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(54) **HEAT-GENERATING DEVICE AND BOILER**

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(57) **ABSTRACT**

A heat generating device includes: a heat generating container configured to allow a hydrogen-based gas containing hydrogen to be introduced; a heat generating element provided inside the heat generating container and configured to generate heat by occluding and discharging the hydrogen; a first heat removal path configured to allow a first heat removal fluid heated by the heat generating element to flow therethrough; and a second heat removal path configured to allow a second heat removal fluid to flow therethrough in a direction opposite to a direction in which the first heat removal fluid flows.

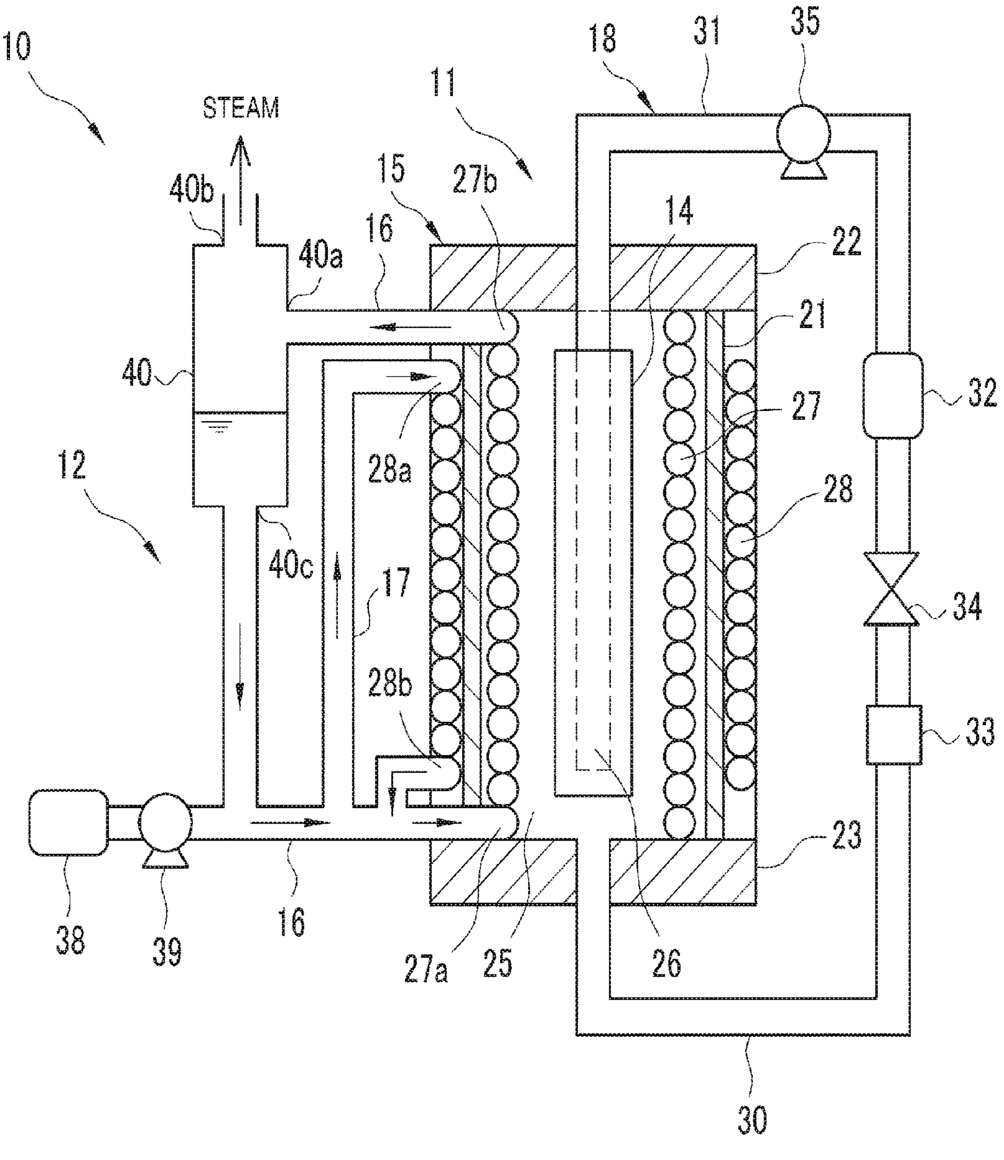

FIG. 1

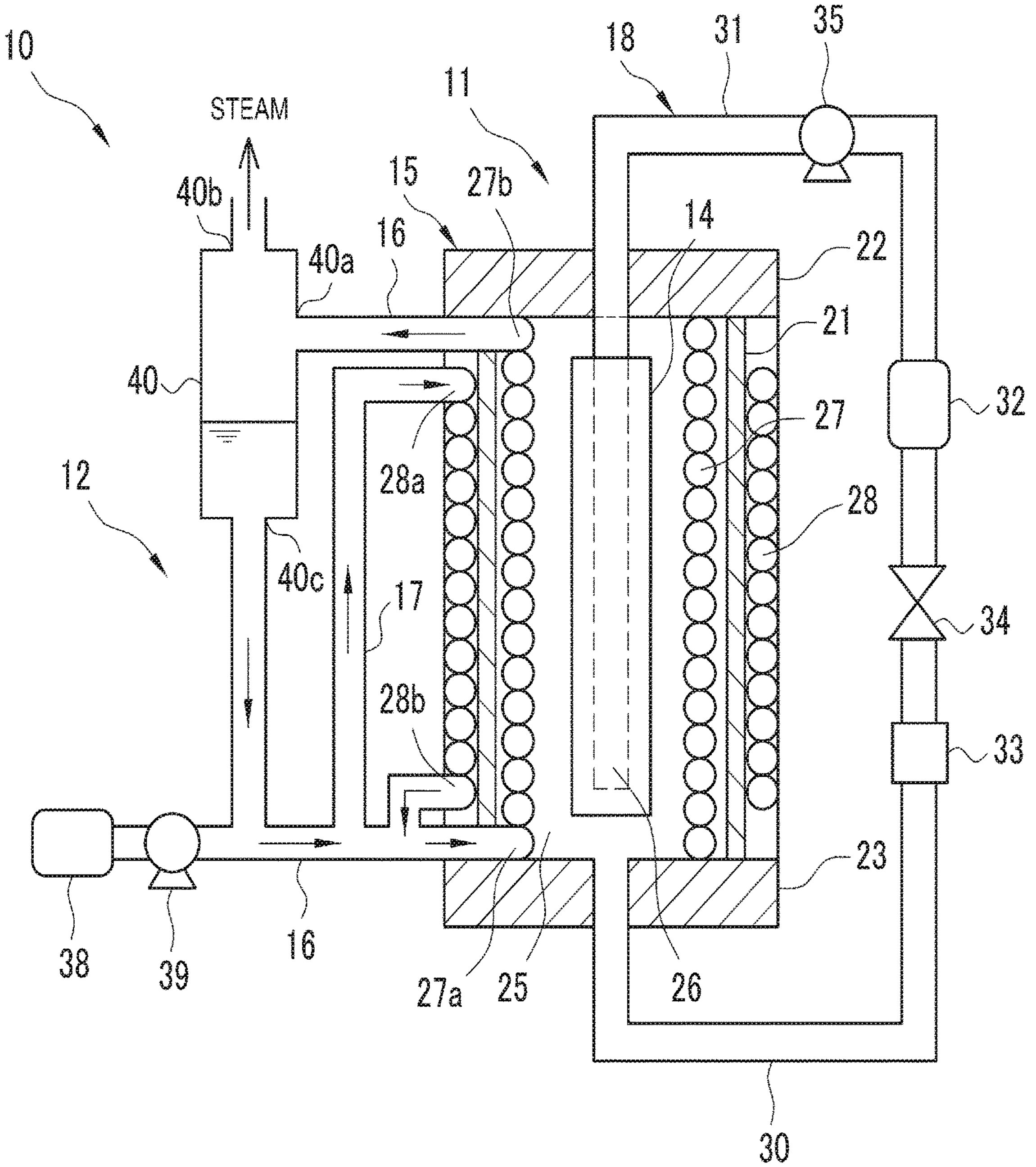
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FIG. 2

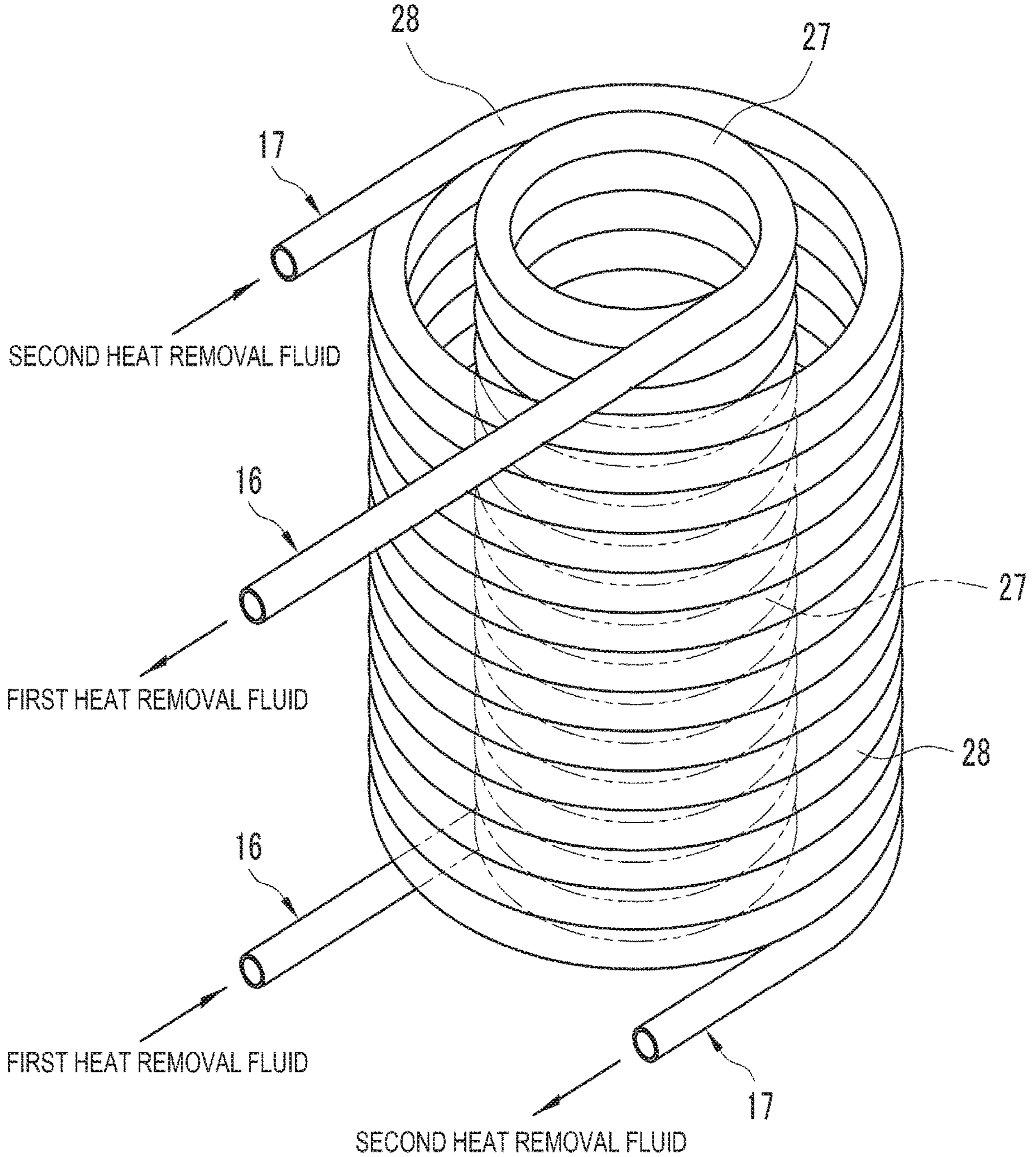
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FIG. 3

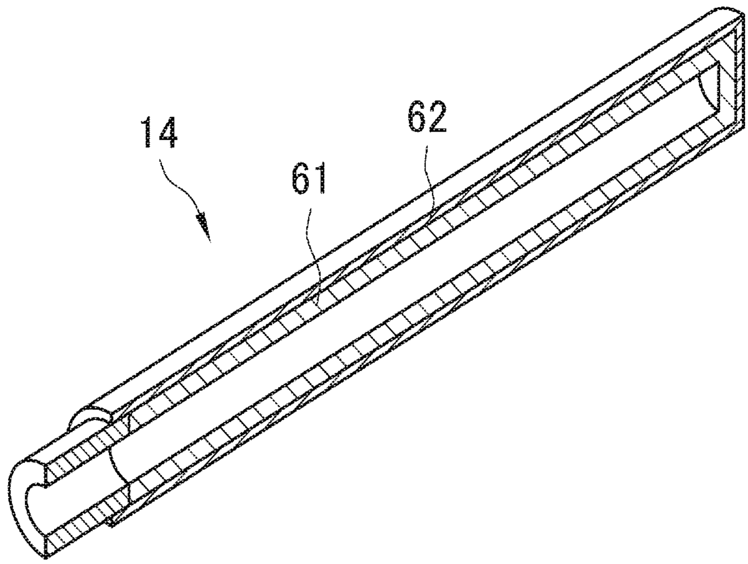

FIG. 4

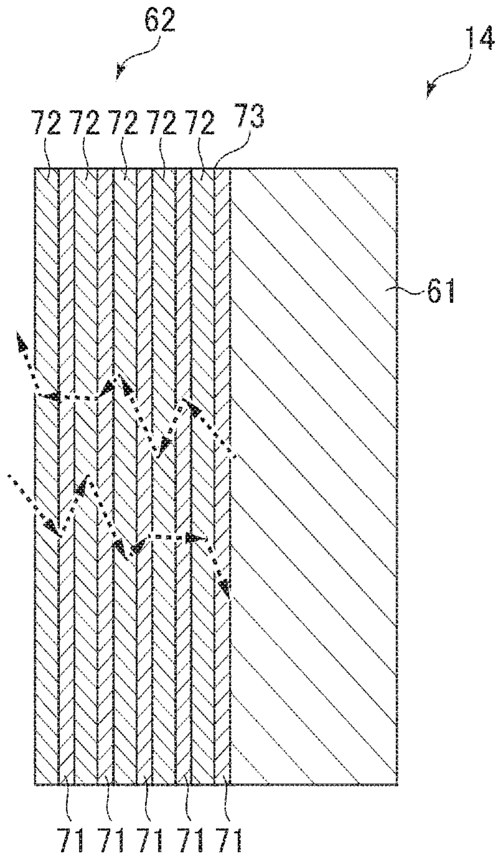

FIG. 5

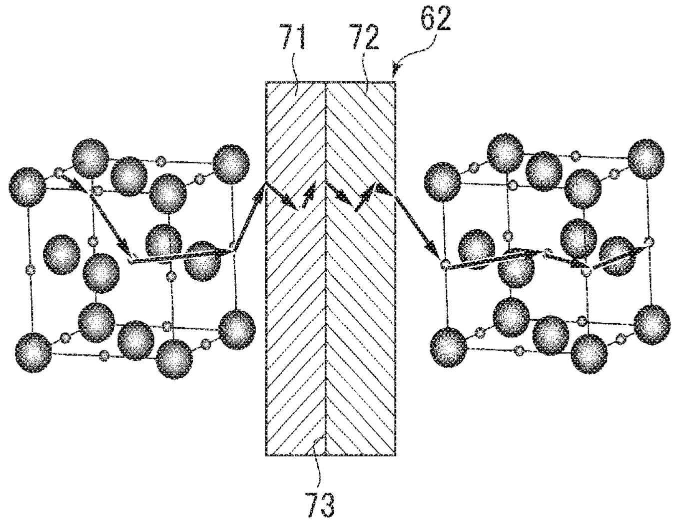

FIG. 6

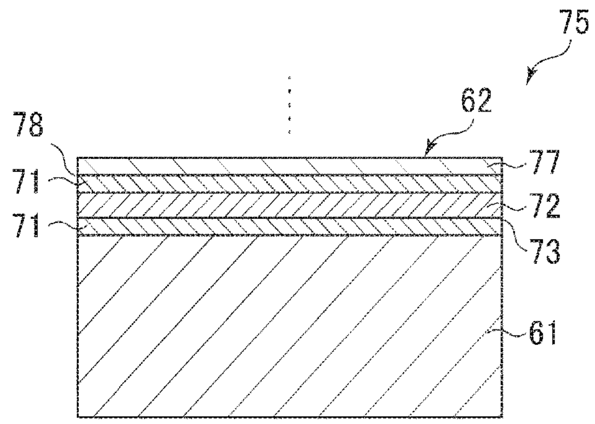

FIG. 7

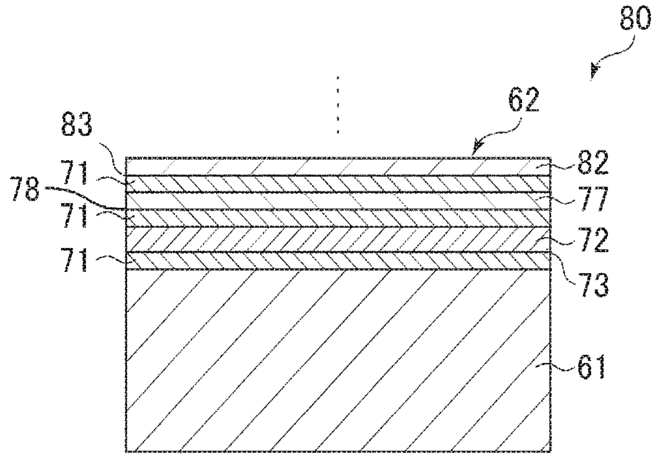

FIG. 8

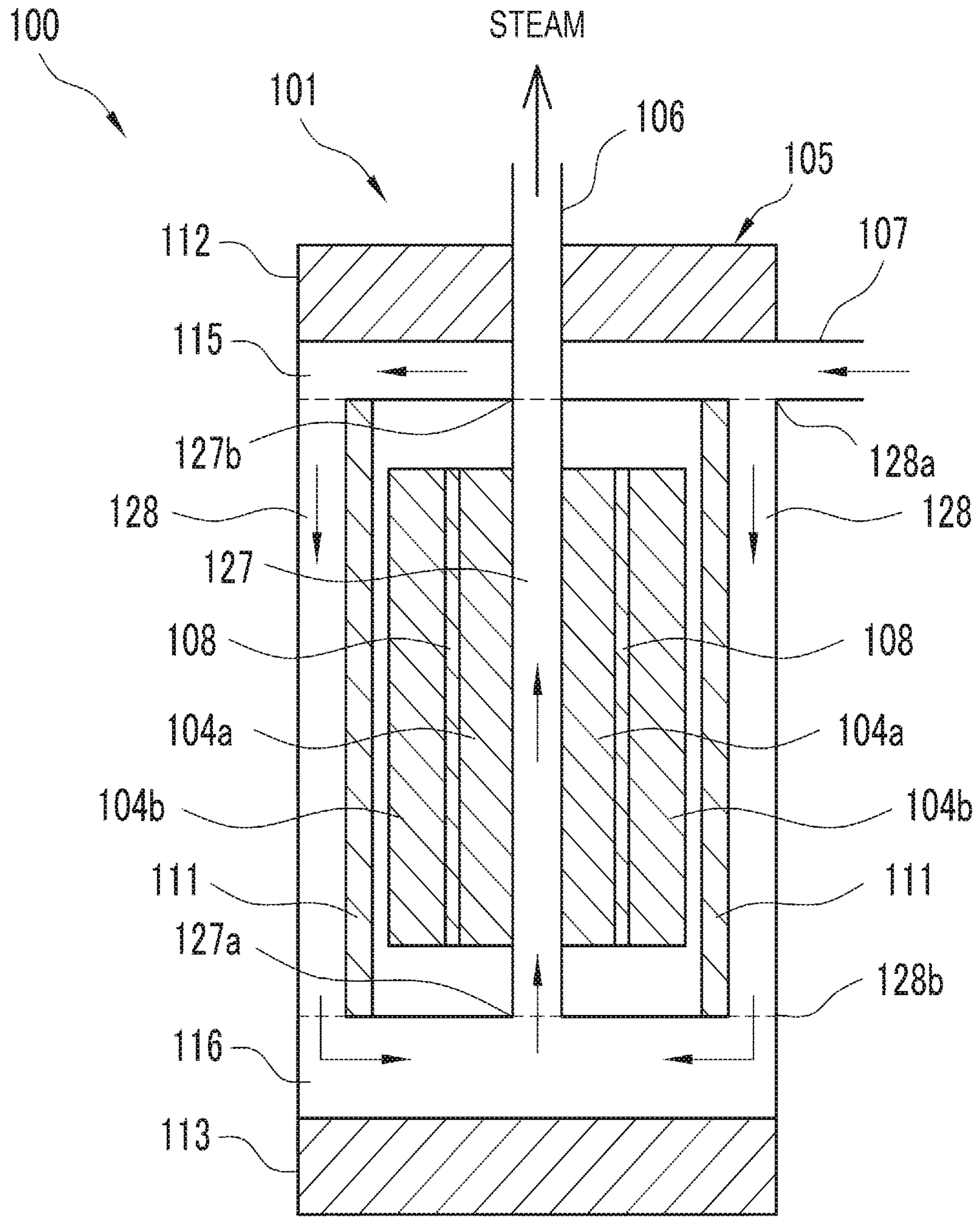
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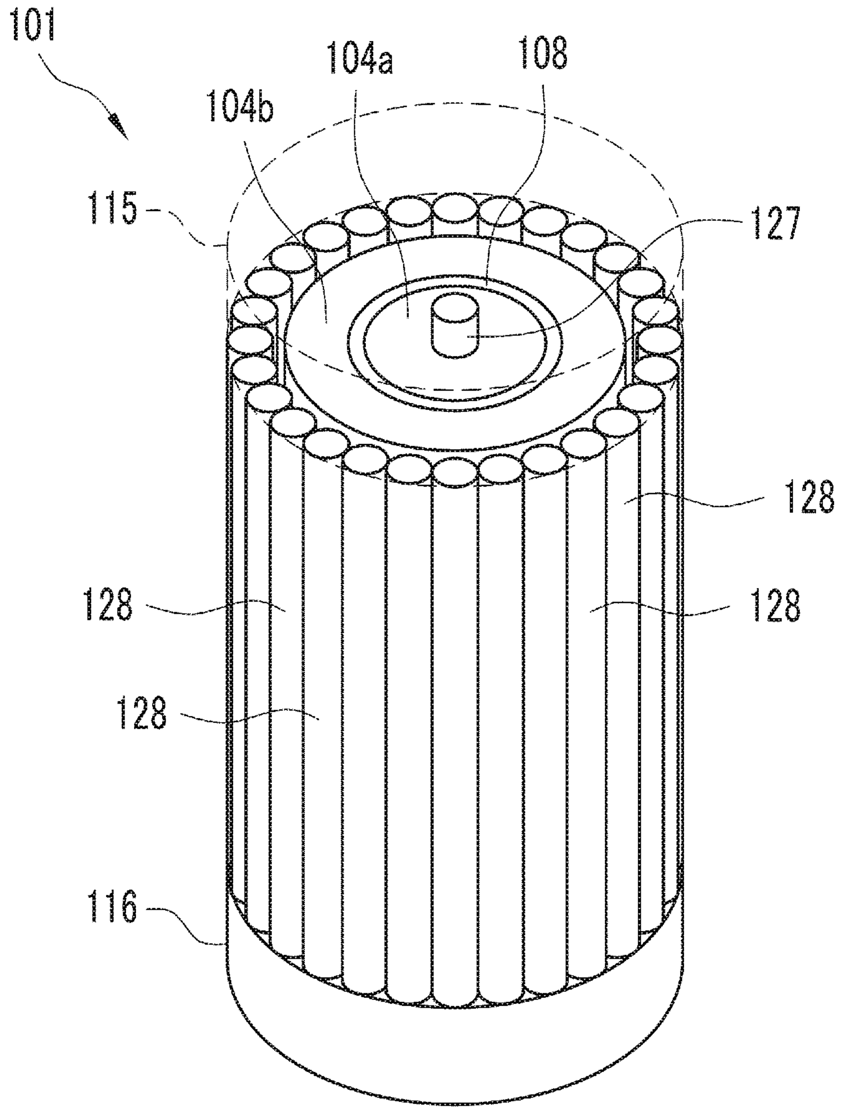
FIG. 9



HEAT-GENERATING DEVICE AND BOILER

TECHNICAL FIELD

[0001] The present invention relates to a heat generating device and a boiler.

BACKGROUND ART

[0002] As a boiler, there is known a boiler configured to efficiently recover heat, for example, by spirally arranging a water pipe so as to surround a heat source (for example, see Patent Literature 1), or by annularly arranging a plurality of water pipes so as to surround a heat source (for example, see Patent Literature 2).

[0003] In Patent Literature 1, a heat generating element cell using a hydrogen storage metal or a hydrogen storage alloy is used as a heat source, and the heat generating element cell is heated to generate heat equal to or more than input energy of a heater. Water flow is unidirectional from a lower part to an upper part of the boiler.

[0004] In Patent Literature 2, a flame burner is used as a heat source, a water pipe is constituted with an inner water pipe and an outer water pipe, and the inner water pipe and the outer water pipe are connected to each other by an upper header and a lower header. Water or water vapor is circulated upward through the inner water pipe and the outer water pipe from the lower header to the upper header, thereby dispersing heat received by the water pipe from the flame burner.

CITATION LIST

Patent Literature

[0005] Patent Literature 1: JP6795129B

[0006] Patent Literature 2: JPH03-70901A

SUMMARY OF INVENTION

Technical Problem

[0007] In Patent Literature 1, when a steam flow increase/decrease signal is received from the boiler, it is necessary to vary (load variation) an excess heat amount of the heat generating element cell. When the excess heat amount of the heat generating element cell is attempted to be adjusted according to the load variation, the following problems occur. That is, a temperature of the heat generating element cell decreases on a water pipe inlet side (the lower part of the boiler), and there may be a region where no excess heat is generated. Since the region where no excess heat is generated is generated in the heat generating element cell, the water flowing from the lower part to the upper part of the boiler is not heated enough, and steam may not be generated. In addition, on a water pipe outlet side (the upper part of the boiler), a portion where the temperature of the heat generating element cell is extremely high is generated, and the heat generating element cell may be damaged. Even when the configuration in which the heat received by the water pipe is dispersed as in Patent Literature 2 is applied, the temperature of the heat generating element cell partially decreases or increases.

[0008] Therefore, an object of the present invention is to provide a heat generating device and a boiler capable of achieving a uniform temperature of a heat generating element.

Solution to Problem

[0009] A heat generating device according to the present invention includes: a heat generating container configured to allow a hydrogen-based gas containing hydrogen to be introduced; a heat generating element provided inside the heat generating container and configured to generate heat by occluding and discharging the hydrogen; a first heat removal path configured to allow a first heat removal fluid heated by the heat generating element to flow therethrough; and a second heat removal path configured to allow a second heat removal fluid to flow therethrough in a direction opposite to a direction in which the first heat removal fluid flows.

[0010] A boiler according to the present invention includes the heat generating device, the first heat removal path is supplied with water as the first heat removal fluid, the water is heated by the heat generating element, and steam or warm water is discharged from the first heat removal path.

Advantageous Effects of Invention

[0011] According to the present invention, the first heat removal fluid and the second heat removal fluid flow in directions opposite to each other, and thus a uniform temperature of the heat generating element can be achieved.

BRIEF DESCRIPTION OF DRAWINGS

[0012] FIG. **1** is a schematic diagram of a boiler according to a first embodiment.

[0013] FIG. **2** is a diagram showing a structure of a first heat removal path and a second heat removal path according to the first embodiment.

[0014] FIG. **3** is a cross-sectional view showing a structure of a heat generating element.

[0015] FIG. **4** is a cross-sectional view showing a structure of a multilayer film.

[0016] FIG. **5** is a diagram showing generation of excess heat.

[0017] FIG. **6** is a diagram showing a heat generating element having a first layer, a second layer, and a third layer according to a first modification.

[0018] FIG. **7** is a diagram showing a heat generating element having a first layer, a second layer, a third layer, and a fourth layer according to a second modification.

[0019] FIG. **8** is a schematic diagram of a boiler according to a second embodiment.

[0020] FIG. **9** is a diagram showing a structure of a first heat removal path and a second heat removal path according to the second embodiment.

DESCRIPTION OF EMBODIMENTS

First Embodiment

[0021] As shown in FIG. **1**, a boiler **10** includes a heat generating device **11**, a water path **12**, and a control unit (not shown). The boiler **10** heats water flowing through the water path **12** by heat generated by the heat generating device **11** to generate steam or warm water. The boiler **10** is used not only for supplying steam but also for supplying warm water like a water heater. That is, the "boiler" in the present application includes a water heater.

[0022] The heat generating device **11** includes a heat generating element **14**, a heat generating container **15**, a first heat removal path **16**, a second heat removal path **17**, a hydrogen circulation line **18**, and a temperature adjustment unit (not shown). The heat generating element **14** is provided inside the heat generating container **15** and generates heat by occluding and discharging hydrogen. The heat generating element **14** is heated by a heater of the temperature adjustment unit to be described later. The heat generating element **14** generates heat (hereinafter, referred to as excess heat) having a temperature equal to or higher than a heating temperature of the heater by occluding and discharging hydrogen. In this example, the heat generating element **14** is formed into a bottomed cylindrical shape. The heat generating element **14** is attached to an upper base **22** of the heat generating container **15** to be described later. A detailed configuration of the heat generating element **14** will be described later with reference to another drawing.

[0023] A hydrogen-based gas containing hydrogen is introduced into the heat generating container **15**. The heat generating container **15** is a hollow container, and accommodates the heat generating element **14** therein. The heat generating container **15** includes a cylindrical side wall **21**, an upper base **22** provided at an upper end of the side wall **21**, and a lower base **23** provided at a lower end of the side wall **21**. The heat generating container **15** is a sealed container in which an opening at the upper end of the side wall **21** is closed by the upper base **22**, and an opening at the lower end of the side wall **21** is closed by the lower base **23**. The side wall **21** is formed into a cylindrical shape in the present embodiment, but is not limited thereto, and may be formed into an elliptical cylindrical shape or a rectangular cylindrical shape, for example. In FIG. **1**, an axial direction of the heat generating container **15** (the side wall **21**) is parallel to the vertical direction of the paper surface.

[0024] The heat generating container **15** has therein a first chamber **25** and a second chamber **26** partitioned by the heat generating element **14**. The first chamber **25** is defined by a front surface (an outer surface) that is one surface of the heat generating element **14** and an inner surface of the heat generating container **15**. The first chamber **25** is connected to an introduction line **30** of the hydrogen circulation line **18** to be described later. The hydrogen-based gas is introduced into the first chamber **25** from the introduction line **30**. The second chamber **26** is defined by a back surface (an inner surface) that is the other surface of the heat generating element **14**. The second chamber **26** is connected to a lead-out line **31** of the hydrogen circulation line **18** to be described later. The hydrogen-based gas in the second chamber **26** is led out to the lead-out line **31**.

[0025] The first chamber **25** is pressurized by introducing the hydrogen-based gas. The second chamber **26** is depressurized by leading out the hydrogen-based gas. Accordingly, a hydrogen pressure in the first chamber **25** is higher than a hydrogen pressure in the second chamber **26**. The hydrogen pressure in the first chamber **25** is, for example, 100 [kPa]. The hydrogen pressure in the second chamber **26** is, for example, 1×10^{-4} [Pa] or less. The second chamber **26** may be in a vacuum state. In this manner, the first chamber **25** and the second chamber **26** have different hydrogen pressures. Therefore, the inside of the heat generating container **15** is in a state in which a pressure difference is generated between two sides of the heat generating element **14**.

[0026] When the pressure difference is generated between the two sides of the heat generating element **14**, a hydrogen molecule contained in the hydrogen-based gas is adsorbed on the front surface (the outer surface) that is one surface of the heat generating element **14** at a high pressure side, and the hydrogen molecule is dissociated into two hydrogen atoms. The hydrogen atoms obtained by dissociation infiltrate into the heat generating element **14**. That is, hydrogen is occluded into the heat generating element **14**. The hydrogen atoms diffuse into and pass through the heat generating element **14**. On the back surface (the inner surface) that is the other surface of the heat generating element **14** at a low pressure side, the hydrogen atoms that pass through the heat generating element **14** are recombined with each other and discharged as a hydrogen molecule. That is, hydrogen is discharged from the heat generating element **14**.

[0027] In this manner, hydrogen permeates through the heat generating element **14** from the high pressure side to the low pressure side. The phrase "permeate" refers to that hydrogen is occluded on the one surface of the heat generating element and discharged from the other surface of the heat generating element. The heat generating element **14** to be described in detail later generates heat by occluding hydrogen, and generates heat also by discharging hydrogen. Therefore, the heat generating element **14** generates heat by permeation of hydrogen. In the following description, "hydrogen permeates through" the heat generating element may be described as "the hydrogen-based gas permeates through" the heat generating element.

[0028] A pressure sensor (not shown) that detects an internal pressure of the first chamber **25** is provided inside the first chamber **25**. A pressure sensor (not shown) that detects an internal pressure of the second chamber **26** is provided inside the second chamber **26**. The pressure sensors provided in the first chamber **25** and the second chamber **26** are electrically connected to the control unit (not shown), and output signals corresponding to the detected pressures to the control unit.

[0029] One end of the first heat removal path **16** is connected to a steam introduction unit **40***a* of a separator **40** to be described later, and the other end of the first heat removal path **16** is connected to a water discharge unit **40***c* of the separator **40**. A water supply tank **38** is connected to the other end of the first heat removal path **16**. A first heat removal fluid flows through the first heat removal path **16**. The first heat removal fluid is liquid water or vaporized water (steam).

[0030] One end and the other end of the second heat removal path **17** are connected to a high-temperature inlet **27***a* of a high-temperature heat removal pipe **27** of the first heat removal path **16**. A connection portion between the one end of the second heat removal path **17** and the first heat removal path **16** is located upstream of a connection portion between the other end of the second heat removal path **17** and the first heat removal path **16** in the first heat removal path **16**. Therefore, a part of the first heat removal fluid (liquid water) flowing through the first heat removal path **16** flows into the one end of the second heat removal path **17**. The first heat removal fluid flowing into the second heat removal path **17** is a second heat removal fluid. Therefore, the second heat removal fluid is liquid water. The second heat removal fluid flowing through the second heat removal path **17** flows into the first heat removal path **16** from the other end of the second heat removal path **17** and joins the first heat removal fluid flowing through the first heat removal path **16**.

[0031] A detailed structure of the first heat removal path **16** and the second heat removal path **17** will be described with reference to FIG. **2**.

[0032] The first heat removal path **16** includes a high-temperature heat removal pipe **27** provided around the heat generating element **14**. The high-temperature heat removal pipe **27** has a high-temperature inlet **27***a* provided at a lower end of the side wall **21** and a high-temperature outlet **27***b* provided at an upper end of the side wall **21**. The high-temperature heat removal pipe **27** extends spirally along the side wall **21** from the lower end toward the upper end of the side wall **21**, and is wound such that there is no gap between the vertically adjacent high-temperature heat removal pipes **27**. A cross-sectional shape of the high-temperature heat removal pipe **27** is circular in this example, but is not particularly limited, and may be rectangular or the like.

[0033] In the first heat removal path **16**, liquid water that has entered the high-temperature heat removal pipe **27** from the high-temperature inlet **27***a* is heated by the heat generating element **14** in the high-temperature heat removal pipe **27**, and exits from the high-temperature outlet **27***b* as vaporized water (steam). A temperature of the liquid water entering the high-temperature inlet **27***a* is, for example, 90° C. A temperature of the vaporized water (steam) exiting from the high-temperature outlet **27***b* is, for example, 100° C. In the present embodiment, a pressure of the high-temperature outlet **27***b* or a pressure of the separator **40** to be described later is assumed to be 1 atm (0.1 MPa), and the steam at 100° C. is discharged from the first heat removal path **16**. However, by applying pressure to the high-temperature outlet **27***b* or the separator **40** to be described later, liquid water (warm water) having a temperature exceeding 100° C. can be discharged from the first heat removal path **16**.

[0034] The second heat removal path **17** includes a low-temperature heat removal pipe **28** spirally provided around the first heat removal path **16**. The low-temperature heat removal pipe **28** has a low-temperature inlet **28***a* provided at the upper end of the side wall **21** and a low-temperature outlet **28***b* provided at the lower end of the side wall **21**. The low-temperature heat removal pipe **28** extends spirally along the side wall **21** from the lower end toward the upper end of the side wall **21**, and is wound such that there is no gap between the vertically adjacent low-temperature heat removal pipes **28**. A cross-sectional shape of the low-temperature heat removal pipe **28** is circular in this example, but is not particularly limited, and may be rectangular or the like.

[0035] In the second heat removal path **17**, a temperature of liquid water that has entered the low-temperature heat removal pipe **28** from the low-temperature inlet **28***a* is increased by heat exchange with the first heat removal fluid in the low-temperature heat removal pipe **28**, and the liquid water exits from the low-temperature outlet **28***b*. A temperature of the liquid water entering the low-temperature inlet **28***a* is, for example, 25° C. A temperature of the liquid water exiting from the low-temperature outlet **28***b* is, for example, 90° C. That is, in the second heat removal path **17**, a temperature of cold water that has entered the low-temperature heat removal pipe **28** is increased by heat exchange with the first heat removal fluid, and the cold water exits from the low-temperature heat removal pipe **28** as warm water. The liquid water (the second heat removal fluid) exiting from the low-temperature outlet **28***b* joins the liquid water (the first heat removal fluid) flowing through the high-temperature inlet **27***a* of the high-temperature heat removal pipe **27** in the first heat removal path **16**. Accordingly, the temperature of the liquid water (the first heat removal fluid) entering the high-temperature inlet **27***a* of the high-temperature heat removal pipe **27** is increased.

[0036] In the first heat removal path **16**, the high-temperature heat removal pipe **27** is provided around the heat generating element **14**, and the first heat removal fluid flowing in the high-temperature heat removal pipe **27** is heated by the heat generating element **14**. That is, the first heat removal path **16** is configured to allow the first heat removal fluid heated by the heat generating element **14** to flow therethrough.

[0037] The high-temperature heat removal pipe **27** of the first heat removal path **16** extends spirally along the side wall **21** from the lower end toward the upper end of the side wall **21**. The low-temperature heat removal pipe **28** of the second heat removal path **17** extends spirally along the side wall **21** from the upper end toward the lower end of the side wall **21**, contrary to the high-temperature heat removal pipe **27**. That is, the second heat removal path **17** is configured to allow the second heat removal fluid to flow therethrough in a direction opposite to a direction in which the first heat removal fluid flows.

[0038] The hydrogen circulation line **18** is provided outside the heat generating container **15**. One end of the hydrogen circulation line **18** is connected to the upper base **22** of the heat generating container **15**, and the other end of the hydrogen circulation line **18** is connected to the lower base **23** of the heat generating container **15** (see FIG. **1**). The hydrogen circulation line **18** introduces the hydrogen-based gas containing hydrogen from the outside to the inside of the heat generating container **15** and discharges the hydrogen-based gas from the inside to the outside of the heat generating container **15**.

[0039] The hydrogen circulation line **18** includes the introduction line **30**, the lead-out line **31**, a hydrogen tank **32**, and a filter **33**. Although not shown in FIG. **1**, the heat generating device **11** includes a supply line for supplying the hydrogen-based gas to the hydrogen tank **32**, and an evacuation line for evacuating the hydrogen-based gas from the hydrogen circulation line **18**. For example, the hydrogen-based gas is supplied from the supply line to the hydrogen tank **32** when an operation of the heat generating device **11** is started, and the hydrogen-based gas in the hydrogen circulation line **18** is evacuated to the evacuation line when the operation of the heat generating device **11** is stopped.

[0040] The introduction line **30** connects the hydrogen tank **32** and the first chamber **25**, and introduces the hydrogen-based gas in the hydrogen tank **32** into the first chamber **25**. The introduction line **30** includes a pressure adjustment valve **34**. The pressure adjustment valve **34** depressurizes the hydrogen-based gas sent from the hydrogen tank **32** to a predetermined pressure. The pressure adjustment valve **34** is electrically connected to the control unit.

[0041] The lead-out line **31** connects the second chamber **26** and the hydrogen tank **32**, and leads out the hydrogen-based gas in the second chamber **26** to the hydrogen tank **32**. The lead-out line **31** includes a pump **35**. The pump **35** leads out the hydrogen-based gas in the second chamber **26** to the lead-out line **31**, pressurizes the hydrogen-based gas to a predetermined pressure, and sends the hydrogen-based gas to the hydrogen tank **32**. Examples of the pump **35** include a metal bellows pump. The pump **35** is electrically connected to the control unit.

[0042] The hydrogen tank **32** stores the hydrogen-based gas. The hydrogen-based gas is a gas containing isotopes of hydrogen. As the hydrogen-based gas, at least one of a deuterium gas and a protium gas is used. The protium gas includes a mixture of naturally occurring protium and deuterium, that is, a mixture in which an abundance ratio of protium is 99.985% and an abundance ratio of deuterium is 0.015%.

[0043] The filter **33** removes impurities contained in the hydrogen-based gas. Here, a permeation amount of hydrogen permeating through the heat generating element **14** (hereinafter, referred to as a hydrogen permeation amount) is determined by the temperature of the heat generating element **14**, the pressure difference between two sides of the heat generating element **14**, and a front surface state of the heat generating element **14**. When the hydrogen-based gas contains impurities, the impurities may adhere to the front surface of the heat generating element **14**, and may deteriorate the front surface state of the heat generating element **14**. When the impurities adhere to the front surface of the heat generating element **14**, adsorption and dissociation of the hydrogen molecule on the front surface of the heat generating element **14** are hindered, and the hydrogen permeation amount decreases.

[0044] Examples of impurities that hinder the adsorption and dissociation of the hydrogen molecule on the front surface of the heat generating element **14** include water (including steam), hydrocarbons (methane, ethane, methanol, ethanol, and the like), C, S, and Si. It is considered that water is discharged from an inner wall or the like of the heat generating container **15**, or is obtained by reducing, by hydrogen, an oxide film contained in a member provided inside the heat generating container **15**. It is considered that hydrocarbons, C, S, and Si are discharged from various members provided inside the heat generating container **15**. Therefore, the filter **33** at least removes the impurities including water (including steam), hydrocarbons, C, S, and Si. The filter **33** removes the impurities contained in the hydrogen-based gas, so that the hydrogen permeation amount through the heat generating element **14** can be prevented from decreasing.

[0045] Although not shown, the temperature adjustment unit adjusts a temperature of the heat generating element **14** and maintains the heat generating element **14** at an appropriate temperature for heat generation. The appropriate temperature for heat generation in the heat generating element **14** is within a range of, for example, 50° C. or higher and 1500° C. or lower. The temperature adjustment unit includes a temperature sensor and a heater. The temperature sensor detects the temperature of the heat generating element **14**. The temperature sensor is, for example, a thermocouple, and is provided inside the heat generating container **15**. The temperature sensor is electrically connected to the control unit, and outputs a signal corresponding to the detected temperature to the control unit. The heater heats the heat generating element **14**. The heater is, for example, an electric heating wire of an electric resistance heat generating type, and is wound around an outer periphery of the heat generating element **14**. The heater is electrically connected to a power supply, and generates heat by inputting electric power from the power supply. The heater may be an electric furnace disposed to cover the outer periphery of the heat generating element **14**.

[0046] The water path **12** includes the first heat removal path **16**, the second heat removal path **17**, the water supply tank **38**, a water pump **39**, and the separator **40**. The first heat removal path **16** and the second heat removal path **17** constitute a part of the water path **12**. The water supply tank **38** supplies the liquid water to the first heat removal path **16**. The water pump **39** is provided downstream of the water supply tank **38**, and is configured to allow the water in the water path **12** to flow therethrough.

[0047] The separator **40** is configured to receive the water (steam) vaporized by heating with the heat generating element **14** in the high-temperature heat removal pipe **27** and to separate the steam from the water (to separate condensate contained in the steam). The steam separated by the separator **40** is supplied to the outside of the boiler **10**. The separator **40** includes a steam introduction unit **40***a* connected to one end of the first heat removal path **16**, a steam extraction unit **40***b* for extracting the steam separated by the separator **40**, and a water discharge unit **40***c* connected to the other end of the first heat removal path **16**. The steam introduction unit **40***a* and the steam extraction unit **40***b* are provided at an upper part of the separator **40**, and the water discharge unit **40***c* is provided at a lower part of the separator **40**. The steam introduction unit **40***a* introduces the steam from the first heat removal path **16** to the separator **40**. The water discharge unit **40***c* refluxes the water separated by the separator **40** to the other end of the first heat removal path **16**.

[0048] In the water path **12**, the liquid water supplied from the water supply tank **38** flows through a path (between the heat generating container **15** and the water discharge unit **40***c*) upstream of the high-temperature heat removal pipe **27** of the first heat removal path **16**, and the water (steam) heated and vaporized in the high-temperature heat removal pipe **27** flows through a path (between the heat generating container **15** and the steam introduction unit **40***a*) downstream of the high-temperature heat removal pipe **27** of the first heat removal path **16**.

[0049] The control unit controls an operation of each unit of the heat generating device **11**. The control unit mainly includes, for example, an arithmetic device (a central processing unit), and a storage unit such as a read only memory and a random access memory. The arithmetic device executes various kinds of arithmetic processing using a program, data, and the like stored in the storage unit.

[0050] The control unit is electrically connected to the pressure adjustment valve **34**, the pump **35**, the temperature sensor (not shown), the power supply (not shown), and the like. The control unit controls an output of excess heat generated by the heat generating element **14** by adjusting a pressure of the heat generating container **15**, input electric power of the heater (not shown), and the like.

[0051] The control unit functions as an output control unit that controls an output of the heater based on the temperature detected by the temperature sensor. The control unit controls the power supply to adjust input electric power to the heater, thereby maintaining the heat generating element **14** at an appropriate temperature for heat generation.

[0052] The control unit controls the pressure adjustment valve **34** and the pump **35** to adjust a hydrogen pressure difference generated between the first chamber **25** and the second chamber **26**, based on a pressure detected by the pressure sensor (not shown) provided in each of the first chamber **25** and the second chamber **26**.

[0053] The control unit performs a hydrogen occluding step of occluding hydrogen in the heat generating element **14** and a hydrogen discharging step of discharging hydrogen from the heat generating element **14**. In the present embodiment, the control unit simultaneously performs the hydrogen occluding step and the hydrogen discharging step by generating the hydrogen pressure difference between the first chamber **25** and the second chamber **26**. The control unit causes a pressure in the first chamber **25** to be higher than a pressure in the second chamber **26** by introducing the hydrogen-based gas from the introduction line **30** to the first chamber **25** and leading out the hydrogen-based gas in the second chamber **26** to the lead-out line **31**, and maintains a state in which occluding of hydrogen on the front surface of the heat generating element **14** and discharging of hydrogen on the back surface of the heat generating element **14** are simultaneously performed.

[0054] The phrase "simultaneously" in the present disclosure refers to exact simultaneous or refers to a short period of time to an extent that can be regarded as substantially simultaneous. Since hydrogen continuously permeates through the heat generating element **14** by simultaneously performing the hydrogen occluding step and the hydrogen discharging step, the excess heat can be efficiently generated in the heat generating element **14**. The control unit may alternately repeat the hydrogen occluding step and the hydrogen discharging step. That is, the control unit may first perform the hydrogen occluding step to occlude hydrogen in the heat generating element **14**, and thereafter perform the hydrogen discharging step to discharge hydrogen occluded in the heat generating element **14**. In this manner, the excess heat can be generated by the heat generating element **14** by alternately repeating the hydrogen occluding step and the hydrogen discharging step.

[0055] Next, a detailed structure of the heat generating element **14** will be described with reference to FIGS. **3** and **4**. As shown in FIG. **3**, the heat generating element **14** is formed into a bottomed cylindrical shape with one end opened and the other end closed. The heat generating element **14** includes a support **61** and a multilayer film **62**, and the multilayer film **62** is provided on one surface (for example, the front surface) of the support **61**. In the heat generating element **14**, the multilayer film **62** is formed along an outer peripheral surface and an outer bottom surface of the support **61** formed into a bottomed cylindrical shape with one end opened and the other end closed, and the multilayer film **62** is also formed into a bottomed cylindrical shape with one end opened and the other end closed. In the heat generating element **14**, the multilayer film **62** is provided at the first chamber **25** side (a high pressure side), and the support **61** is provided at the second chamber **26** side (a low pressure side) (see FIG. **1**). Due to the pressure difference generated between the first chamber **25** and the second chamber **26**, hydrogen introduced into the first chamber **25** permeates the inside of the heat generating element **14** sequentially through the multilayer film **62** and the support **61**, and moves to the second chamber **26**. That is, hydrogen permeates from the outer surface to the inner surface of the heat generating element **14**. Accordingly, the heat generating element **14** generates excess heat in a process of hydrogen permeation from the high pressure side to the low pressure side.

[0056] The support **61** is made of at least one of a porous body, a hydrogen permeable film, and a proton conductor. In this example, the support **61** is formed into a plate shape having a front surface and a back surface. The porous body has pores having a size through which the hydrogen-based gas can pass. The porous body is made of, for example, a metal, a non-metal, or ceramics. The porous body is preferably made of a material that does not hinder a reaction (hereinafter, referred to as an exothermic reaction) between the hydrogen-based gas and the multilayer film **62**. The hydrogen permeable film is made of, for example, a hydrogen storage metal or a hydrogen storage alloy. Examples of the hydrogen storage metal include Ni, Pd, V, Nb, Ta, and Ti. Examples of the hydrogen storage alloy include $LaNi_5$, $CaCu_5$, $MgZn_2$, $ZrNi_2$, $ZrCr_2$, TiFe, TiCo, Mg_2Ni, and Mg_2Cu. The hydrogen permeable film is a film having a mesh-like sheet. Examples of the proton conductor include a $BaCeO_3$-based conductor (for example, $Ba(Ce_{0.95}Y_{0.05})O_{3-\delta}$), a $SrCeO_3$-based conductor (for example, $Sr(Ce_{0.95}Y_{0.05})O_{3-\delta}$), a $CaZrO_3$-based conductor (for example, $CaZr_{0.95}Y_{0.05}O_{3-\alpha}$), a $SrZrO_3$-based conductor (for example, $SrZr_{0.9}Y_{0.1}O_{3-\alpha}$), β Al_2O_3, and β Ga_2O_3.

[0057] As shown in FIG. **4**, the multilayer film **62** is provided on the support **61**. The multilayer film **62** has a first layer **71** made of a hydrogen storage metal or a hydrogen storage alloy, and a second layer **72** made of a hydrogen storage metal or a hydrogen storage alloy different from the first layer **71**, or ceramics. A heterogeneous material interface **73** to be described later is formed between the support **61** and the first layer **71** and the second layer **72**. The multilayer film **62** is formed by alternately stacking the first layer **71** and the second layer **72** in order on one surface (for example, the front surface) of the support **61**. The first layer **71** and the second layer **72** each have five layers. The number of layers of each of the first layer **71** and the second layer **72** may be changed as appropriate. The multilayer film **62** may be formed by alternately stacking the second layer **72** and the first layer **71** in order on the front surface of the support **61**. The multilayer film **62** preferably has one or more first layers **71** and one or more second layers **72**, and one or more heterogeneous material interfaces **73** are preferably formed.

[0058] The first layer **71** is made of, for example, any one of Ni, Pd, Cu, Mn, Cr, Fe, Mg, Co, and an alloy thereof. An alloy for forming the first layer **71** is preferably an alloy made of two or more of Ni, Pd, Cu, Mn, Cr, Fe, Mg, and Co. The alloy for forming the first layer **71** may be an alloy obtained by adding an additive element to Ni, Pd, Cu, Mn, Cr, Fe, Mg, and Co.

[0059] The second layer **72** is made of, for example, any one of Ni, Pd, Cu, Mn, Cr, Fe, Mg, Co, an alloy thereof, and SiC. An alloy for forming the second layer **72** is preferably an alloy made of two or more of Ni, Pd, Cu, Mn, Cr, Fe, Mg, and Co. The alloy for forming the second layer **72** may be an alloy obtained by adding an additive element to Ni, Pd, Cu, Mn, Cr, Fe, Mg, and Co.

[0060] A combination of the first layer **71** and the second layer **72** is preferably Pd—Ni, Ni—Cu, Ni—Cr, Ni—Fe, Ni—Mg, and Ni—Co when types of elements are expressed as "first layer **71**-second layer **72** (second layer **72**-first layer **71**)". When the second layer **72** is made of ceramics, the "first layer **71**-second layer **72**" is preferably Ni—SiC.

[0061] As shown in FIG. **5**, hydrogen atoms permeate through the heterogeneous material interface **73**. FIG. **5** is a schematic diagram showing a state in which hydrogen atoms in a metal lattice of the first layer **71** permeate through the heterogeneous material interface **73** and move to a metal lattice of the second layer **72** in the first layer **71** and the second layer **72** each made of a hydrogen storage metal having a face-centered cubic structure. It is known that hydrogen is light and hops in a manner of quantum diffusion in hydrogen-occupied sites (octahedral sites or tetrahedral sites) of substance A and substance B. Therefore, hydrogen occluded in the heat generating element **14** hops in the multilayer film **62** in a manner of quantum diffusion. In the heat generating element **14**, hydrogen permeates through the first layer **71**, the heterogeneous material interface **73**, and the second layer **72** in a manner of quantum diffusion.

[0062] A thickness of each of the first layer **71** and the second layer **72** is preferably less than 1000 nm. When the thickness of each of the first layer **71** and the second layer **72** is 1000 nm or more, hydrogen is less likely to permeate through the multilayer film **62**. When the thickness of each of the first layer **71** and the second layer **72** is less than 1000 nm, a nano-structure that does not exhibit property can be maintained. The thickness of each of the first layer **71** and the second layer **72** is more preferably less than 500 nm. When the thickness of each of the first layer **71** and the second layer **72** is less than 500 nm, a nano-structure that does not exhibit a bulk property at all can be maintained.

[0063] Next, an example of a method for manufacturing the heat generating element **14** will be described. First, the support **61** formed into a bottomed cylindrical shape is prepared. Next, the multilayer film **62** is formed on the outer surface of the support **61** using a wet film forming method. Accordingly, the heat generating element **14** having a bottomed cylindrical shape can be manufactured. Examples of the wet film forming method include a spin coating method, a spray coating method, and a dipping method. The multilayer film **62** may be formed by using an atomic layer deposition (ALD) method, or the multilayer film **62** may be formed on the support **61** while rotating the support **61** by using a sputtering device including a rotation mechanism that rotates the support **61**. The multilayer film **62** is not limited to being provided on the outer surface of the support **61**, and may be provided on an inner surface of the support **61**, or on two surfaces of the support **61**.

[0064] For example, the heat generating element **14** having a bottomed cylindrical shape can be manufactured by forming a sheet-shaped base using a material constituting the support **61**, preparing a heat generating sheet by forming the multilayer film **62** on a surface of the sheet-shaped base, and winding the heat generating sheet around the outer surface of the support **61** formed into a bottomed cylindrical shape. In this case, the multilayer film **62** can be formed by using, for example, an evaporation device to make a hydrogen storage metal or a hydrogen storage alloy for forming the first layer **71** or the second layer **72** into a gas phase state, and then alternately forming the first layer **71** and the second layer **72** on the surface of the sheet-shaped base by aggregation or adsorption. The first layer **71** and the second layer **72** are preferably formed continuously in a vacuum state. Accordingly, between the first layer **71** and the second layer **72**, no natural oxide film is formed and only the heterogeneous material interface **73** is formed. The evaporation device may be a physical evaporation device in which the hydrogen storage metal or the hydrogen storage alloy is evaporated by a physical method. The physical evaporation device is preferably a sputtering device, a vacuum evaporation device, and a chemical vapor deposition (CVD) device. The hydrogen storage metal or the hydrogen storage alloy may be deposited on the front surface of the support **61** by an electroplating method, and the first layer **71** and the second layer **72** may be alternately formed.

[0065] In the heat generating device **11**, flow directions of the first heat removal fluid and the second heat removal fluid face each other. Heat from a part (an upper part) of the heat generating element **14** in the vicinity of the high-temperature outlet **27*b*** of the high-temperature heat removal pipe **27** is removed by the second heat removal fluid (cold water) through the first heat removal fluid (steam), so that abnormal temperature rise is prevented. A temperature of a part (a lower part) of the heat generating element **14** in the vicinity of the high-temperature inlet **27*a*** of the high-temperature heat removal pipe **27** is increased by the second heat removal fluid (warm water), so that a temperature decrease is prevented. In this way, the heat generating device **11** can achieve a uniform temperature of the heat generating element **14**. In the heat generating device **11**, since there is no portion where the temperature of the heat generating element **14** is extremely high, damage to the heat generating element **14** is prevented. Further, the heat generating element **14** can be stably used within an excess heat generation temperature range.

[0066] The excess heat of the heat generating element **14** is transferred to the first heat removal fluid via the high-temperature heat removal pipe **27** by convection caused by the hydrogen-based gas in the heat generating container **15** and radiation. The boiler **10** can generate steam (the first heat removal fluid) by heating and vaporizing liquid water (the first heat removal fluid) flowing through the high-temperature heat removal pipe **27** by the excess heat of the heat generating element **14**.

[0067] The heat generating element **14** can heat the first heat removal fluid by at least one heating method selected from conduction, convection, and radiation. For example, by bringing the heat generating element **14** into contact with the high-temperature heat removal pipe **27**, the excess heat of the heat generating element **14** is transferred to the first heat removal fluid by conduction, convection caused by the hydrogen-based gas, and radiation.

[0068] Since the heat generating element **14** generates heat using hydrogen, the heat generating element **14** can be said as a clean heat energy source without generating a greenhouse gas such as carbon dioxide. Hydrogen to be used is generated from water and is thus inexpensive. Unlike a nuclear fission reaction, heat generation of the heat generating element **14** is safe since there is no chain reaction.

[0069] The present invention is not limited to the first embodiment and can be modified as appropriate without departing from the scope of the present invention. Hereinafter, modifications of the first embodiment will be described. In the drawings and a description of the modifications, the same or equivalent components and members as those in the first embodiment are denoted by the same reference numerals. The repeated description with the first embodiment is omitted as appropriate, and configurations different from those in the first embodiment will be mainly described.

First Modification

[0070] The heat generating device **11** may include a heat generating element **75** shown in FIG. **6** instead of the heat generating element **14**. In the heat generating element **75** as shown in FIG. **6**, a multilayer film **62** of a stacked body further has a third layer **77** in addition to the first layer **71** and the second layer **72**. The third layer **77** is made of a hydrogen storage metal, a hydrogen storage alloy, or ceramics different from the first layer **71** and the second layer **72**. A thickness of the third layer **77** is preferably less than 1000 nm. In FIG. **6**, the first layer **71**, the second layer **72**, and the third layer **77** are stacked on the front surface of the support **61** in order of the first layer **71**, the second layer **72**, the first layer **71**, and the third layer **77**. The first layer **71**, the second layer **72**, and the third layer **77** may be stacked on the front surface of the support **61** in order of the first layer **71**, the third layer **77**, the first layer **71**, and the second layer **72**. That is, the multilayer film **62** has a stacking structure in which the first layer **71** is provided between the second layer **72** and the third layer **77**. The multilayer film **62** preferably has one or more third layers **77**. Similarly to the heterogeneous material interface **73**, the hydrogen atoms permeate through a heterogeneous material interface **78** formed between the first layer **71** and the third layer **77**.

[0071] The third layer **77** is made of, for example, any one of Ni, Pd, Cu, Cr, Fe, Mg, Co, an alloy thereof, SiC, CaO, Y_2O_3, TiC, LaB_6, SrO, and BaO. An alloy for forming the third layer **77** is preferably an alloy made of two or more of Ni, Pd, Cu, Cr, Fe, Mg, and Co. The alloy for forming the third layer **77** may be an alloy obtained by adding an additive element to Ni, Pd, Cu, Cr, Fe, Mg, and Co.

[0072] In particular, the third layer **77** is preferably made of any one of CaO, Y_2O_3, TiC, LaB_6, SrO, and BaO. In the heat generating element **75** having the third layer **77** made of any one of CaO, Y_2O_3, TiC, LaB_6, SrO, and BaO, an occluding amount of hydrogen is increased, an amount of hydrogen permeating through the heterogeneous material interface **73** and the heterogeneous material interface **78** is increased, and a high output of excess heat can be achieved. The thickness of the third layer **77** made of any one of CaO, Y_2O_3, TiC, LaB_6, SrO, and BaO is preferably 10 nm or less. Accordingly, the hydrogen atoms easily permeate through the multilayer film **62**. The third layer **77** made of any one of CaO, Y_2O_3, TiC, LaB_6, SrO, and BaO may not be formed into a complete film shape and may be formed into an island shape. The first layer **71** and the third layer **77** are preferably formed continuously in a vacuum state. Accordingly, between the first layer **71** and the third layer **77**, a natural oxide film is not formed and only the heterogeneous material interface **78** is formed.

[0073] A combination of the first layer **71**, the second layer **72**, and the third layer **77** is preferably Pd—CaO—Ni, Pd—Y_2O_3—Ni, Pd—TiC—Ni, Pd—LaB_6—Ni, Ni—CaO—Cu, Ni—Y_2O_3—Cu, Ni—TiC—Cu, Ni—LaB_6—Cu, Ni—Co—Cu, Ni—CaO—Cr, Ni—Y_2O_3—Cr, Ni—TiC—Cr, Ni—LaB_6—Cr, Ni—CaO—Fe, Ni—Y_2O_3—Fe, Ni—TiC—Fe, Ni—LaB_6—Fe, Ni—Cr—Fe, Ni—CaO—Mg, Ni—Y_2O_3—Mg, Ni—TiC—Mg, Ni—LaB_6—Mg, Ni—CaO—Co, Ni—Y_2O_3—Co, Ni—TiC—Co, Ni—LaB_6—Co, Ni—CaO—SiC, Ni—Y_2O_3—SiC, Ni—TiC—SiC, and Ni—LaB_6—SiC when types of elements are expressed as "first layer **71**-third layer **77**-second layer **72**".

Second Modification

[0074] The heat generating device **11** includes a heat generating element **80** shown in FIG. **7** instead of the heat generating element **14**. In the heat generating element **80** as shown in FIG. **7**, a multilayer film **62** of a stacked body further has a fourth layer **82** in addition to the first layer **71**, the second layer **72**, and the third layer **77**. The fourth layer **82** is made of a hydrogen storage metal, a hydrogen storage alloy, or ceramics different from the first layer **71**, the second layer **72**, and the third layer **77**. A thickness of the fourth layer **82** is preferably less than 1000 nm. In FIG. **7**, the first layer **71**, the second layer **72**, the third layer **77**, and the fourth layer **82** are stacked on the front surface of the support **61** in order of the first layer **71**, the second layer **72**, the first layer **71**, the third layer **77**, the first layer **71**, and the fourth layer **82**. The first layer **71**, the second layer **72**, the third layer **77**, and the fourth layer **82** may be stacked on the front surface of the support **61** in order of the first layer **71**, the fourth layer **82**, the first layer **71**, the third layer **77**, the first layer **71**, and the second layer **72**. That is, the multilayer film **62** has a stacking structure in which the second layer **72**, the third layer **77**, and the fourth layer **82** are stacked in any order and the first layer **71** is provided between the second layer **72** and the third layer **77**, between the third layer **77** and the fourth layer **82**, and between the second layer **72** and the fourth layer **82**. The multilayer film **62** preferably has one or more fourth layers **82**. Similarly to the heterogeneous material interface **73** and the heterogeneous material interface **78**, the hydrogen atoms permeate through a heterogeneous material interface **83** formed between the first layer **71** and the fourth layer **82**.

[0075] The fourth layer **82** is made of, for example, any one of Ni, Pd, Cu, Cr, Fe, Mg, Co, an alloy thereof, SiC, CaO, Y_2O_3, TiC, LaB_6, SrO, and BaO. An alloy for forming the fourth layer **82** is preferably an alloy made of two or more of Ni, Pd, Cu, Cr, Fe, Mg, and Co. The alloy for forming the fourth layer **82** may be an alloy obtained by adding an additive element to Ni, Pd, Cu, Cr, Fe, Mg, and Co.

[0076] In particular, the fourth layer **82** is preferably made of any one of CaO, Y_2O_3, TiC, LaB_6, SrO, S and BaO. In the heat generating element **80** having the fourth layer **82** made of any one of CaO, Y_2O_3, TiC, LaB_6, SrO, and BaO, an occluding amount of hydrogen is increased, an amount of hydrogen permeating through the heterogeneous material interface **73**, the heterogeneous material interface **78**, and the heterogeneous material interface **83** is increased, and a high output of excess heat can be achieved. A thickness of the fourth layer **82** made of any one of CaO, Y_2O_3, TiC, LaB_6, SrO, and BaO is preferably 10 nm or less. Accordingly, the hydrogen atoms easily permeate through the multilayer film **62**. The fourth layer **82** made of any one of CaO, Y_2O_3, TiC, LaB_6, SrO, and BaO may not be formed into a complete film shape and may be formed into an island shape. The first layer **71** and the fourth layer **82** are preferably formed continuously in a vacuum state. Accordingly, between the first layer **71** and the fourth layer **82**, no natural oxide film is formed and only the heterogeneous material interface **83** is formed.

[0077] A combination of the first layer **71**, the second layer **72**, the third layer **77**, and the fourth layer **82** is preferably Ni—CaO—Cr—Fe, Ni—Y_2O_3—Cr—Fe, Ni—TiC—Cr—Fe, and Ni—LaB_6—Cr—Fe when types of elements are expressed as "first layer **71**-fourth layer **82**-third layer **77**-second layer **72**".

Second Embodiment

[0078] In the first embodiment, the high-temperature heat removal pipe **27** and the low-temperature heat removal pipe **28** are spirally provided. However, in the second embodiment, a high-temperature heat removal pipe and a low-temperature heat removal pipe are provided in a vertical direction.

[0079] As shown in FIG. **8**, a boiler **100** includes a heat generating device **101**. Although not shown, the boiler **100** further includes a water path and a control unit as in the first embodiment, and is configured to heat water flowing through the water path by heat generated by the heat generating device **101** to generate steam. In the boiler **100**, a configuration of the heat generating device **101** is different from that of the first embodiment, and other configurations are the same as those of the first embodiment.

[0080] The heat generating device **101** includes heat generating elements **104***a* and **104***b*, a heat generating container **105**, a first heat removal path **106**, and a second heat removal path **107**. A heater **108** is provided between the heat generating element **104***a* and the heat generating element **104***b*. Although not shown, the heat generating device **101** further includes a temperature adjustment unit and a hydrogen circulation line similarly to the first embodiment, and is configured such that the temperature of the heat generating elements **104***a* and **104***b* is adjusted by the temperature adjustment unit and a hydrogen-based gas is introduced into the heat generating container **105** through the hydrogen circulation line.

[0081] As shown in FIG. **9**, each of the heat generating elements **104***a* and **104***b* is formed into a cylindrical shape. The heat generating element **104***a* and the heat generating element **104***b* are concentrically arranged. The heat generating element **104***a* is provided inside the heat generating element **104***b*. An axial direction of the heat generating elements **104***a* and **104***b* is the vertical direction. In the second embodiment, excess heat can be generated by the heat generating elements **104***a* and **104***b* by alternately repeating a hydrogen occluding step and a hydrogen discharging step by the control unit (not shown). That is, the control unit first performs the hydrogen occluding step to occlude hydrogen in the heat generating elements **104***a* and **104***b*, and thereafter performs the hydrogen discharging step to discharge hydrogen occluded in the heat generating elements **104***a* and **104***b*. In the hydrogen occluding step, a hydrogen-based gas is supplied into the heat generating container **105**. In the hydrogen discharging step, the inside of the heat generating container **105** is vacuum evacuated and the heat generating elements **104***a* and **104***b* are heated by the heater **108**. In this manner, the excess heat can be generated by the heat generating elements **104***a* and **104***b* by alternately repeating the hydrogen occluding step and the hydrogen discharging step.

[0082] The heat generating container **105** is a hollow container, and accommodates the heat generating elements **104***a* and **104***b* therein (see FIG. **8**). The heat generating container **105** includes a cylindrical side wall **111**, an upper base **112** provided at an upper end of the side wall **111**, and a lower base **113** provided at a lower end of the side wall **111**. The heat generating container **105** is a sealed container in which an opening at the upper end of the side wall **111** is closed by the upper base **112**, and an opening at the lower end of the side wall **111** is closed by the lower base **113**. The side wall **111** is formed into a cylindrical shape in the present embodiment, but is not limited thereto, and may be formed into an elliptical cylindrical shape or a rectangular cylindrical shape, for example. The side wall **111** has an upper header **115** at the upper end and a lower header **116** at the lower end. The upper header **115** and the lower header **116** constitute a part of the second heat removal path **107** to be described later. In FIG. **8**, an axial direction of the heat generating container **105** (the side wall **111**) and the axial direction of the heat generating elements **104***a* and **104***b* are parallel to the vertical direction of the paper surface.

[0083] The first heat removal path **106** is configured to allow the first heat removal fluid heated by the heat generating elements **104***a* and **104***b* to flow therethrough. The first heat removal path **106** includes a high-temperature heat removal pipe **127** provided inside the heat generating element **104***a*. The high-temperature heat removal pipe **127** extends in the axial direction of the heat generating elements **104***a* and **104***b*. In this example, an outer surface of the high-temperature heat removal pipe **127** is in contact with an inner surface of the heat generating element **104***a*. The high-temperature heat removal pipe **127** has a high-temperature inlet **127***a* provided at the lower end of the side wall **111** and a high-temperature outlet **127***b* provided at the upper end of the side wall **111**. The high-temperature inlet **127***a* is connected to the lower header **116**. A cross-sectional shape of the high-temperature heat removal pipe **127** is circular in this example, but is not particularly limited, and may be rectangular or the like.

[0084] In the first heat removal path **106**, liquid water that has entered the high-temperature heat removal pipe **127** from the high-temperature inlet **127***a* is heated by the heat generating elements **104***a* and **104***b* in the high-temperature heat removal pipe **127**, and exits from the high-temperature outlet **127***b* as vaporized water (steam). In the boiler **100** of the present embodiment, a pressure of the high-temperature outlet **127***b* or a pressure of a separator (not shown) is assumed to be 1 atm (0.1 MPa), and the steam at 100° C., for example, is discharged from the first heat removal path **106**. However, by applying pressure to the high-temperature outlet **127***b* or the separator (not shown), liquid water (warm water) having a temperature exceeding 100° C. can be discharged from the first heat removal path **106**.

[0085] The second heat removal path **107** is configured to allow the second heat removal fluid to flow therethrough in a direction opposite to a direction in which the first heat removal fluid flows. The second heat removal path **107** includes a plurality of low-temperature heat removal pipes **128** provided along an outer periphery of the heat generating element **104***b*. The plurality of low-temperature heat removal pipes **128** extend in the axial direction of the heat generating elements **104***a* and **104***b*. The plurality of low-temperature heat removal pipes **128** are disposed between the upper header **115** and the lower header **116**. Each of the low-temperature heat removal pipes **128** has a low-temperature inlet **128***a* provided at the upper end of the side wall **111** and a low-temperature outlet **128***b* provided at the lower end of the side wall **111**. The low-temperature inlet **128***a* is connected to the upper header **115**. The low-temperature outlet **128***b* is connected to the lower header **116**. The low-temperature outlet **128***b* of each of the low-temperature heat removal pipes **128** is connected to the high-temperature inlet **127***a* of the high-temperature heat removal pipe **127** via the lower header **116**. A cross-sectional shape of each of the low-temperature heat removal pipes **128** is circular in this example, but is not particularly limited, and may be rectangular or the like.

[0086] In the heat generating device **101**, flow directions of the first heat removal fluid and the second heat removal fluid face each other. That is, in the heat generating device **101**, along the axial direction of the heat generating elements **104***a* and **104***b*, the second heat removal fluid flows from an upper side to a lower side of the heat generating container **105**, and the first heat removal fluid flows from the lower side to the upper side of the heat generating container **105**. The second heat removal fluid (cold water) that has entered the low-temperature heat removal pipe **128** from the low-temperature inlet **128***a* is heated by the heat generating elements **104***a* and **104***b* in the process of flowing through the low-temperature heat removal pipe **128**, and the temperature of the second heat removal fluid increases. The second heat removal fluid (warm water) heated in the low-temperature heat removal pipe **128** exits from the low-temperature outlet **128***b* and enters the high-temperature inlet **127***a* of the high-temperature heat removal pipe **127** as the first heat removal fluid (warm water). The first heat removal fluid (warm water) in the high-temperature heat removal pipe **127** is further heated by the heat generating elements **104***a* and **104***b*, and exits from the high-temperature outlet **127***b* as vaporized water (steam). Heat from a part (an upper part) of each of the heat generating elements **104***a* and **104***b* in the vicinity of the high-temperature outlet **127***b* of the high-temperature heat removal pipe **127** is removed by the second heat removal fluid (cold water), so that abnormal temperature rise is prevented. A temperature of a part (a lower part) of each of the heat generating elements **104***a* and **104***b* in the vicinity of the high-temperature inlet **127***a* of the high-temperature heat removal pipe **127** is increased by the second heat removal fluid (warm water), so that a temperature decrease is prevented. In this way, the heat generating device **101** can achieve a uniform temperature of the heat generating elements **104***a* and **104***b* as in the first embodiment. In the heat generating device **101**, since there is no portion where the temperature of the heat generating elements **104***a* and **104***b* is extremely high, damage to the heat generating elements **104***a* and **104***b* is prevented. Further, the heat generating elements **104***a* and **104***b* can be stably used within an excess heat generation temperature range.

[0087] The excess heat of the heat generating elements **104***a* and **104***b* is transferred to the first heat removal fluid via the high-temperature heat removal pipe **127** by conduction, convection caused by the hydrogen-based gas, and radiation. The boiler **100** can generate steam (the first heat removal fluid) by heating and vaporizing liquid water (the first heat removal fluid) flowing through the high-temperature heat removal pipe **127** by the excess heat of the heat generating elements **104***a* and **104***b*.

[0088] The heat generating device **101** includes the heat generating element **104***a* and the heat generating element **104***b*, but the number of heat generating elements can be changed as appropriate. A shape of the heat generating element is not limited to the cylindrical shape, and may be a plate shape or the like.

REFERENCE SIGN LIST

[0089] **10**, **100** boiler

[0090] **11**, **101** heat generating device

[0091] **14**, **75**, **80**, **104***a*, **104***b* heat generating element

[0092] **15**, **105** heat generating container

[0093] **16**, **106** first heat removal path

[0094] **17**, **107** second heat removal path

[0095] **27**, **127** high-temperature heat removal pipe

[0096] **28**, **128** low-temperature heat removal pipe

[0097] **61** support

[0098] **62** multilayer film

[0099] **71** first layer

[0100] **72** second layer

[0101] **77** third layer

[0102] **82** fourth layer

[0103] **73**, **78**, **83** heterogeneous material interface

1. A heat generating device comprising:

a heat generating container configured to allow a hydrogen-based gas containing hydrogen to be introduced;

a heat generating element provided inside the heat generating container and configured to generate heat by occluding and discharging the hydrogen;

a first heat removal path configured to allow a first heat removal fluid heated by the heat generating element to flow therethrough; and

a second heat removal path configured to allow a second heat removal fluid to flow therethrough in a direction opposite to a direction in which the first heat removal fluid flows.

2. The heat generating device according to claim **1**, wherein

the first heat removal path includes a high-temperature heat removal pipe spirally provided around the heat generating element, and

the second heat removal path includes a low-temperature heat removal pipe spirally provided around the first heat removal path.

3. The heat generating device according to claim **2**, wherein

the heat generating container has a cylindrical side wall,

the high-temperature heat removal pipe has a high-temperature inlet provided at a lower end of the side wall and a high-temperature outlet provided at an upper end of the side wall, and

the low-temperature heat removal pipe has a low-temperature inlet provided at the upper end and a low-temperature outlet provided at the lower end.

4. The heat generating device according to claim **1**, wherein

the heat generating element has a cylindrical shape,

the first heat removal path includes a high-temperature heat removal pipe provided inside the heat generating element,

the second heat removal path includes a plurality of low-temperature heat removal pipes provided along an outer periphery of the heat generating element, and

the high-temperature heat removal pipe and the plurality of low-temperature heat removal pipes extend in an axial direction of the heat generating element.

5. The heat generating device according to claim **4**, wherein

the heat generating container has a cylindrical side wall,

the high-temperature heat removal pipe has a high-temperature inlet provided at a lower end of the side wall and a high-temperature outlet provided at an upper end of the side wall, the plurality of low-temperature heat removal pipes each has a low-temperature inlet provided at the upper end and a low-temperature outlet provided at the lower end, and

the high-temperature inlet of the high-temperature heat removal pipe and the low-temperature outlet of each of the plurality of low-temperature heat removal pipes are connected.

6. The heat generating device according to claim **1**, wherein

the heat generating element heats the first heat removal fluid by at least one heating method selected from conduction, convection, and radiation.

7. A boiler comprising:

the heat generating device according to claim **1**, wherein

the first heat removal path is supplied with water as the first heat removal fluid, and

the water is heated by the heat generating element, and steam or warm water is discharged from the first heat removal path.

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