit for the temperature of the reformer. A roughly proportional control is sufficient for the mass flows of fuel, air and water.

- The electrical efficiency ratios of the total system are higher than in prior-art systems. In combination with the steam reformer, an electrical efficiency ratio of over 40% can

be achieved, and over 35% with an autothermic reformer. In both cases, the total efficiency ratio for current and heat is at approximately 100%.

5 In order to accomplish reformation, the steam/fuel ratio, the so-called steam/carbon ratio or S/C ratio, must be controlled, e.g., considering steam reformation, at approximately S/C = 3. Independent of output, a fuel cell delivers energy, i.e., approximately half as current and half as exhaust heat. If the exhaust heat is used for steam generation, a S/C ratio of approximately 5 is the result.

10 Indeed, this is more than is required, however, there is no need for measuring and controlling the mass flows.

15 Consequently, e.g., the stack temperature is thermostatically controlled with a steam pressure of 10 bar and at a temperature of approximately 160°C to 180°C, i.e., independent of output. This can be achieved with a simple pressure-maintaining valve.

20 The fuel cell system in accordance with the invention is used for the generation of current and heat from liquid and gaseous fuels. Said system comprises a reformer and a fuel cell stack having an operating temperature above 120°C and providing exhaust heat that is utilized for the generation of steam in the evaporation channels 2. The evaporation channels 2 are arranged so as to be in direct thermal contact with the stack 1 that is to be cooled. A pressure-maintaining device at the outlet of the evaporation channels 2 is disposed to adjust the pressure in said channels to a value that results in the desired stack temperature.

25 **Abstract:**

30 The fuel cell system in accordance with the invention is used for the generation of current and heat from liquid and gaseous fuels. Said system comprises a reformer and a fuel cell stack having an operating temperature above 120°C and providing exhaust heat that is utilized for the generation of steam in the evaporation channels (2). The evaporation channels (2) are arranged so as to be in direct thermal contact with the stack (1) that is to be cooled. A pressure-maintaining device at the outlet of the evaporation channels (2) is disposed to adjust the pressure in said channels to a value that results in the desired stack temperature.

**Patentkrav**

1. Brændstofcellesystem til at generere strøm og varme fra flydende og gasformige brændstoffer, som har en reformer og en brændstofcellestak, 5 arbejdstemperaturen af hvilken ligger over 100°C og overskudsvarmen deraf anvendes til at generere damp i fordampningskanaler (2), **kendetegnet ved at**
- fordampningskanalerne (2) er anbragt i direkte termisk kontakt med stakken (1) som skal afkøles og
  - en trykopretholdelsesindretning (16) er indrettet til at indstille trykket i 10 fordampningskanalerne (2) ved udløbet deraf til en værdi, som giver den ønskede staktemperatur,
  - en shift-reaktor (5) også varmes eller afkøles med dampen idet den står i varmeoverførselsforbindelse med fordampningskanaler (6),
  - trykopretholdelsesindretningen er indrettet til at regulere temperaturen af 15 fordampningskanalerne (6).
2. Brændstofcellesystem ifølge krav 1, **kendetegnet ved at** trykopretholdelsesindretningen har en trykopretholdelsesventil (16), foran hvilken en vandlås (15) er installeret. 20
3. Brændstofcellesystem ifølge krav 1, **kendetegnet ved at** stakken (1) er omsluttet af en vakuum-isoleret beholder (3) med en standby-opvarmning (4).
4. Brændstofcellesystem ifølge krav 1, **kendetegnet ved at** shift-reaktoren (5) 25 er huset i den vakuum-isolerede beholder (3).
5. Brændstofcellesystem ifølge krav 1, **kendetegnet ved at** trykopretholdelsesindretningen har en trykopretholdelsesventil (16) og at en strålepumpe (17) er anbragt efter trykopretholdelsesventilen (16) for at indsuge 30 brændstoffet til reformeren.
6. Brændstofcellesystem ifølge krav 1, **kendetegnet ved at** massestrømningerne ændres proportionelt som krævet af en styreindretning (25) med en ventil (14) til brændstoffet, med en ventilator (13) til luften og med en pumpe (8) til vandet. 35

7. Brændstofcellesystem ifølge krav 1, **kendetegnet ved at** reformeren er en dampreformer med indirekte opvarmning.
8. Brændstofcellesystem ifølge krav 1, **kendetegnet ved at** reformeren er en autotermisk reformer.
9. Fremgangsmåde til at generere strøm og varme fra flydende og gasformige brændstoffer, som har en reformer og en brændstofcellestak, arbejdstemperaturen af hvilken ligger over 100°C og overskudsvarmen deraf anvendes til at generere damp, og har en shift-reaktor,
- idet stakken (1) og shift-reaktoren afkøles med fordampningskanaler (2, 6) som står i direkte termisk kontakt med stakken (1) og shift-reaktoren (5) som skal afkøles og
  - idet med en trykopretholdelsesindretning indstilles trykket i fordampningskanalerne (2) ved udløbet deraf til en værdi, som giver den ønskede staktemperatur,
  - hvor temperaturen af fordampningskanalerne (6) reguleres af trykopretholdelsesindretningen (16).
- 10 **10.** Fremgangsmåde ifølge krav 9, **kendetegnet ved at** den genererede damp blandes med brændstof ved hjælp af en strålepumpe til reformeren.
11. Fremgangsmåde ifølge krav 9, **kendetegnet ved at** massestrømningerne ændres proportionelt som krævet af en styreindretning (25) med en ventil (14) til brændstoffet, med en ventilator (13) til luften og med en pumpe (8) til vandet.

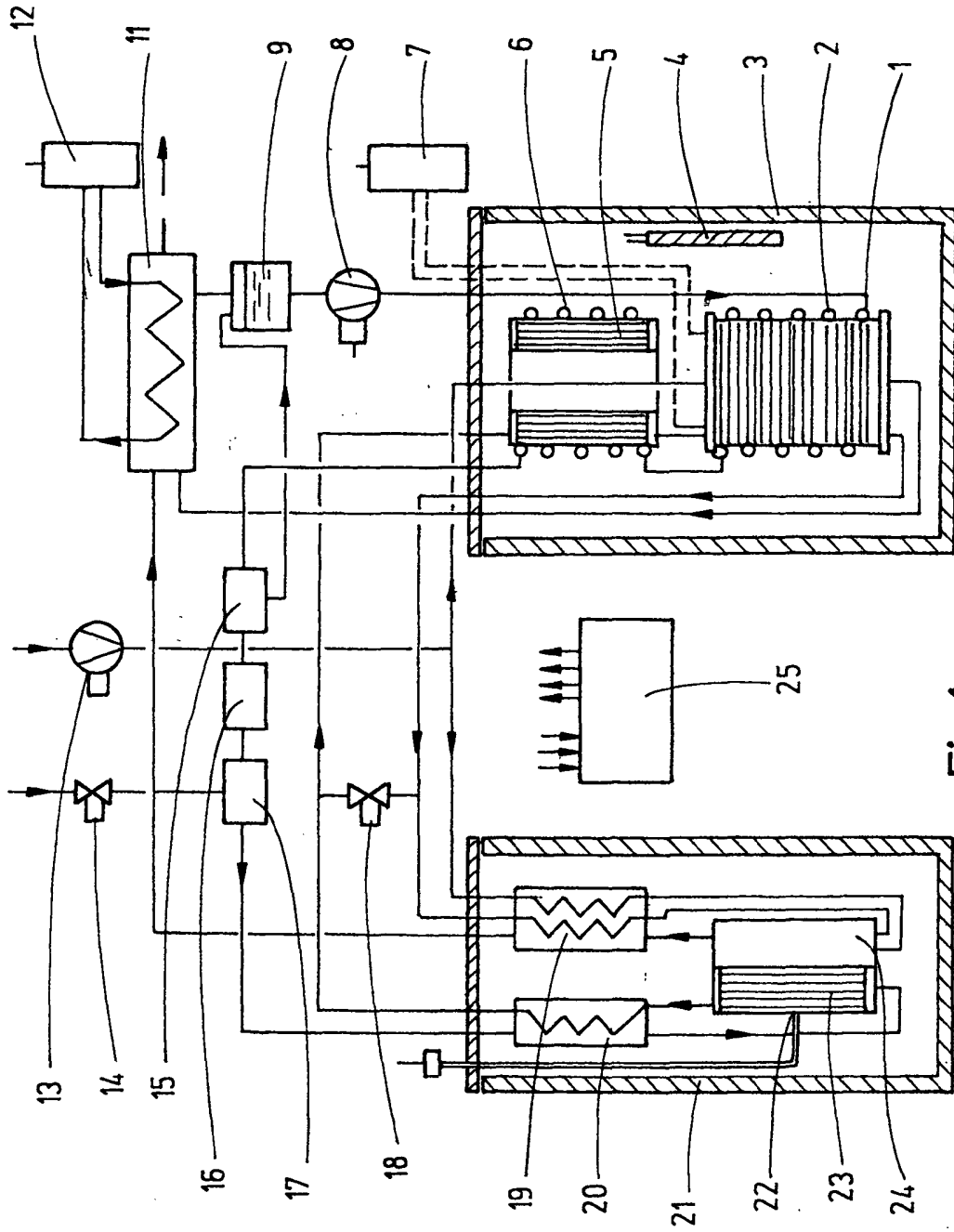


Fig.1

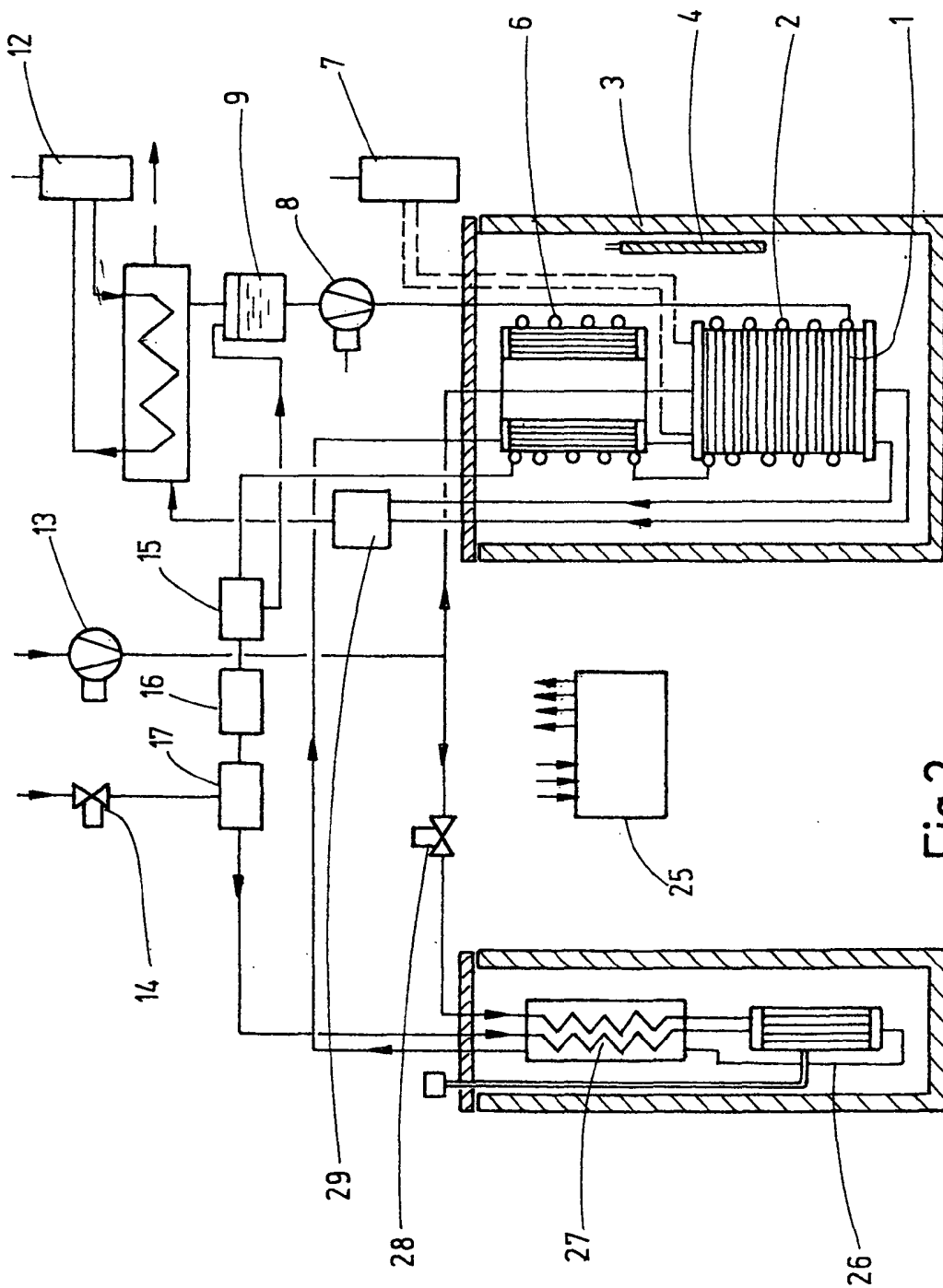


Fig.2