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Kobayashi et al.

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(45) **Date of Patent:** **May 5, 2026**

(54) **HEAT GENERATION DEVICE, HEAT UTILIZATION SYSTEM AND FILM-LIKE HEAT GENERATION ELEMENT**

(58) **Field of Classification Search**
CPC F24V 30/00; F28C 20/003; Y02E 60/14; Y02E 60/32; F01K 3/188
See application file for complete search history.

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(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 1022 days.

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Primary Examiner — Ko-Wei Lin

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(30) **Foreign Application Priority Data**

Nov. 19, 2019 (JP) 2019-208483

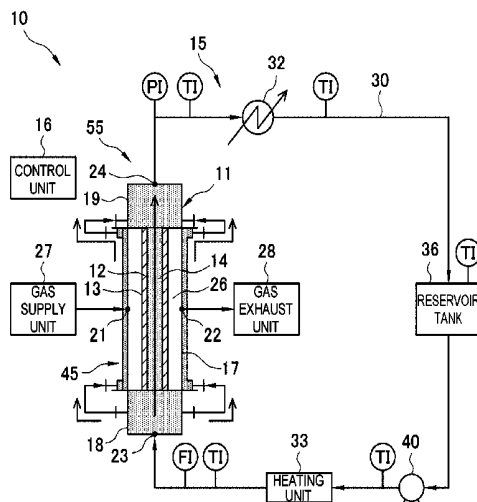
(57) **ABSTRACT**

(51) **Int. Cl.**
F28D 20/00 (2006.01)
F24V 30/00 (2018.01)
G21B 3/00 (2006.01)

A heat generating device includes: a sealed container; a tubular body provided in a hollow portion of the sealed container; a heat generating element provided on an outer surface of the tubular body and configured to generate heat by occluding and discharging hydrogen supplied to the hollow portion; and a flow path formed by an inner surface of the tubular body and through which configured to allow a fluid that exchanges heat with the heat generating element to flow. The heat generating element includes a base made of a hydrogen storage metal, and a multilayer film provided on the base. The multilayer film has a first layer made of a hydrogen storage metal and having a thickness of less than 1000 nm, and a second layer made of a hydrogen storage

(Continued)

(52) **U.S. Cl.**
CPC **F24V 30/00** (2018.05); **G21B 3/002** (2013.01)



metal, which is different from that of the first layer, and having a thickness of less than 1000 nm.

10 Claims, 20 Drawing Sheets

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FIG. 1

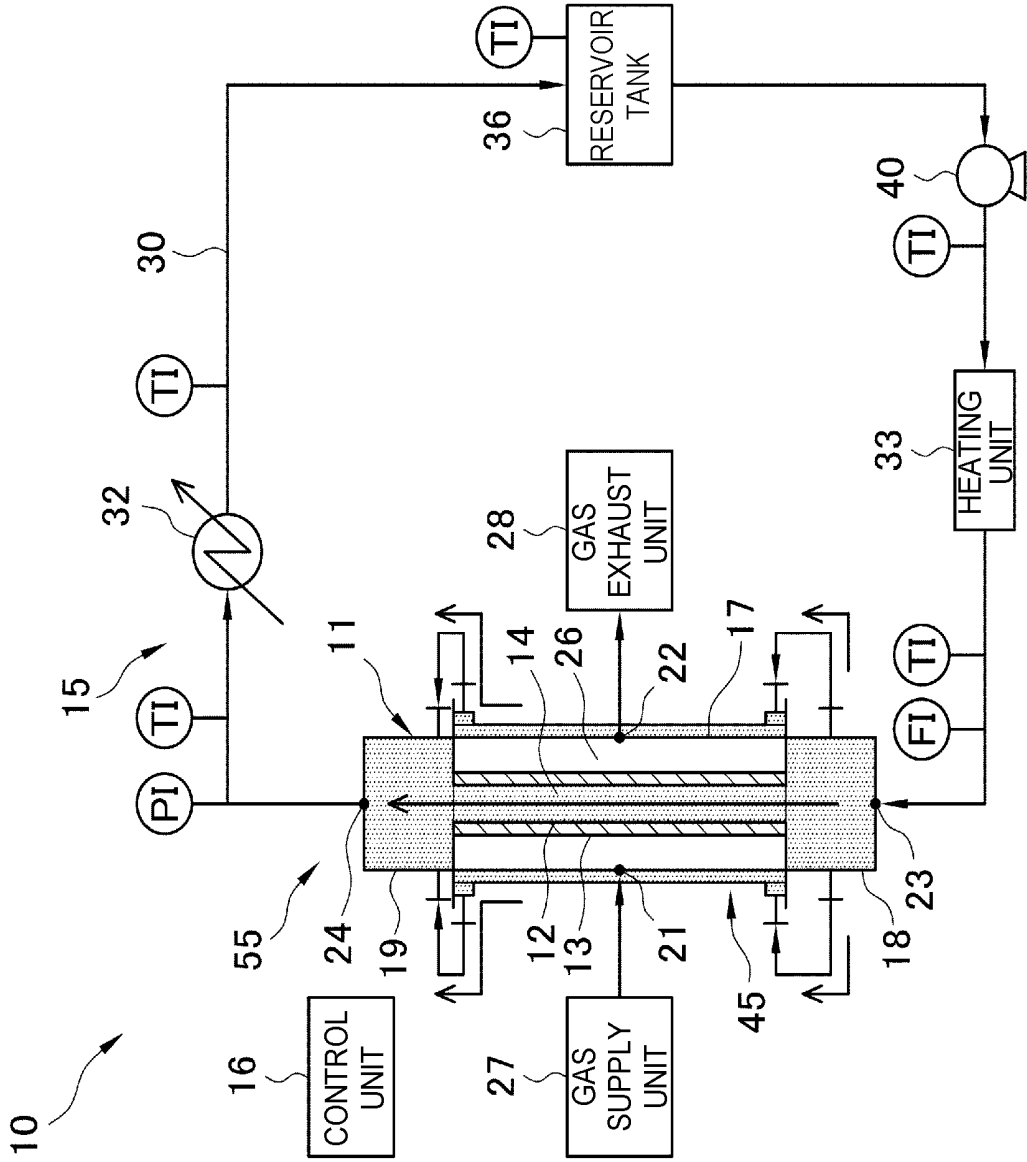


FIG. 2

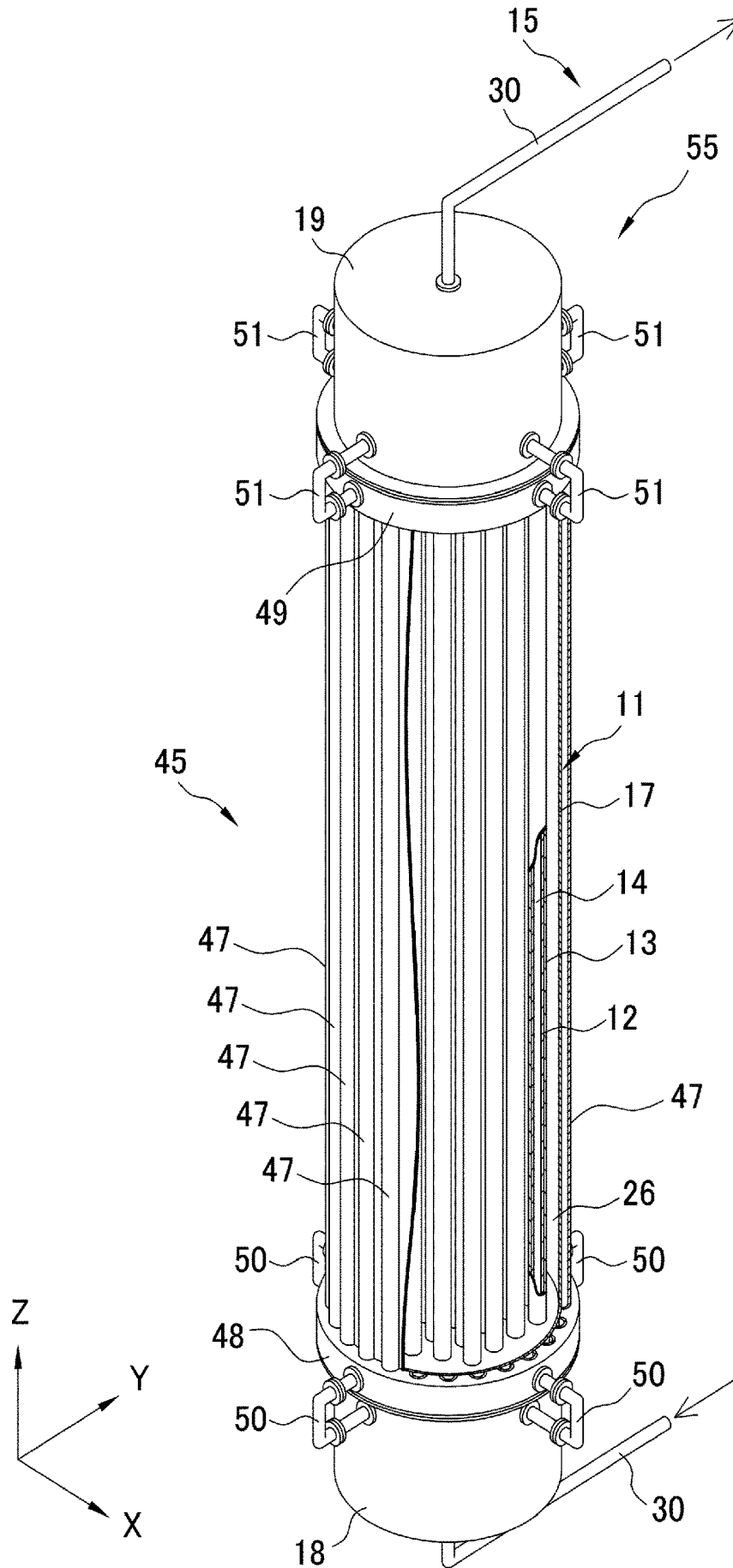


FIG. 3

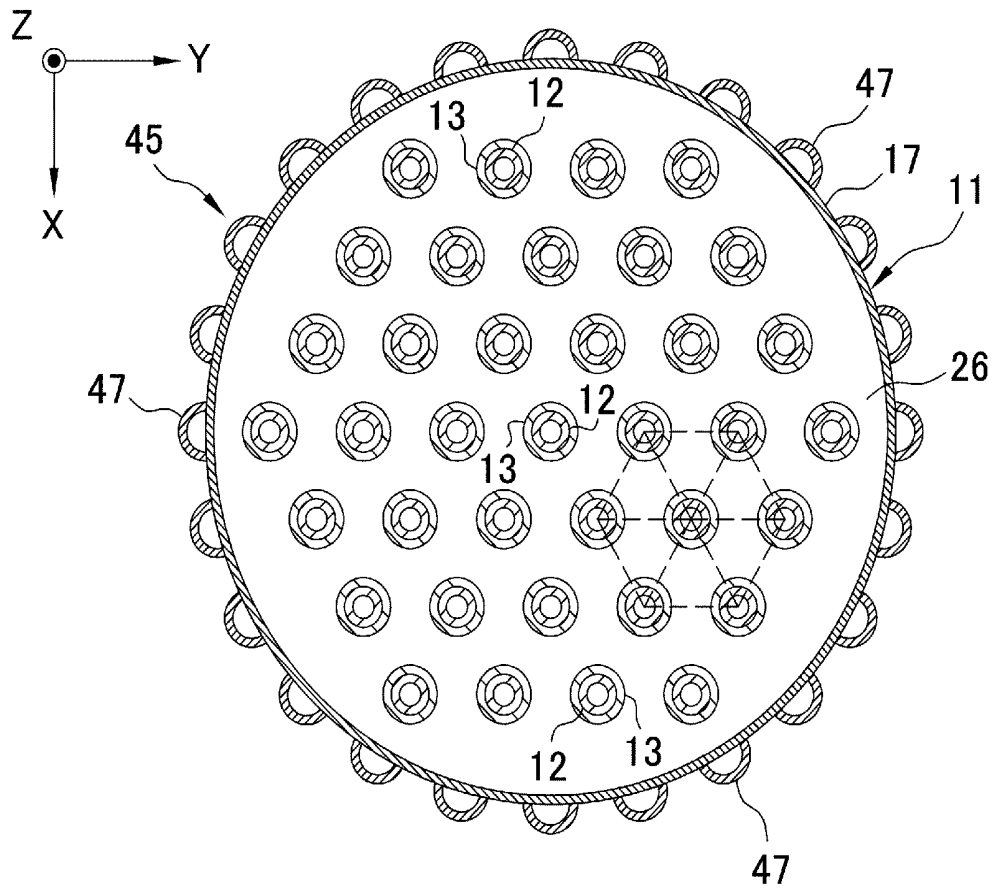


FIG. 5

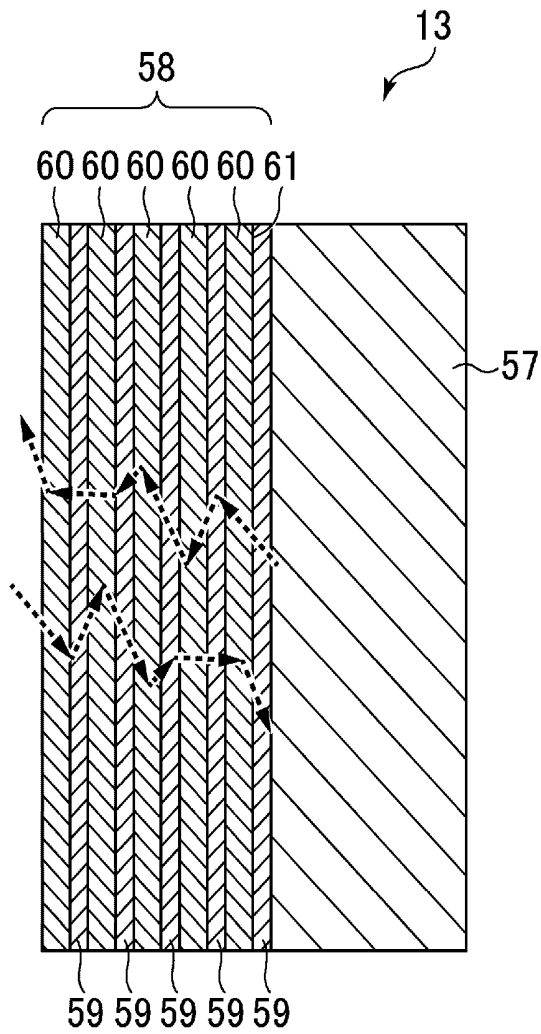


FIG. 6

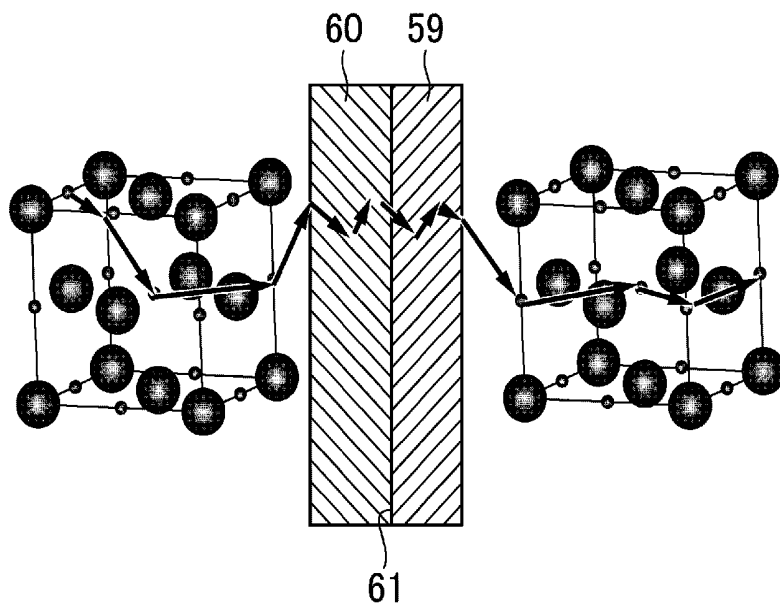


FIG. 9

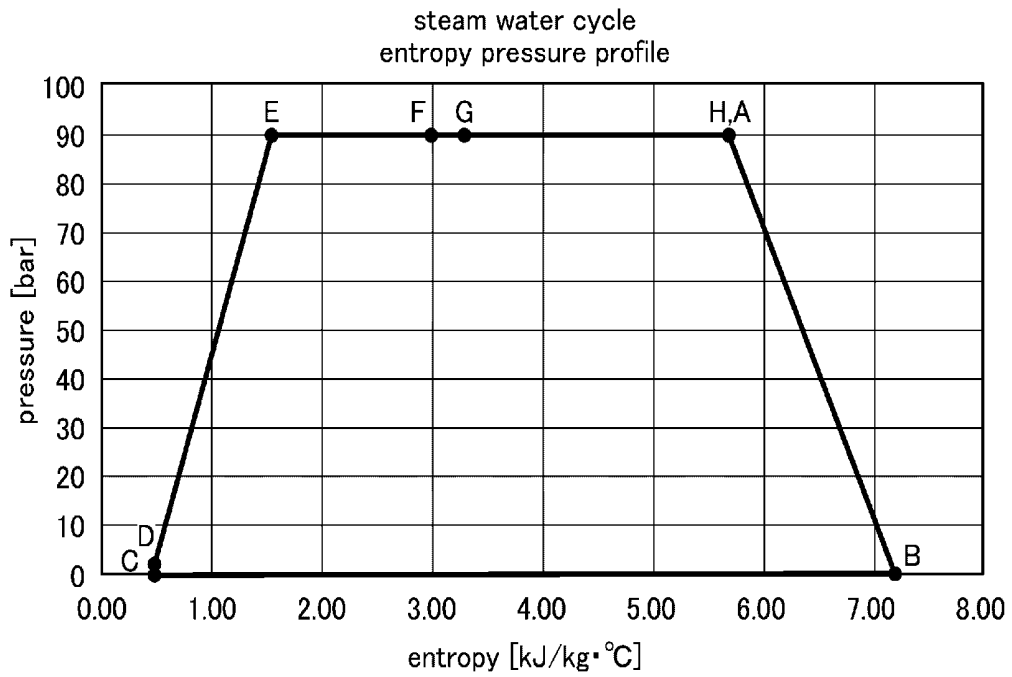


FIG. 10

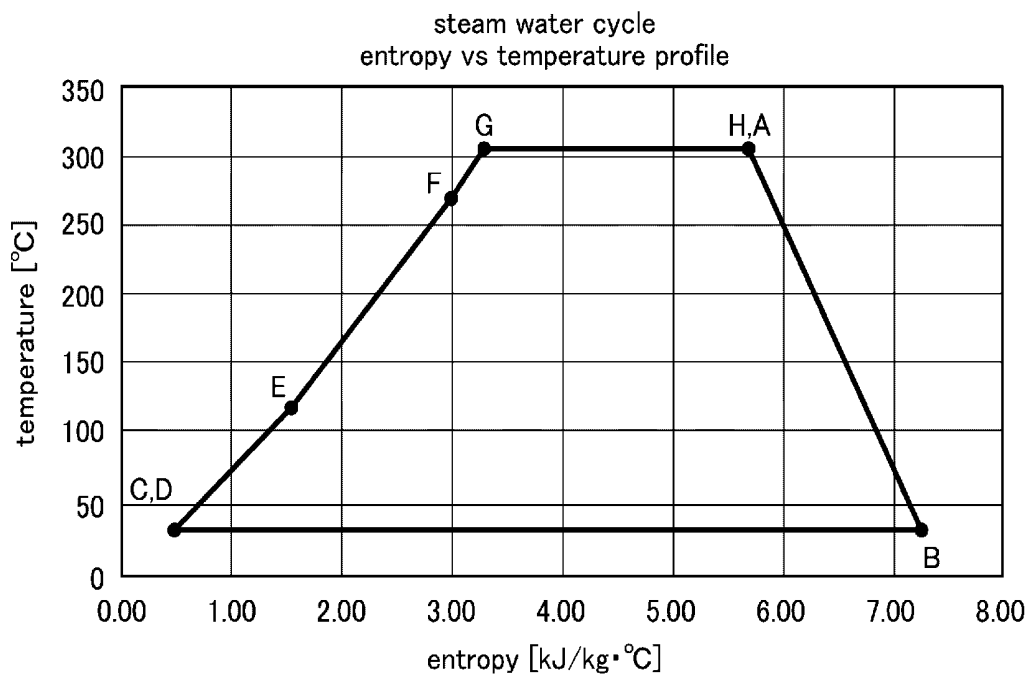


FIG. 11

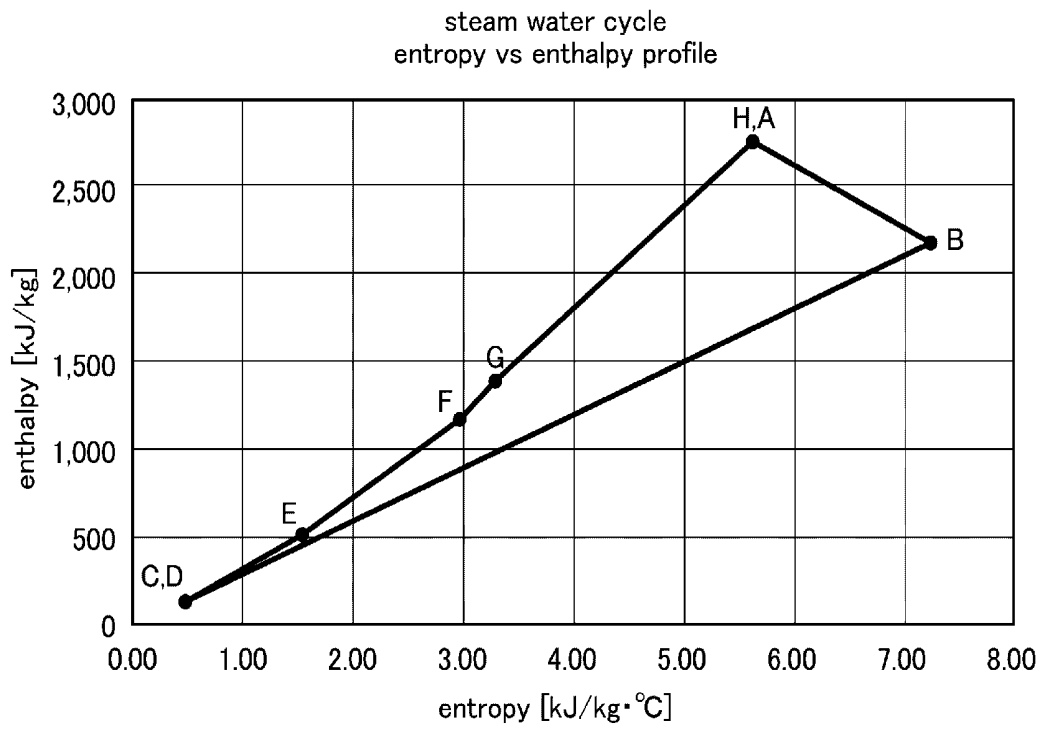


FIG. 14

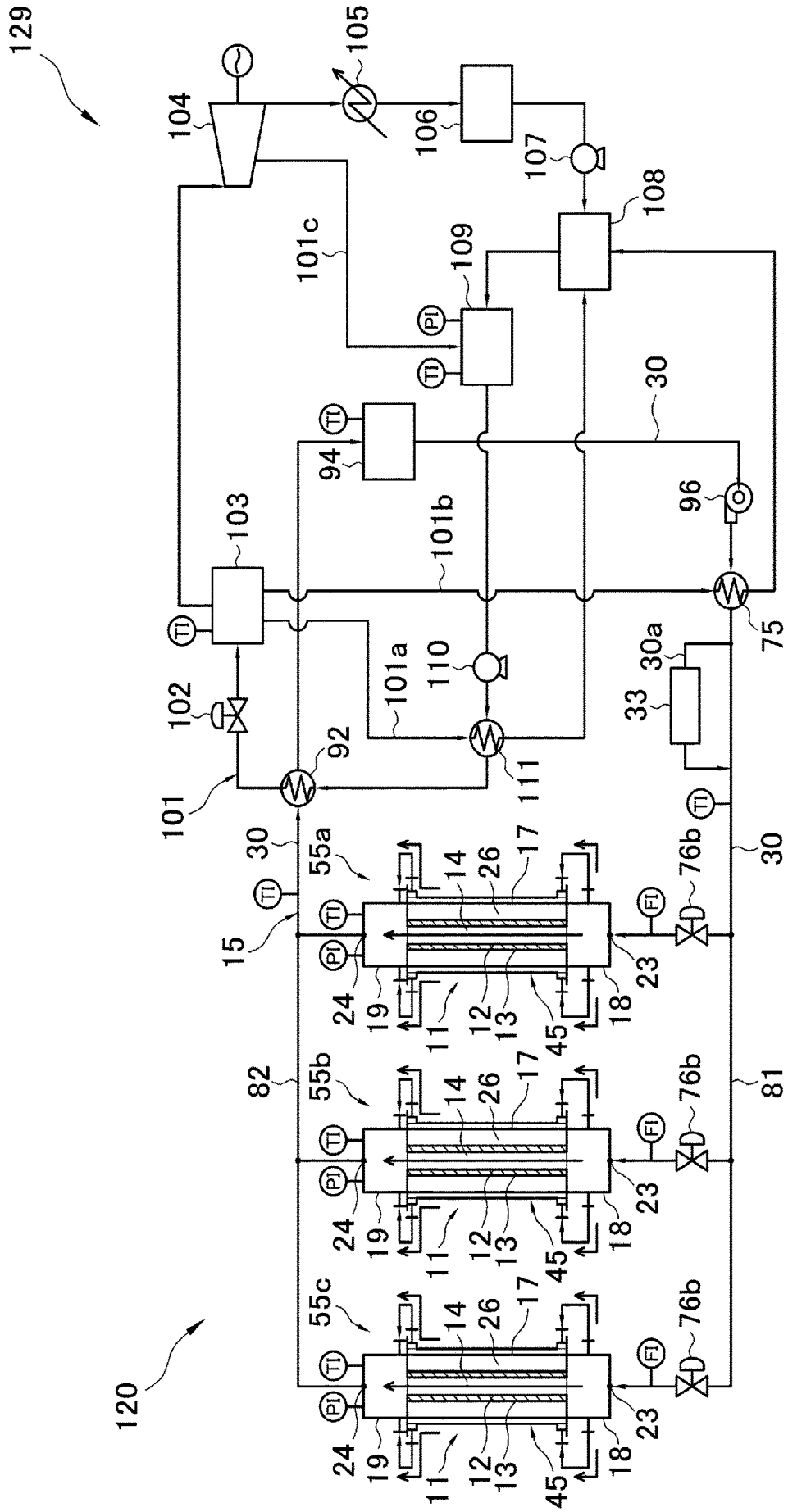


FIG. 15

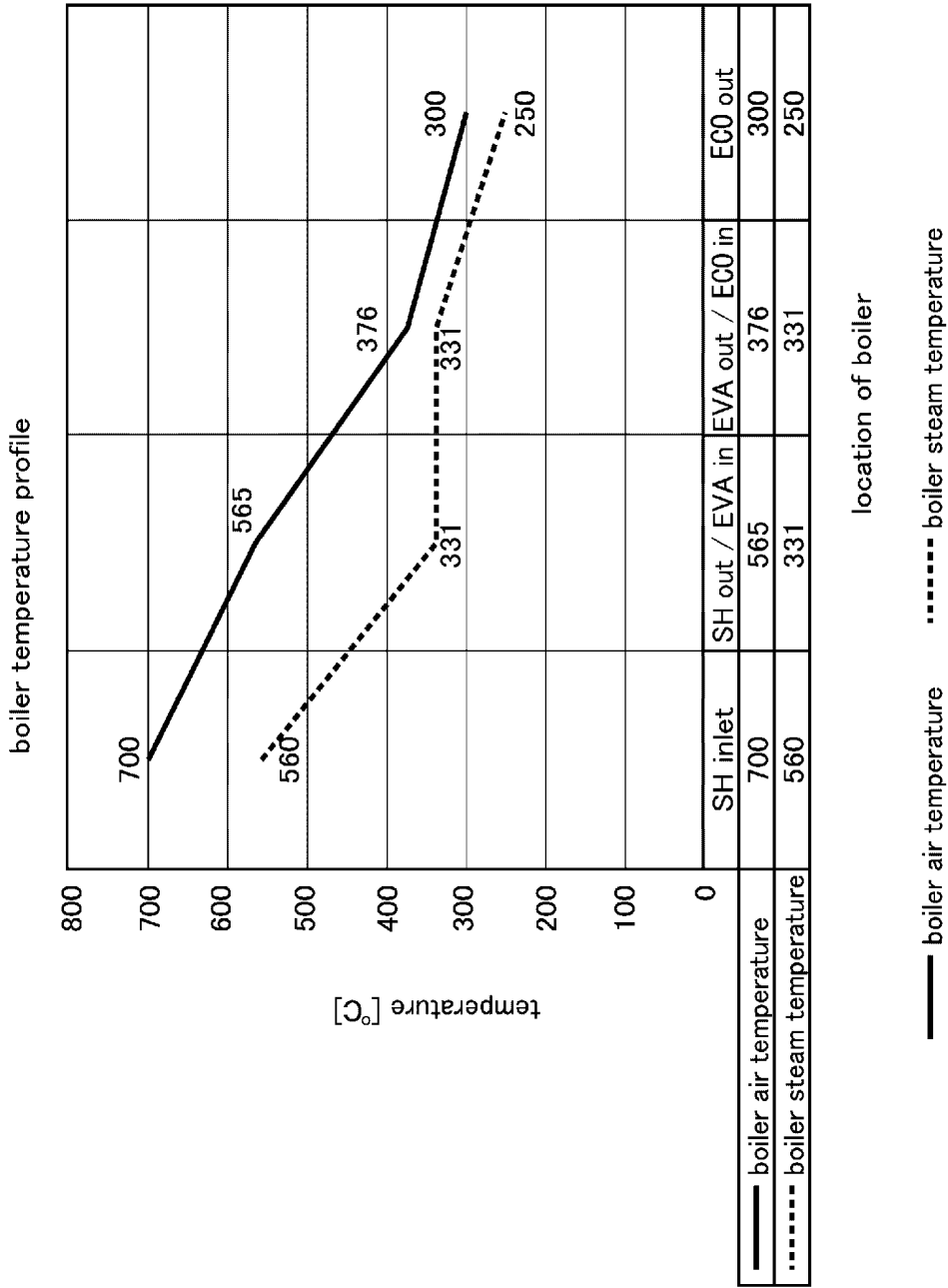


FIG. 16

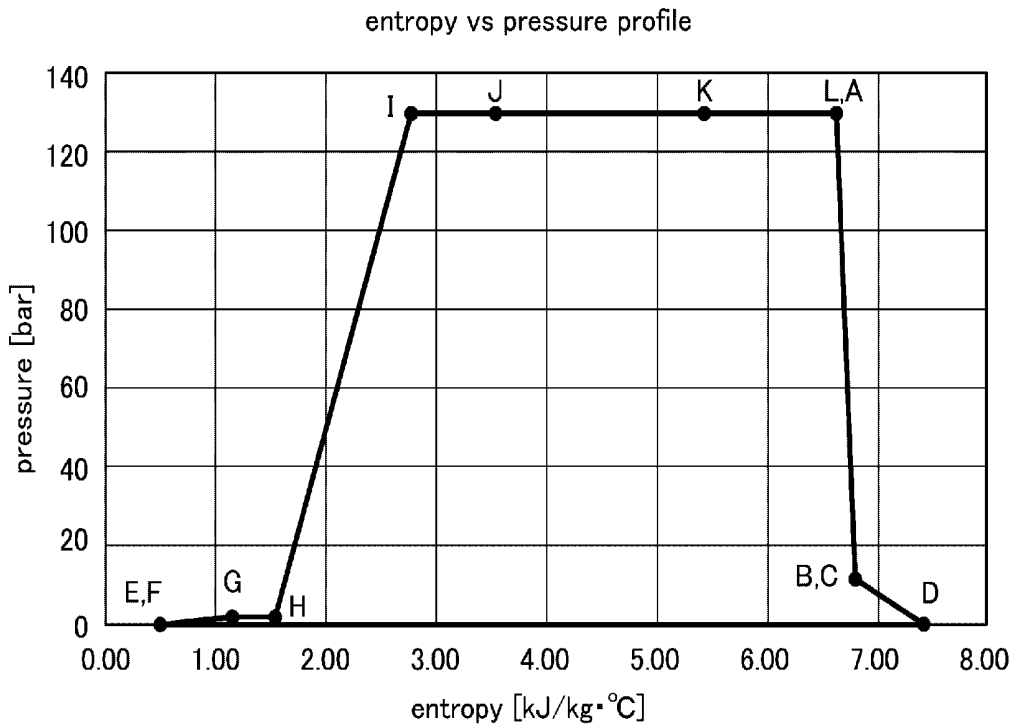


FIG. 17

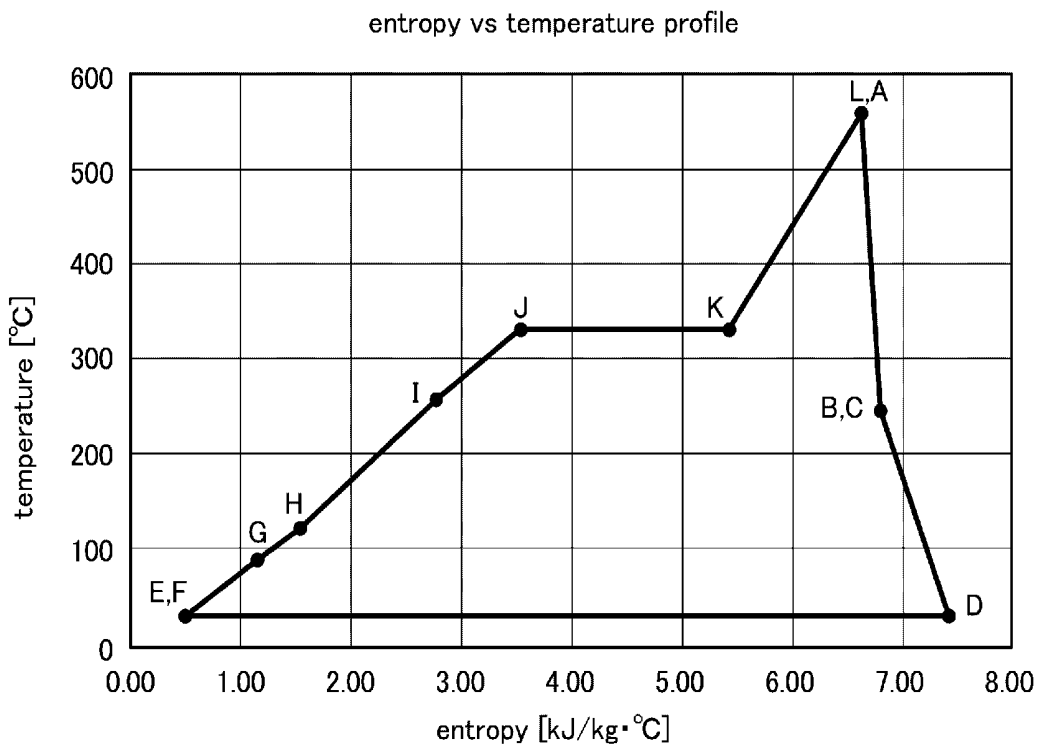


FIG. 18

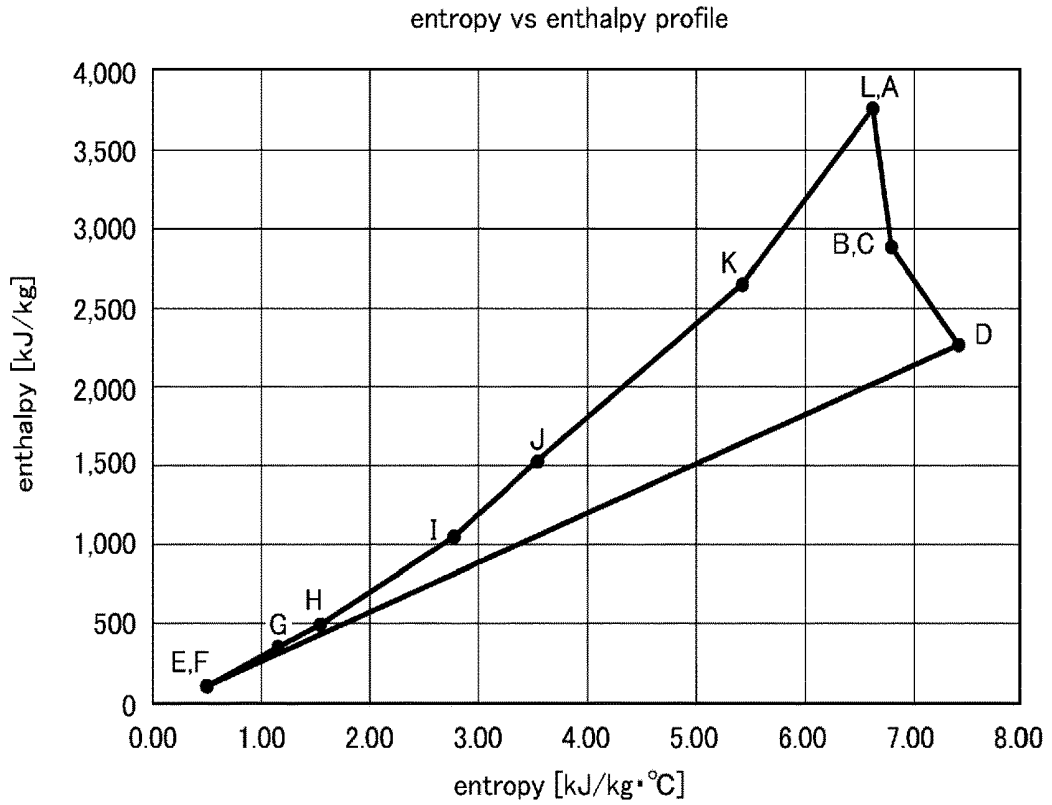


FIG. 19

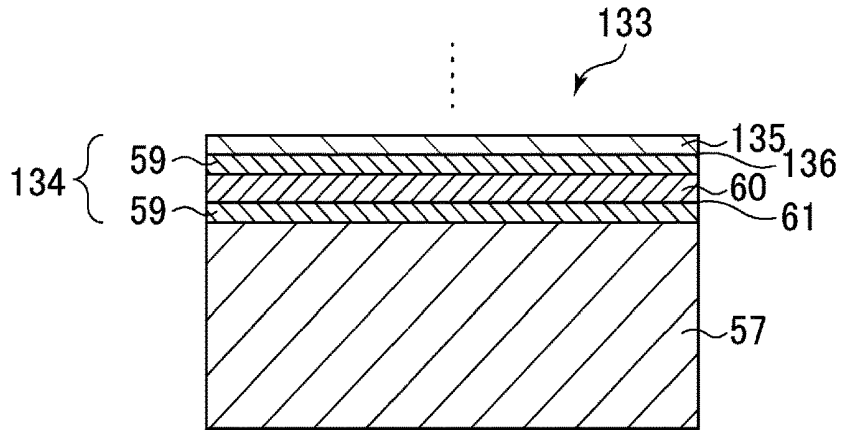


FIG. 20

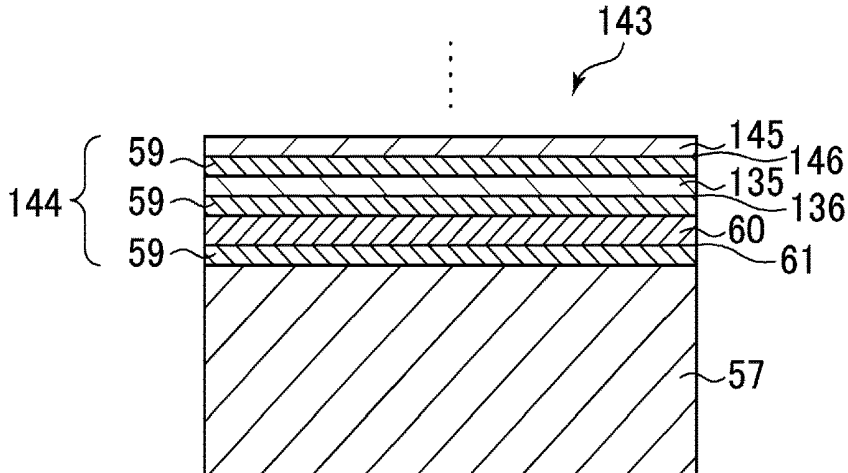


FIG. 21

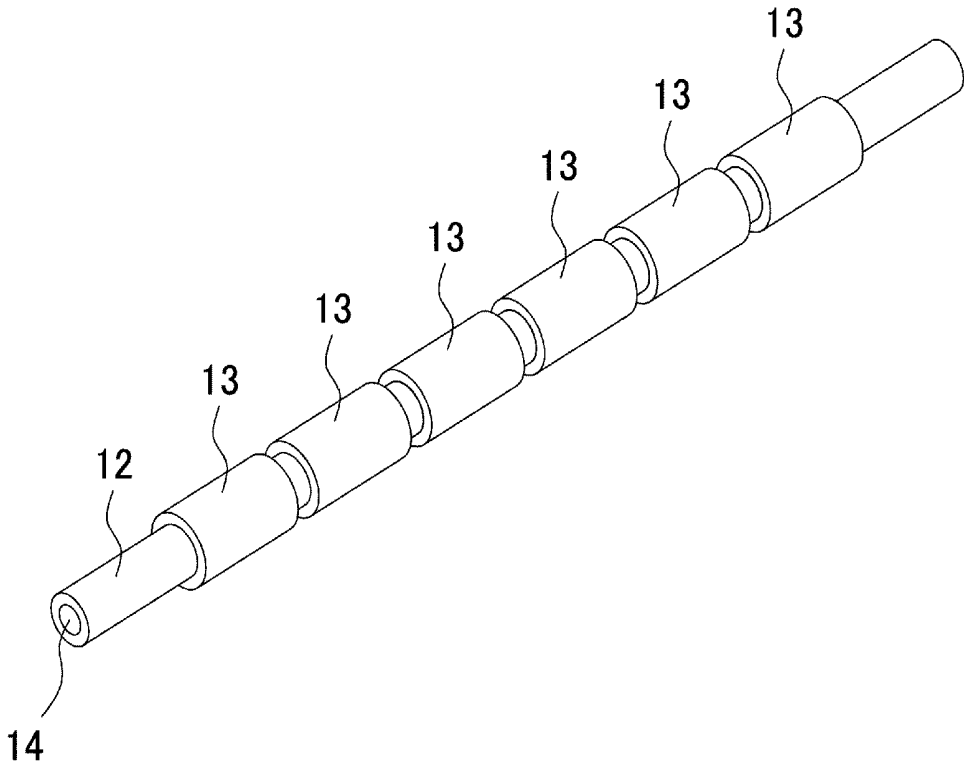


FIG. 22

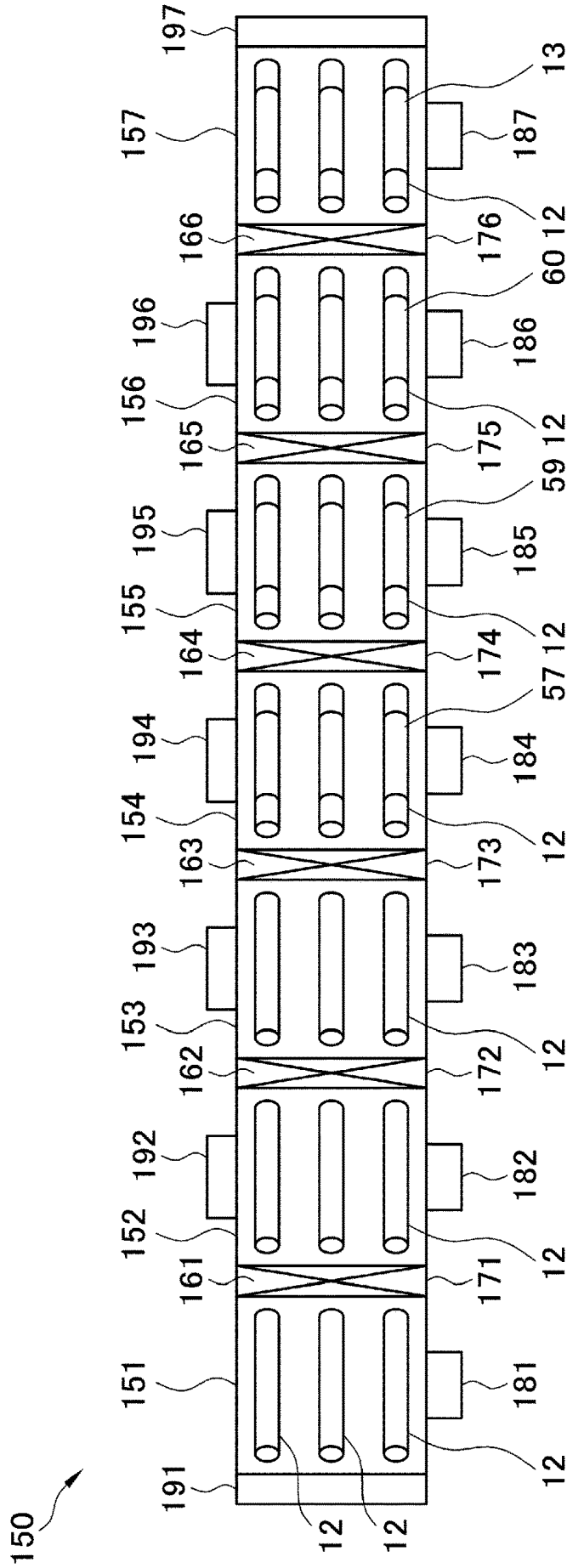


FIG. 23

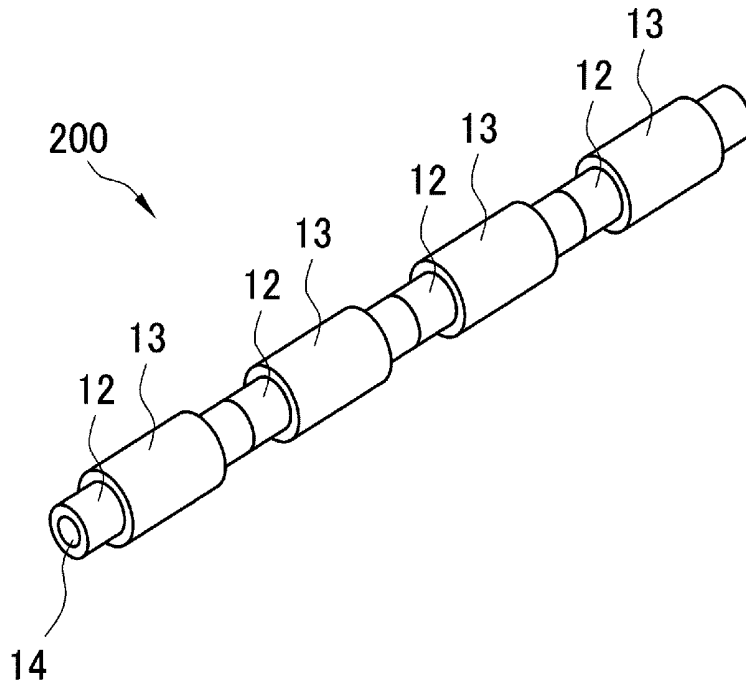


FIG. 24

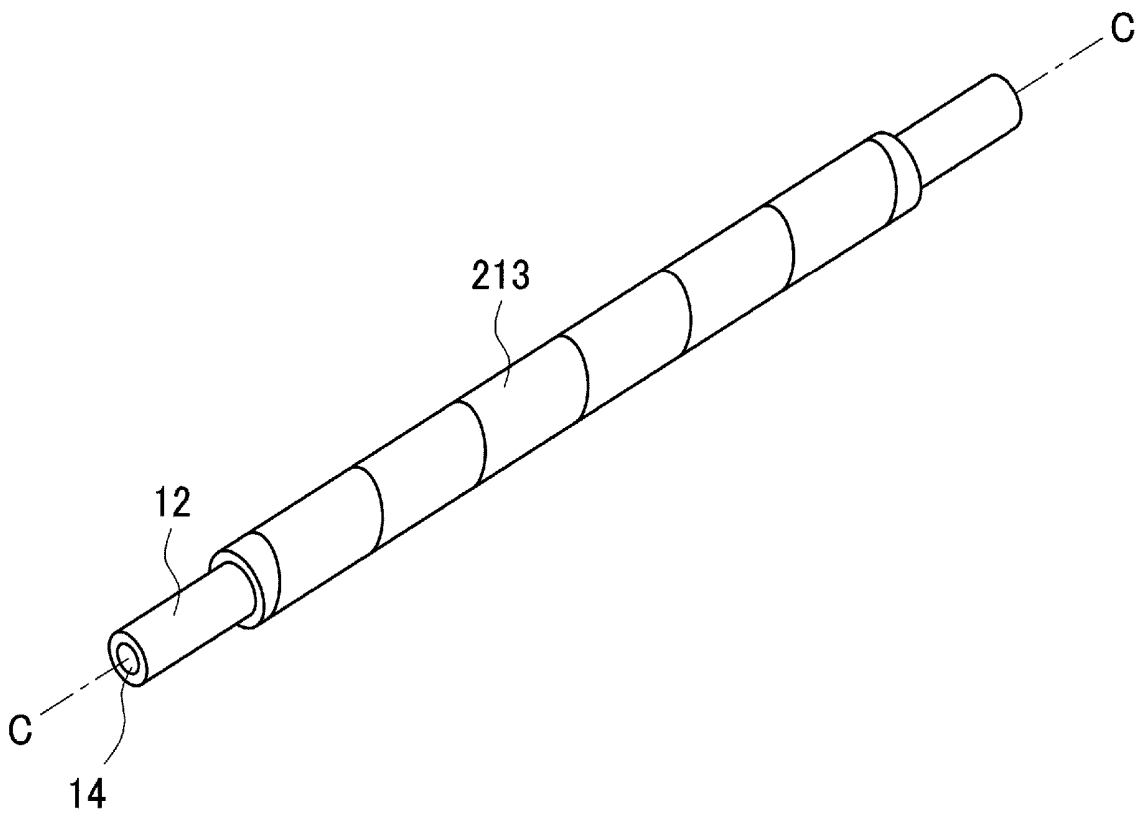


FIG. 25

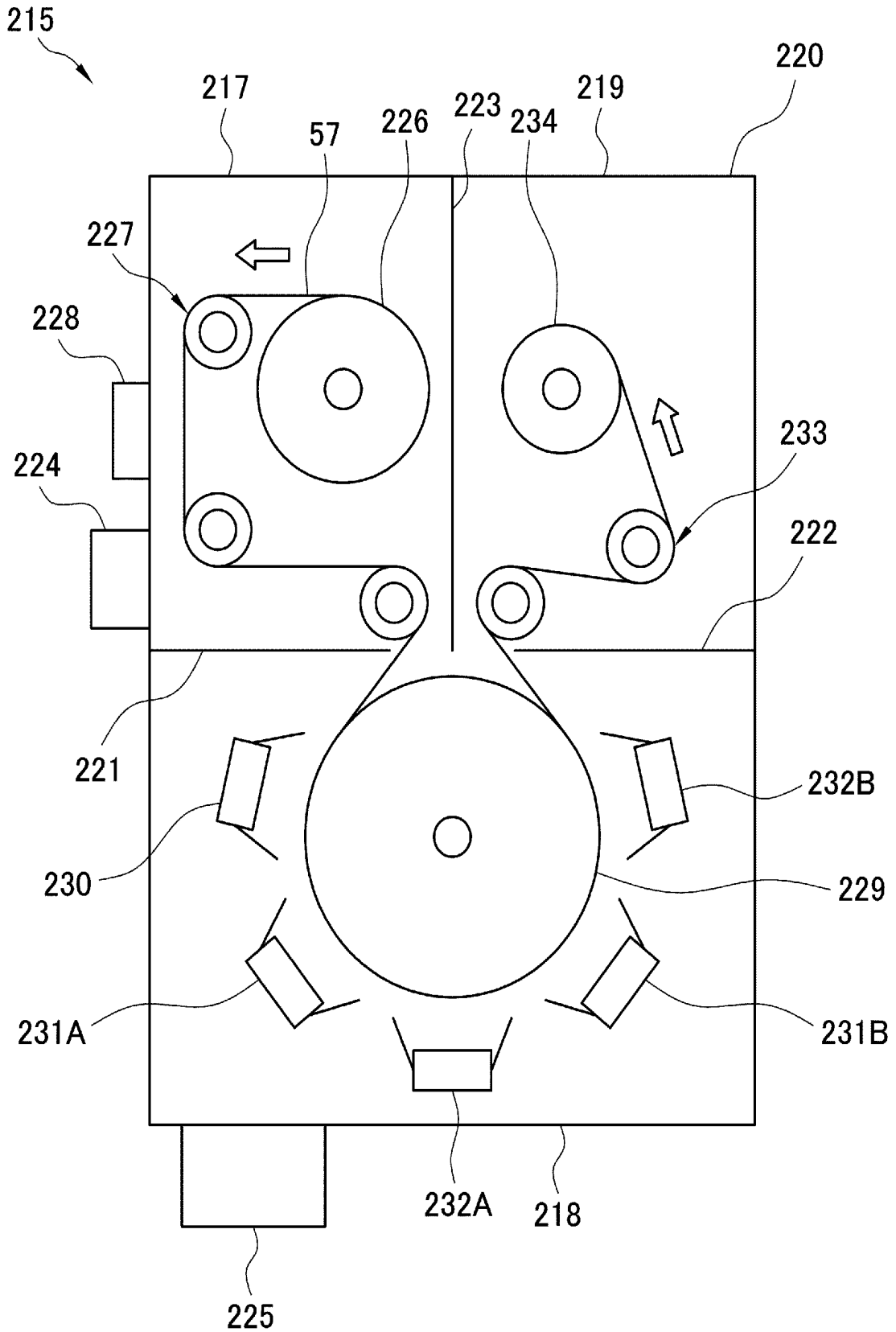
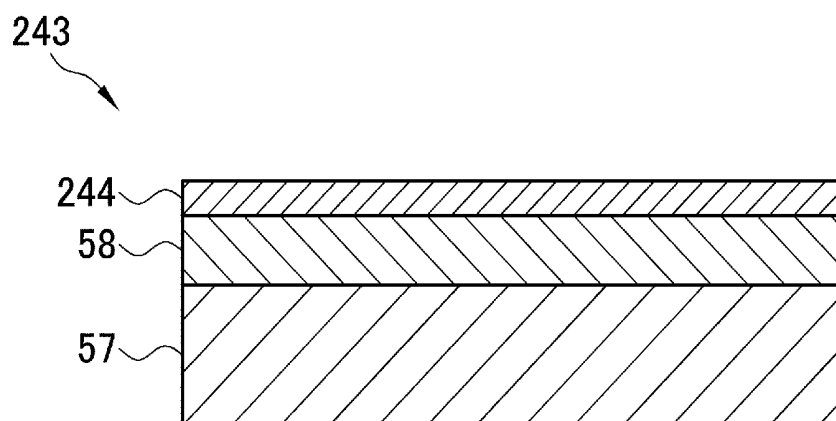


FIG. 26



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HEAT GENERATION DEVICE, HEAT UTILIZATION SYSTEM AND FILM-LIKE HEAT GENERATION ELEMENT

TECHNICAL FIELD

The present invention relates to a heat generating device, a heat utilization system, and a film-shaped heat generating element.

BACKGROUND ART

In recent years, a heat generation phenomenon in which heat is generated by occluding and discharging hydrogen using a hydrogen storage metal or the like is reported (see, for example, NPL 1). Hydrogen can be generated from water and is thus inexhaustible and inexpensive as a resource, and does not generate a greenhouse gas such as carbon dioxide and is thus clean energy. Unlike a nuclear fission reaction, the heat generation phenomenon using the hydrogen storage metal or the like is safe since there is no chain reaction. Heat generated by occluding and discharging hydrogen can be utilized as it is, and can be further utilized by being converted into electric power. Therefore, the heat is expected as an effective energy source.

CITATION LIST

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SUMMARY OF INVENTION

Technical Problem

However, an energy source is still mainly obtained from thermal power generation or nuclear power generation. Therefore, from the viewpoint of environmental problems and energy problems, there is a demand for a novel heat utilization system and heat generating device that utilize an inexpensive, clean, and safe energy source and that have not been disclosed in the related art.

Therefore, an object of the invention is to provide a novel heat generating device and heat utilization system that utilize an inexpensive, clean, and safe energy source, and a film-shaped heat generating element as an inexpensive, clean, and safe energy source.

Solution to Problem

A heat generating device according to the invention includes: a hollow sealed container; a tubular body provided in a hollow portion formed by an inner surface of the sealed container; a heat generating element provided on an outer surface of the tubular body and configured to generate heat by occluding and discharging hydrogen contained in a hydrogen-based gas supplied to the hollow portion; and a flow path formed by an inner surface of the tubular body and through which configured to allow a fluid that exchanges

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heat with the heat generating element to flow. The heat generating element includes a base made of a hydrogen storage metal, a hydrogen storage alloy, or a proton conductor, and a multilayer film provided on the base. The multilayer film has a first layer made of a hydrogen storage metal or a hydrogen storage alloy and having a thickness of less than 1000 nm, and a second layer made of a hydrogen storage metal or a hydrogen storage alloy, which is different from that of the first layer, or ceramics and having a thickness of less than 1000 nm.

A heat utilization system according to the invention includes the above-described heat generating device; and a fluid utilization device that utilizes the fluid heated by the heat generating element.

A film-shaped heat generating element according to the invention includes: a film-shaped base made of a hydrogen storage metal, a hydrogen storage alloy, or a proton conductor; and a film-shaped multilayer film provided on the base. The multilayer film has a first layer made of a hydrogen storage metal or a hydrogen storage alloy and having a thickness of less than 1000 nm, and a second layer made of a hydrogen storage metal or a hydrogen storage alloy, which is different from that of the first layer, or ceramics and having a thickness of less than 1000 nm.

Advantageous Effects of Invention

According to the invention, since the heat generating element that generates heat by occluding and discharging hydrogen is utilized as an energy source, inexpensive, clean, and safe energy can be supplied.

BRIEF DESCRIPTION OF DRAWINGS

FIG. 1 is a schematic diagram showing a heat generating device according to a first embodiment.

FIG. 2 is a cutaway perspective view showing a part of a sealed container.

FIG. 3 is a cross-sectional view of the sealed container.

FIG. 4 is an explanatory diagram showing a flow of a fluid in the sealed container.

FIG. 5 is a cross-sectional view showing a structure of a heat generating element having a first layer and a second layer.

FIG. 6 is an explanatory diagram showing generation of excess heat.

FIG. 7 is a schematic diagram showing a heat generating device according to a second embodiment.

FIG. 8 is a schematic diagram showing a heat generating device according to a third embodiment.

FIG. 9 is a graph showing a relationship between entropy and pressure of a Rankine cycle including the heat generating device and a steam turbine according to the third embodiment.

FIG. 10 is a graph showing a relationship between entropy and temperature of a Rankine cycle including the heat generating device and the steam turbine according to the third embodiment.

FIG. 11 is a graph showing a relationship between entropy and enthalpy of a Rankine cycle including the heat generating device and the steam turbine according to the third embodiment.

FIG. 12 is a schematic diagram showing a heat generating device according to a fourth embodiment.

FIG. 13 is a schematic diagram showing a heat generating device according to a fifth embodiment.

FIG. 14 is a schematic diagram showing a heat generating device according to a sixth embodiment.

FIG. 15 is a graph showing a state of heat exchange in a boiler of the sixth embodiment.

FIG. 16 is a graph showing a relationship between entropy and pressure of a Rankine cycle including the heat generating device and a steam turbine according to the sixth embodiment.

FIG. 17 is a graph showing a relationship between entropy and temperature of a Rankine cycle including the heat generating device and the steam turbine according to the sixth embodiment.

FIG. 18 is a graph showing a relationship between entropy and enthalpy of a Rankine cycle including the heat generating device and the steam turbine according to the sixth embodiment.

FIG. 19 is a cross-sectional view of a heat generating element having a first layer, a second layer, and a third layer.

FIG. 20 is a cross-sectional view of the heat generating element having the first layer, the second layer, the third layer, and a fourth layer.

FIG. 21 is a perspective view of a tubular body provided with a plurality of heat generating elements.

FIG. 22 is a schematic diagram of a heat generating element production apparatus for producing the heat generating element.

FIG. 23 is a perspective view of a heat generating unit in which the tubular bodies formed with the heat generating elements are connected to each other.

FIG. 24 is a perspective view of a film-shaped heat generating element.

FIG. 25 is a schematic diagram of a film-shaped heat generating element production apparatus for producing the film-shaped heat generating element.

FIG. 26 is a cross-sectional view showing a structure of the film-shaped heat generating element having a passivation film.

DESCRIPTION OF EMBODIMENTS

First Embodiment

In FIG. 1, a heat generating device 10 includes a sealed container 11, a tubular body 12, a heat generating element 13, a flow path 14, a fluid circulation unit 15, and a control unit 16. In the heat generating device 10, the heat generating element 13 is provided outside the tubular body 12, the flow path 14 is provided inside the tubular body 12, and a fluid flowing through the flow path 14 is heated by the heat generating element 13 to generate a high-temperature fluid.

The fluid includes at least one of a liquid and a gas. As the fluid, a fluid excellent in thermal conductivity and chemically stable is preferable. Examples of the gas include helium gas, argon gas, chlorofluorocarbon gas, hydrogen gas, nitrogen gas, water vapor, air, and carbon dioxide. Examples of the liquid include water, a molten salt (such as KNO_3 (40%)— NaNO_3 (60%)), and a liquid metal (such as Pb). As the fluid, a mixed phase fluid in which solid particles are dispersed in a gas or a liquid may be used. Examples of the solid particles include a metal, a metal compound, an alloy, and ceramics. Examples of the metal include copper, nickel, titanium, and cobalt. Examples of the metal compound include an oxide, a nitride, and a silicide of the above-described metals. Examples of the alloy include stainless steel and chromium molybdenum steel. Examples of the

ceramics include alumina. The type of fluid can be appropriately selected depending on the application of the heat generating device 10.

In the present embodiment, water is used as the fluid. The heat generating device 10 heats water flowing through the flow path 14 by the heat generating element 13 to generate high-temperature and high-pressure water (hereinafter referred to as high-temperature and high-pressure water).

The sealed container 11 is configured to accommodate the tubular body 12 and the heat generating element 13. The sealed container 11 has a hollow tubular shape. The sealed container 11 has a cylindrical shape in this example, but may have various shapes such as an elliptic cylindrical shape and a square tubular shape. The height of the sealed container 11 is set to 13 to 15 m, for example. The diameter of the sealed container 11 is 3.1 m, for example. The size of the sealed container 11 is not particularly limited, and can be appropriately designed.

The sealed container 11 is made of a material having heat resistance and pressure resistance. The material of the sealed container 11 can be appropriately selected in accordance with use conditions (for example, temperature and pressure). Examples of the material of the sealed container 11 include carbon steel, austenitic stainless steel, and heat-resistant non-ferrous alloy. Examples of the austenitic stainless steel include SUS304L, SUS316L, SUS310S, and the like which are standardized by JIS (Japanese Industrial Standards). For example, as the material of the sealed container 11, carbon steel is used when the use temperature is 350° C. or lower, SUS304L is used when the use temperature is higher than 350° C., SUS316L or SUS310S is used when the use temperature is 600 to 700° C., and a non-ferrous alloy suitable for heat resistance is used when the use temperature is higher than 700° C.

The sealed container 11 has a main body 17 formed in a tubular shape, a fluid inflow chamber 18 provided at one end of the main body 17, and a fluid outflow chamber 19 provided at the other end of the main body 17. In the sealed container 11, the side where the fluid inflow chamber 18 is provided with respect to the main body 17 is the lower side, and the side where the fluid outflow chamber 19 is provided with respect to the main body 17 is the upper side.

The main body 17 has a gas inlet 21 which is an inlet of the hydrogen-based gas and a gas outlet 22 which is an outlet of the hydrogen-based gas. The main body 17 has a cylindrical shape in this example, but may have various shapes such as an elliptic cylindrical shape and a square tubular shape. The fluid inflow chamber 18 has a fluid inlet 23 which is an inlet of the fluid. The fluid outflow chamber 19 has a fluid outlet 24 which is an outlet of the fluid.

The hydrogen-based gas means a gas containing an isotope of hydrogen. As the hydrogen-based gas, at least one of a deuterium gas and a light hydrogen gas is used. The light hydrogen gas includes a mixture of naturally occurring light hydrogen and deuterium, i.e., a mixture in which the abundance ratio of light hydrogen is 99.985% and the abundance ratio of deuterium is 0.015%. In the following description, when light hydrogen and deuterium are not distinguished from each other, they are referred to as “hydrogen”.

Inside the sealed container 11, a hollow portion 26 in which the tubular body 12 and the heat generating element 13 are arranged is provided. The hollow portion 26 is formed by an inner surface of the sealed container 11. To be specific, the hollow portion 26 is a tubular space defined by an inner surface of the main body 17 and an outer surface of the heat generating element 13 to be described later.

The hollow portion **26** is connected to a gas supply unit **27** via the gas inlet **21**. Although not shown, the gas supply unit **27** is constituted by a gas cylinder that stores the hydrogen-based gas, a pipe that connects the gas cylinder and the hollow portion **26**, a valve for adjusting the flow rate of the hydrogen-based gas and the pressure in the pipe, and the like, and supplies the hydrogen-based gas to the hollow portion **26**.

The hollow portion **26** is connected to a gas exhaust unit **28** via the gas outlet **22**. Although not shown, the gas exhaust unit **28** is constituted by a vacuum pump, a pipe connecting the vacuum pump and the hollow portion **26**, a valve for adjusting the flow rate of the hydrogen-based gas and the pressure in the pipe, and the like, and performs vacuum evacuation of the hollow portion **26**.

The tubular body **12** is provided in the hollow portion **26** of the sealed container **11**. The tubular body **12** is a hollow pipe. The inside of the tubular body **12** is controlled to a predetermined pressure by the control unit **16** to be described later. In the present embodiment, the pressure is controlled so that water does not become water vapor at about 300° C. and is kept in a liquid state. The pressure inside the tubular body **12** is 100 bar in the present embodiment, but is not limited to this and can be appropriately designed.

The tubular body **12** is made of a material having heat resistance and pressure resistance. A material of the tubular body **12** can be appropriately selected in accordance with use conditions (for example, temperatures and pressures). As the material of the tubular body **12**, the same material as the sealed container **11**, that is, carbon steel, austenitic stainless steel, heat-resistant non-ferrous alloy steel, or the like is used.

The shape of the tubular body **12** can be various shapes such as a cylindrical shape, an elliptical cylindrical shape, and a square tubular shape. Various dimensions of the tubular body **12** are not particularly limited, and can be appropriately designed. For example, the tubular body **12** may have a cylindrical shape having a length of 10 m, a thickness (wall thickness) of 0.005 to 0.010 m, and a diameter of 0.05 m. It is preferable that the thickness is appropriately designed based on the temperature and pressure of the fluid flowing through the inside of the tubular body **12** (the flow path **14** to be described later). The tubular body **12** can be formed in a desired length by, for example, connecting a plurality of pipe members in series. The number of the tubular body **12** is not particularly limited, and may be one or more. For example, 800 pieces of tubular body **12** can be installed in the sealed container **11**. In the present embodiment, a plurality of tubular bodies **12** are provided in the hollow portion **26**. That is, the heat generating device **10** includes a plurality of tubular bodies **12** provided in the hollow portion **26**. In FIG. 1, only one tubular body **12** of the plurality of tubular bodies **12** is shown and the other tubular bodies **12** are omitted for simplification of the drawing.

The heat generating element **13** is provided on an outer surface of the tubular body **12**. Therefore, the heat generating element **13** has a tubular shape. In the present embodiment, one heat generating element **13** is provided for each of the plurality of tubular bodies **12**. That is, the heat generating device **10** includes a plurality of heat generating elements **13**.

The heat generating element **13** is arranged in the hollow portion **26** and is in contact with the hydrogen-based gas supplied to the hollow portion **26**. The thickness (wall thickness) of the heat generating element **13** is not particularly limited, and can be appropriately designed so as to

obtain a desired output as the heat generating device **10**. For example, the thickness is set to 0.005 to 0.010 m. In the heat generating element **13**, one heat generating element **13** is provided on the entire outer surface of one tubular body **12**. It should be noted that a plurality of heat generating elements **13** may be provided on the outer surface of one tubular body **12** at intervals from each other.

The heat generating element **13** generates heat by occlusion and discharge of hydrogen contained in the hydrogen-based gas. When the hydrogen-based gas is supplied to the hollow portion **26**, the heat generating element **13** occludes hydrogen contained in the hydrogen-based gas. When the heat generating element **13** is heated in a state in which the hollow portion **26** is evacuated, the heat generating element **13** is heated to a temperature equal to or higher than the heating temperature and generates heat (hereinafter referred to as excess heat).

When the operation of the heat generating device **10** is started, the heat generating element **13** is heated by water (fluid) heated by a heating unit **33** to be described later, and generates excess heat by reaching a predetermined temperature. The present embodiment assumes a case where the heat generating element **13** is heated to, for example, 270 to 300° C. to generate excess heat. The temperature of the heat generating element **13** in a state of generating excess heat is set to fall within a range of, for example, 300° C. or higher and 1500° C. or lower.

The flow path **14** is provided inside the tubular body **12**. The flow path **14** is formed by an inner surface of the tubular body **12**. The flow path **14** circulates a fluid that performs heat exchange with the heat generating element **13**. The flow path **14** is not connected to the hollow portion **26**. Therefore, the fluid and the hydrogen-based gas are prevented from flowing between the flow path **14** and the hollow portion **26**.

When the heated fluid flows into the flow path **14**, the heat generating element **13** is heated via the tubular body **12**. Accordingly, the heat generating element **13** generates excess heat, and the fluid flowing through the flow path **14** is heated via the tubular body **12**. As a result, a high-temperature and high-pressure fluid is generated in the flow path **14**, and the high-temperature and high-pressure fluid flows out from the flow path **14**. In the case of the present embodiment, the water flowing into the flow path **14** is heated by the heat generating element **13** generating excess heat, and flows out from the flow path **14** as high-temperature and high-pressure water at, for example, 300° C. A part of the water in the flow path **14** may become water vapor.

The fluid circulation unit **15** includes a circulation line **30** that is connected to the flow path **14** and circulates the fluid between the inside and the outside of the tubular body **12**. The circulation line **30** connects the fluid inlet **23** of the fluid inflow chamber **18** and the fluid outlet **24** of the fluid outflow chamber **19** outside the sealed container **11**.

The circulation line **30** is provided with a cooling unit **32** for cooling the fluid and a heating unit **33** for heating the fluid. That is, the heat generating device **10** further includes the cooling unit **32** and the heating unit **33**.

In the present embodiment, in addition to the cooling unit **32** and the heating unit **33**, a reservoir tank **36** that stores water and a pump **40** that circulates water are provided in the circulation line **30**. Further, a pressure indicator PI, a temperature indicator TI, and a flow rate indicator FI are provided in each portion of the circulation line **30**. The number of the pressure indicator PI, the temperature indicator TI, and the flow rate indicator FI is not particularly limited, but is preferably one or more. In each portion of the circulation line **30** between the fluid outlet **24** and the fluid

inlet **23** of the sealed container **11**, the pressure indicator PI, the temperature indicator TI, the cooling unit **32**, the temperature indicator TI, the reservoir tank **36**, the pump **40**, the temperature indicator TI, the heating unit **33**, the temperature indicator TI, and the flow rate indicator FI are provided in this order. The reservoir tank **36** is provided with a temperature indicator TI.

The cooling unit **32** is electrically connected to the control unit **16**, and the driving thereof is controlled by the control unit **16**. The cooling unit **32** cools high-temperature and high-pressure water as a fluid flowing out from the flow path **14**. In the cooling unit **32**, for example, high-temperature and high-pressure water at 300° C. is cooled to 270° C.

The cooling unit **32** has a function as a boiler in this example. The cooling unit **32** as a boiler performs heat exchange between the high-temperature and high-pressure water and boiler water as a heat medium, and generates high-temperature and high-pressure steam (hereinafter referred to as superheated steam) from the boiler water. The superheated steam is supplied to a steam turbine, and power can be generated by a generator connected to the steam turbine.

The heating unit **33** is electrically connected to the control unit **16**, and the driving thereof is controlled by the control unit **16**. The heating unit **33** heats water as a fluid to be caused to flow into the flow path **14**.

The heating unit **33** is, for example, an electric furnace that generates heat by electric supply. The heating unit **33** may be a fuel furnace that generates heat by burning fuel. When the operation of the heat generating device **10** is started, water is heated to, for example, 270° C. in the heating unit **33**. When the fluid heated by the heating unit **33** flows into the flow path **14**, the temperature of the heat generating element **13** is increased to a predetermined temperature to generate excess heat. That is, the heating unit **33** functions as a start-up heater that raises the temperature of the heat generating element **13** to a predetermined temperature at the start of operation of the heat generating device **10**.

The heating unit **33** is directly provided in the circulation line **30** in the present embodiment, but may be provided in a branch line branched from the circulation line **30**. When the heating unit **33** is provided in the branch line, a part or all of the fluid flowing through the circulation line **30** is caused to flow into the branch line, and the fluid heated by the heating unit **33** is returned to the circulation line **30**. This allows the heated fluid to flow into the flow path **14**. By connecting the circulation line **30** and the branch line via a valve, the flow rate of water flowing into the branch line can be controlled.

During operation of the heat generating device **10**, driving of the cooling unit **32** and the heating unit **33** is controlled such that the temperature of the fluid flowing into the flow path **14** is maintained within a predetermined range. For example, if the heat generating element **13** generates excess heat, the temperature of the water flowing into the flow path **14** is maintained at about 270° C. As a result, the temperature of the heat generating element **13** is made substantially constant, and the temperature and flow rate of the high-temperature and high-pressure water flowing out from the flow path **14** are stabilized.

The control unit **16** is electrically connected to each unit of the heat generating device **10** and controls the operation of each unit. The control unit **16** includes, for example, an arithmetic device (Central Processing Unit), a storage unit such as a read-only memory (Read Only Memory) or a random access memory (Random Access Memory). The

arithmetic device executes various kinds of arithmetic processing using, for example, a program and data stored in the storage unit.

The control unit **16** performs temperature decrease control for decreasing the temperature of the heat generating element **13** by driving the cooling unit **32** and causing the fluid cooled by the cooling unit **32** to flow into the flow path **14**, and temperature increase control for increasing the temperature of the heat generating element **13** by driving the heating unit **33** and causing the fluid heated by the heating unit **33** to flow into the flow path **14**. The control unit **16** adjusts the temperature of the fluid flowing into the flow path **14** by switching between the temperature decrease control and the temperature increase control based on the temperature of the fluid flowing through the circulation line **30**.

The control unit **16** controls temperatures, pressures, flow rates, and the like of each unit of the heat generating device **10** based on detection results of the temperature indicator TI, detection results of the pressure indicator PI, detection results of the flow rate indicator FI, and the like. For example, when the heat generating element **13** generates excess heat at 270 to 300° C., the control unit **16** sets the temperature of the fluid flowing into the flow path **14** to 270° C. and the pressure of the fluid to 100 bar. The enthalpy of the fluid flowing into the flow path **14** is 283 kcal/kg, which is 28.3×10^8 kcal/h. The water flowing into the flow path **14** is heated to 300° C. by the heat generating element **13**, and flows out from the flow path **14** as high-temperature and high-pressure water. Since the saturation temperature of water when the pressure is 100 bar is 311° C., the water flowing into the flow path **14** does not turn into water vapor even if the temperature is raised to 300° C.

FIG. 2 is a cutaway perspective view showing a part of the sealed container **11**. In FIG. 2, a part of one tubular body **12** and one heat generating element **13** among the plurality of tubular bodies **12** and heat generating elements **13** is cut off to illustrate the inside thereof.

As shown in FIG. 2, the fluid circulation unit **15** further includes an external fluid line **45** in addition to the circulation line **30**. Each tubular body **12** provided in the hollow portion **26** of the sealed container **11** is heated by heat of the fluid flowing through the flow path **14** provided inside or heat of the heat generating element **13** provided on the outer surface, and the temperature rises to thermally expand. On the other hand, since the main body **17** of the sealed container **11** is not in contact with the tubular body **12** and the heat generating element **13** and the temperature rise thereof is suppressed more than that of the tubular body **12**, the main body **17** is less thermally expanded than the tubular body **12**. Therefore, thermal stress is generated in the plurality of tubular bodies **12** and the main body **17** of the sealed container **11**. The external fluid line **45** is intended to prevent damage due to this thermal stress.

The external fluid line **45** is provided on the outer surface of the sealed container **11** and is connected to the circulation line **30** to allow a part of the fluid to flow therethrough. The external fluid line **45** includes a plurality of first pipes **47** provided on the outer surface of the sealed container **11**, a first ring pipe **48** connecting one ends of the plurality of first pipes **47**, a second ring pipe **49** connecting the other ends of the plurality of first pipes **47**, a plurality of second pipes **50** connecting the first ring pipe **48** and the fluid inflow chamber **18**, and a plurality of third pipes **51** connecting the second ring pipe **49** and the fluid outflow chamber **19**.

Each of the plurality of first pipes **47** extends in the vertical direction (Z direction in the drawing) of the sealed container **11**. The first ring pipe **48** is provided on a flange

at one end of the main body **17** of the sealed container **11**. The second ring pipe **49** is provided on the flange at the other end of the main body **17** of the sealed container **11**. The first ring pipe **48** and the second ring pipe **49** are formed by forming a pipe material into a ring shape along the outer periphery of the main body **17**, and are configured to allow a fluid to flow inside. The plurality of second pipes **50** guide the fluid in the fluid inflow chamber **18** to the first ring pipe **48**. The fluid in the first ring pipe **48** passes through the plurality of first pipes **47** and moves to the second ring pipe **49**. The plurality of third pipes **51** guide the fluid in the second ring pipe **49** to the fluid outflow chamber **19**. The numbers of the first pipe **47**, the second pipe **50**, and the third pipe **51** are not particularly limited, and can be appropriately changed.

As shown in FIG. **3**, the plurality of first pipes **47** are arranged at equal intervals in the circumferential direction of the sealed container **11**. The cross-sectional shape of each first pipe **47** is a semicircular shape in the present embodiment, but is not limited thereto, and may be a rectangular shape, a semi-elliptical shape, or the like. FIG. **3** is a cross-sectional view taken along the XY plane in the main body **17** of the sealed container **11**.

In the hollow portion **26**, the plurality of tubular bodies **12** are arranged in a staggered manner at equal intervals from each other. That is, in three tubular bodies **12** adjacent to each other, a shape obtained by connecting the centers of each tubular body **12** forms an equilateral triangle (indicated by a dotted line in FIG. **3**). The distance between the centers of the tubular bodies **12** adjacent to each other is set at 0.15 m.

The flow of the fluid in the sealed container **11** will be described with reference to FIG. **4**. The fluid flowing through the circulation line **30** flows into the fluid inflow chamber **18** from the fluid inlet **23**. A part of the fluid in the fluid inflow chamber **18** flows from one end of the plurality of tubular bodies **12** to the flow path **14**. In the flow path **14**, the fluid is heated by the heat generating element **13**. The fluid heated in the flow path **14** flows from the other end of the plurality of tubular bodies **12** to the fluid outflow chamber **19**, and flows out from the fluid outlet **24** to the circulation line **30**.

The remaining part of the fluid in the fluid inflow chamber **18** flows into the plurality of second pipes **50**. The fluid in the plurality of second pipes **50** is guided to the plurality of first pipes **47** via the first ring pipe **48**. In the plurality of first pipes **47**, the fluid is heated by radiant heat of the heat generating element **13**. The fluid heated in the plurality of first pipes **47** is guided to the fluid outflow chamber **19** via the second ring pipe **49** and the plurality of third pipes **51** in this order, and merges with the fluid heated in the flow path **14**.

A heat generating module **55** is configured by the external fluid line **45**, the sealed container **11**, the tubular body **12**, the heat generating element **13**, and the flow path **14** as described above. Although the heat generating device **10** of the present embodiment includes one heat generating module **55**, the number of the heat generating modules **55** is not particularly limited and may be two or more.

The heat generating element **13** will be described in detail with reference to FIG. **5**. As shown in FIG. **5**, the heat generating element **13** includes a base **57** and a multilayer film **58**.

The base **57** is provided on an outer surface of the tubular body **12**. The tubular body **12** is not shown in FIG. **5**. The base **57** is made of a hydrogen storage metal, a hydrogen storage alloy, or a proton conductor. Examples of the hydro-

gen 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 . Examples of the proton conductor include a BaCeO_3 -based conductor (for example, $\text{Ba}(\text{Ce}_{0.95}\text{Y}_{0.05})\text{O}_{3-6}$), a SrCeO_3 -based conductor (for example, $\text{Sr}(\text{Ce}_{0.95}\text{Y}_{0.05})\text{O}_{3-6}$), a CaZrO_3 -based conductor (for example, $\text{CaZr}_{0.95}\text{Y}_{0.05}\text{O}_{3-\alpha}$), a SrZrO_3 -based conductor (for example, $\text{SrZr}_{0.9}\text{Y}_{0.1}\text{O}_{3-\alpha}$), $\beta\text{-Al}_2\text{O}_3$, and $\beta\text{-Ga}_2\text{O}_3$.

The multilayer film **58** is provided on a surface of the base **57**. The multilayer film **58** is formed by a first layer **59** made of a hydrogen storage metal or a hydrogen storage alloy and a second layer **60** made of a hydrogen storage metal or a hydrogen storage alloy, which is different from that of the first layer **59**, or ceramics. A heterogeneous material interface **61** is formed between the base **57** and the first layer **59** and the second layer **60**.

The first layer **59** is made of, for example, any one of Ni, Pd, Cu, Mn, Cr, Fe, Mg, Co, and an alloy thereof. The alloy for forming the first layer **59** is preferably an alloy composed of two or more of Ni, Pd, Cu, Mn, Cr, Fe, Mg, and Co. As the alloy for forming the first layer **59**, an alloy obtained by adding an additive element to Ni, Pd, Cu, Mn, Cr, Fe, Mg, or Co may be used.

The second layer **60** is made of, for example, any one of Ni, Pd, Cu, Mn, Cr, Fe, Mg, Co, an alloy thereof, and SiC. The alloy for forming the second layer **60** is preferably an alloy composed of two or more of Ni, Pd, Cu, Mn, Cr, Fe, Mg, and Co. As the alloy for forming the second layer **60**, an alloy obtained by adding an additive element to Ni, Pd, Cu, Mn, Cr, Fe, Mg, or Co may be used.

As a combination of the first layer **59** and the second layer **60**, it is preferably Pd—Ni, Ni—Cu, Ni—Cr, Ni—Fe, Ni—Mg, or Ni—Co when types of elements are expressed as “first layer **59**-second layer **60** (second layer **60**-first layer **59**)”. When the second layer **60** is made of ceramics, the “first layer **59**-the second layer **60**” is preferably made of Ni—SiC.

The thickness of the first layer **59** and the thickness of the second layer **60** are each preferably less than 1000 nm. When the thickness of each of the first layer **59** and the second layer **60** is 1000 nm or more, it becomes difficult for hydrogen to permeate through the multilayer film **58**. In addition, since the thickness of each of the first layer **59** and the second layer **60** is less than 1000 nm, it is possible to maintain a nanostructure that does not exhibit bulk characteristics. The thickness of each of the first layer **59** and the second layer **60** is more preferably less than 500 nm. Since the thickness of each of the first layer **59** and the second layer **60** is less than 500 nm, it is possible to maintain a nanostructure that does not completely exhibit bulk characteristics.

In FIG. **5**, the multilayer film **58** has a configuration in which the first layer **59** and the second layer **60** are alternately stacked in this order on the surface of the base **57**. Each of the first layer **59** and the second layer **60** includes five layers. The number of layers of the first layer **59** and the second layer **60** may be appropriately changed. The multilayer film **58** may have a configuration in which the second layer **60** and the first layer **59** are alternately stacked in this order on the surface of the base **57**. It is sufficient that the multilayer film **58** has one or more first layers **59** and one or more second layers **60**, and one or more heterogeneous material interfaces **61** are formed.

As shown in FIG. **6**, the heterogeneous material interface **61** is permeable to hydrogen atoms. FIG. **6** is a schematic diagram showing a state in which hydrogen atoms in a metal

lattice of the first layer 59 permeate through the heterogeneous material interface 61 and move into a metal lattice of the second layer 60 when the first layer 59 and the second layer 60 each made of a hydrogen storage metal having a face-centered cubic structure are made to occlude hydrogen and then the first layer 59 and the second layer 60 are heated.

The heat generating element 13 occludes hydrogen by the base 57 and the multilayer film 58 when the hydrogen-based gas is supplied to the sealed container 11. Even when the supply of the hydrogen-based gas to the sealed container 11 is stopped, the heat generating element 13 maintains a state where hydrogen is occluded in the base 57 and the multilayer film 58. When the heating of the heat generating element 13 is started by the fluid, the hydrogens occluded in the base 57 and the multilayer film 58 are discharged and quantum diffusion occurs while hopping the inside of the multilayer film 58. It is known that hydrogen is light and undergoes quantum diffusion while hopping at a site (octahedral site or tetrahedral site) occupied by hydrogen of a certain substance A and substance B. When the heat generating element 13 is heated in a vacuum state, hydrogen permeates through the heterogeneous material interface 61 in a manner of quantum diffusion, and generates excess heat equal to or higher than the temperature of the fluid.

An example of a method for producing the heat generating element 13 will be described. The heat generating element 13 can be produced using, for example, a sputtering method. After the base 57 is formed on the outer surface of the cylindrical tubular body 12, the first layer 59 and the second layer 60 are alternately formed on the base 57 to obtain the heat generating element 13. The base 57 is preferably formed to be thicker than the first layer 59 and the second layer 60, and Ni is used as the material of the base 57, for example. It is preferable that the first layer 59 and the second layer 60 are formed continuously in a vacuum state. As a result, no natural oxide film is formed between the first layer 59 and the second layer 60, and only the heterogeneous material interface 61 is formed. The production method of the heat generating element 13 is not limited to the sputtering method, and a vapor deposition method, a wet method, a thermal spraying method, an electroplating method, or the like can be used.

A heat generating method using the heat generating device 10 includes a hydrogen occluding step of occluding the hydrogen contained in the hydrogen-based gas into the heat generating element 13 by supplying the hydrogen-based gas to the hollow portion 26 of the sealed container 11, and a hydrogen discharging step of discharging the hydrogen occluded in the heat generating element 13 by performing the vacuum evacuation of the hollow portion 26 of the sealed container 11 and the heating of the heat generating element 13. The hydrogen occluding step and the hydrogen discharging step may be repeatedly performed.

As described above, the heat generating device 10 generates a high-temperature fluid (high-temperature and high-pressure water) by performing heat exchange between the heat generating element 13 provided on the outer surface of the tubular body 12 and the fluid (water) flowing through the flow path 14 formed by the inner surface of the tubular body 12. The high-temperature and high-pressure water as a high-temperature fluid can be used to generate superheated steam in the boiler (cooling unit 32). The superheated steam generated in the boiler can be used in a steam turbine. Since the heat generating element 13 generates heat using hydrogen, it does not generate greenhouse gases such as carbon dioxide. Further, since hydrogen used to generate heat in the heat generating element 13 can be generated from water, it

is inexpensive. Further, the heat generation of the heat generating element 13 is considered safe because there is no chain reaction unlike a nuclear fission reaction. Therefore, since the heat generating device 10 uses the heat generating element 13 as an energy source, energy can be supplied inexpensively, cleanly and safely.

In the heat generating device 10, since the external fluid line 45 is provided on the outer surface of the main body 17 of the sealed container 11, even when the main body 17 is heated by radiant heat of the heat generating element 13, heat of the main body 17 is transmitted to the fluid flowing through the external fluid line 45, so that the thermal expansion of the main body 17 is suppressed. Further, in the heat generating device 10, since the flow path 14 is provided inside the tubular body 12, even when the tubular body 12 is heated by the heat generating element 13, heat of the tubular body 12 is transmitted to the fluid flowing through the flow path 14, so that the thermal expansion of the tubular body 12 is suppressed. In the heat generating device 10, even when the tubular body 12 and the main body 17 are thermally expanded, since the elongation of the tubular body 12 and the elongation of the main body 17 are the same degree, so that damage due to thermal stress is prevented.

In the heat generating device 10, the temperature of the fluid circulating in the circulation line 30 is maintained constant by switching between the temperature decrease control and the temperature increase control by the control unit 16, and the heat generation of the heat generating element 13 is stabilized.

Second Embodiment

In the first embodiment, the water flowing into the flow path 14 is heated by the heat generating element 13 to generate high-temperature and high-pressure water, but in the second embodiment, the water flowing into the flow path 14 is heated by the heat generating element 13 to generate superheated steam, and the superheated steam is used as a working fluid for steam turbines to generate electric power. The same members as those in the first embodiment are denoted by the same reference numerals, and description thereof will be omitted.

As shown in FIG. 7, a heat generating device 70 includes one heat generating module 55, similarly to the heat generating device 10 of the first embodiment. The heat generating device 70 is configured such that a liquid (water) as a fluid flows into the flow path 14 and gas (water vapor) as a fluid flows out from the flow path 14. To be specific, when the operation of the heat generating device 70 is started, water as a fluid is heated by the heating unit 33. When the water heated by the heating unit 33 flows into the flow path 14, the heat generating element 13 is heated via the tubular body 12. Thus, the heat generating element 13 generates excess heat. When the heat generating element 13 generates excess heat, water flowing through the flow path 14 is heated via the tubular body 12. As a result, superheated steam is generated in the flow path 14, and the superheated steam flows out from the flow path 14. In some cases, the water in the flow path 14 does not entirely turn into water vapor, and a part thereof flows out from the flow path 14 as water. FIG. 7 shows a state in which water and water vapor have flowed out from the flow path 14, the water has accumulated in the lower portion of the fluid outflow chamber 19, and the water vapor has moved to the upper portion of the fluid outflow chamber 19. The fluid outflow chamber 19 is provided with the pressure indicator PI, the temperature indicator TI, and

a level gauge LI for detecting the height of the liquid surface in the fluid outflow chamber 19.

In the present embodiment, an internal pressure of the tubular body 12 is controlled to 90 bar. When the heat generating element 13 generates excess heat at 270 to 300° C., the control unit 16 sets the temperature of the fluid flowing into the flow path 14 to 270° C. and the pressure of the fluid to 90 bar. The water flowing into the flow path 14 is heated by the heat generating element 13 and flows out from the flow path 14 as superheated steam at, for example, 304° C.

In the second embodiment, the cooling unit 32, the heating unit 33, and a steam turbine 71 are provided in the circulation line 30. The cooling unit 32 cools and condenses the water vapor discharged from the steam turbine 71. As the cooling temperature in the cooling unit 32 is lower, the back pressure of the steam turbine 71 is lowered, and the power generation efficiency of a power generator connected to the steam turbine 71 is improved. The back pressure of the steam turbine 71 is controlled to, for example, 0.05 bar, and is determined based on the cooling method of the cooling unit 32 and the heat medium. The heating unit 33 is provided on a branch line 30a branched from the circulation line 30. The branch line 30a is connected to the circulation line 30 via a valve (not shown). When the operation of the heat generating device 70 is started, a part or all of the water flowing through the circulation line 30 flows into the branch line 30a, is heated by the heating unit 33, and is returned to the circulation line 30. As a result, water heated to, for example, 270° C. by the heating unit 33 flows into the flow path 14, and the heat generating element 13 generates excess heat.

The steam turbine 71 is a fluid utilization device that uses the superheated steam flowing out from the flow path 14 as a working fluid. The steam turbine 71 has a rotary shaft connected to the power generator, and rotate about the rotary shaft by being supplied with superheated steam. The power generator generates power by rotation of the steam turbine 71.

In addition to the cooling unit 32, the heating unit 33, and the steam turbine 71, a steam tank 72, a reservoir tank 73, a deaerator 74, a preheater 75, control valves 76a and 76b, and pumps 77a and 77b are provided on the circulation line 30 of the heat generating device 70. In FIG. 7, in the circulation line 30, in order from the fluid outlet 24 of the sealed container 11, control valve 76a, steam tank 72, steam turbine 71, cooling unit 32, reservoir tank 73, pump 77a, deaerator 74, pump 77b, preheater 75, heating unit 33, and control valve 76b are provided. The deaerator 74, the preheater 75, the control valves 76a and 76b, and the pumps 77a and 77b are electrically connected to the control unit 16.

The steam tank 72 is for temporarily storing the water vapor generated in the flow path 14. The steam tank 72 is connected to the deaerator 74 via a deaerating pipe 30b and is connected to the preheater 75 via a preheating pipe 30c.

The reservoir tank 73 is for storing water condensed by the cooling unit 32. The reservoir tank 73 is provided with the temperature indicator TI. The reservoir tank 73 is connected to a water supply source (not shown), and is configured to be supplied with water from this supply source.

The deaerator 74 degasses oxygen contained in the water flowing into the flow path 14 by using the water vapor supplied from the steam tank 72 via the deaerating pipe 30b. By degassing the water, corrosion of the boiler is prevented. The water degassed by the deaerator 74 is guided to the preheater 75.

The preheater 75 preheats the water flowing into the flow path 14 by using the water vapor supplied from the steam tank 72 via the preheating pipe 30c. In the preheater 75, water is preheated to, for example, 270° C. The water preheated by the preheater 75 flows into the flow path 14.

The control valve 76a adjusts the flow rate and pressure of the water vapor flowing out from the flow path 14. The control valve 76b adjusts the flow rate and pressure of the water flowing into the flow path 14. The pump 77a is for sending the water in the reservoir tank 73 to the deaerator 74. The pump 77b is for sending the water in the deaerator 74 to the preheater 75.

As described above, the heat generating device 70 generates a high-temperature fluid (superheated steam) by performing heat exchange between the heat generating element 13 provided on the outer surface of the tubular body 12 and the fluid (water) flowing through the flow path 14 formed by the inner surface of the tubular body 12. Superheated steam as a high-temperature fluid can be used for the steam turbine 71. The heat generating device 70 and the steam turbine 71 as a fluid utilization device constitute a heat utilization system 79. Therefore, since the heat generating device 70 and the heat utilization system 79 use the heat generating element 13 as an energy source, energy can be supplied inexpensively, cleanly, and safely.

When the fluid flowing out from the flow path 14 is water vapor (superheated steam) as in the present embodiment, the steam turbine 71 is suitable as the fluid utilization device. By using the steam turbine 71 as the fluid utilization device, heat energy obtained in the heat generating device 70 can be recovered as electrical energy. When the fluid flowing out from the flow path 14 is a gas other than water vapor (for example, air, chlorofluorocarbon gas, helium gas, or the like), a gas turbine can be applied as the fluid utilization device. It is also possible to supply the fluid flowing out from the flow path 14 to a separately provided boiler, generate superheated steam in the boiler, and supply this superheated steam to the steam turbine to generate power. Further, as the fluid utilization device, a preheater that preheats combustion air can be applied in a combustion device that generates heat by burning fuel and combustion air. Examples of the combustion device include a boiler, a rotary kiln, a heat treatment furnace for metals, a heating furnace for metal processing, a hot-air furnace, a firing furnace for ceramics, a petroleum refining tower, a dry distillation furnace, and a drying furnace.

Third Embodiment

While the heat generating device 70 of the second embodiment includes one heat generating module 55, in the third embodiment, a plurality of heat generating modules 55 are connected. In this example, a case where three heat generating modules 55 are connected will be described, but the number of heat generating modules 55 is not particularly limited and can be increased or decreased so as to obtain a desired output. The same members as those in the above-described embodiments are denoted by the same reference numerals, and description thereof will be omitted.

As shown in FIG. 8, a heat generating device 80 includes three heat generating modules 55a to 55c. Since the configuration of each of the heat generating modules 55a to 55c is the same as the configuration of the heat generating module 55 of the first embodiment, the description thereof will be omitted. Although not shown in FIG. 8, the heat generating device 80 includes the control unit 16, and the operation of each unit is controlled by the control unit 16.

The gas supply unit 27 and the gas exhaust unit 28 are connected to the hollow portion 26.

The heat generating device 80 further includes a distribution pipe 81 and a collection pipe 82. The distribution pipe 81 is connected to the circulation line 30 and distributes the fluid to each of the heat generating modules 55a to 55c. The collection pipe 82 is connected to the circulation line 30, and collects the fluids flowing out from the heat generating modules 55a to 55c.

The heat generating device 80 has a configuration in which the three heat generating modules 55a to 55c are connected in parallel by the distribution pipe 81 and the collection pipe 82. The three heat generating modules 55a to 55c are not limited to being connected in parallel, and may be connected in series. When the three heat generating modules 55a to 55c are connected in series, the fluid outlet 24 of the heat generating module 55a and the fluid inlet 23 of the heat generating module 55b are connected, and the fluid outlet 24 of the heat generating module 55b and the fluid inlet 23 of the heat generating module 55c are connected, without using the distribution pipe 81 and the collection pipe 82. As a result, the fluid in the circulation line 30 passes through the heat generating module 55a, the heat generating module 55b, and the heat generating module 55c in this order, and is returned to the circulation line 30 again.

The three heat generating modules 55a to 55c are detachable from the distribution pipe 81 and the collection pipe 82. The distribution pipe 81 is provided with the control valve 76b corresponding to each of the heat generating modules 55a to 55c.

The heat generating device 80 has the same configuration as the heat generating device 70 of the second embodiment except that the three heat generating modules 55a to 55c are provided, and each of the heat generating modules 55a to 55c is connected by the distribution pipe 81 and the collection pipe 82. Therefore, the superheated steam generated by the heat generating device 80 is used for the steam turbine 71.

As described above, since the heat generating device 80 includes the three heat generating modules 55a to 55c, it is possible to achieve high output. In addition, since each of the heat generating modules 55a to 55c is detachable from the heat generating device 80 and can be easily replaced, the heat generating device 80 is excellent in maintainability.

The heat generating device 80 and the steam turbine 71 as a fluid utilization device constitute a heat utilization system 89. Since the heat generating device 80 and the heat utilization system 89 use the heat generating element 13 as an energy source, energy can be supplied inexpensively, cleanly, and safely.

A power generation efficiency in the case of operating the steam turbine using the heat generating device 80 was calculated. The power generation efficiency of the steam turbine was calculated by setting the steam pressure to 80 to 100 bar, and the exhaust pressure to 0.05 bar, the exhaust temperature to 32° C., and the exhaust wetness to 15% for the water vapor discharged from the steam turbine. The relationship between steam pressure and power generation efficiency is shown in Table 1.

TABLE 1

Steam temperature [° C.]	312	304	296
Steam pressure [bar]	100	90	80
Steam flow rate ratio	59.7	59.9	60.2
Exhaust pressure [bar]	0.05	0.05	0.05
Exhaust wetness [%]	15	15	15

TABLE 1-continued

Turbine efficiency [%]	53	54	56
Power generation efficiency [%]	20.6	21.1	21.6

As the steam pressure decreases, the saturation temperature decreases and the amount of water vapor generated increases. On the other hand, as the steam flow rate ratio increases, the drop in enthalpy is suppressed. As a result, the power generation efficiency of the steam turbine is improved. For example, when the steam pressure is 80 bar, the steam temperature is 296° C. Therefore, assuming that the heat generating element 13 generates excess heat at a heating temperature of about 300° C., the steam pressure is preferably higher than the 80 bar. When the steam pressure is set to 90 bar, since the steam temperature is 304° C., the heat generating element 13 generates excess heat, and 21.1% of the power generation efficiency of the steam turbine can be achieved.

FIG. 9 is a graph showing a relationship between entropy and pressure of a Rankine cycle including the heat generating device 80 and the steam turbine 71 according to the third embodiment. In FIG. 9, the horizontal axis indicates entropy and the vertical axis indicates pressure. FIG. 10 is a graph showing a relationship between entropy and temperature of a Rankine cycle including the heat generating device 80 and the steam turbine 71 according to the third embodiment. In FIG. 10, the horizontal axis indicates entropy and the vertical axis indicates temperature. FIG. 11 is a graph showing a relationship between entropy and enthalpy of a Rankine cycle including the heat generating device 80 and the steam turbine 71 according to the third embodiment. In FIG. 11, the horizontal axis indicates entropy and the vertical axis indicates enthalpy. In FIG. 9 to FIG. 11, A indicates a state of the fluid at the inlet of the steam turbine 71, B indicates a state of the fluid at the outlet of the steam turbine 71, C indicates a state of the fluid at the cooling unit 32, D indicates a state of the fluid at the pump 77a, E indicates a state of the fluid at the inlet of the preheater 75, F indicates a state of the fluid at the outlet of the preheater 75, G indicates a state of the fluid at the saturation temperature in the flow path 14, and H indicates a state of the fluid flowing out from the flow path 14.

Fourth Embodiment

The fourth embodiment is configured to use a gas as a fluid. In this example, a case where air is used as the fluid will be described, but a gas other than air may be used. The same members as those in the above-described embodiments are denoted by the same reference numerals, and description thereof will be omitted.

As shown in FIG. 12, a heat generating device 90 includes one heat generating module 55, similarly to the heat generating device 10 of the first embodiment. The heat generating device 90 is configured such that a gas as a fluid flows into the flow path 14 and a gas as a fluid flows out from the flow path 14. To be specific, when the operation of the heat generating device 90 is started, air as a fluid is heated by the heating unit 33. When the air heated by the heating unit 33 flows into the flow path 14, the heat generating element 13 is heated via the tubular body 12. Thus, the heat generating element 13 generates excess heat. When the heat generating element 13 generates excess heat, air flowing through the flow path 14 is heated via the tubular body 12. As a result, high-temperature air (hereinafter referred to as high-tem-

perature air) is generated in the flow path 14, and the high-temperature air flows out from the flow path 14.

Since the fourth embodiment is configured to use air as the fluid, it is possible to generate excess heat from the heat generating element 13 in a lower-pressure environment than when water is used as the fluid. For example, assuming that the heat generating element 13 is heated at a high temperature of about 500° C. to generate excess heat, the temperature and pressure of the air flowing into the flow path 14 are set to, for example, 500° C. and 1 bar. The temperature and pressure of the high-temperature air flowing out of the flow path 14 are, for example, 700° C. and 1 bar. The temperatures and pressures of the air and the high-temperature air are not limited to those described above.

In the fourth embodiment, a cooling unit 92 is provided in the circulation line 30 instead of the cooling unit 32 in the first embodiment. Similar to the first embodiment, the circulation line 30 is also provided with the heating unit 33. A description of the heating unit 33 is omitted.

The cooling unit 92 is electrically connected to the control unit 16, and the driving thereof is controlled by the control unit 16. The cooling unit 92 cools high-temperature air as a fluid flowing out from the flow path 14. In the cooling unit 92, for example, high-temperature air at 700° C. is cooled to 300° C.

The cooling unit 92 has a function as a boiler in this example. The cooling unit 92 as a boiler performs heat exchange between the high-temperature air and boiler water as a heat medium, and generates superheated steam from the boiler water. For example, in the cooling unit 92, the pressure is maintained at 130 bar, and superheated steam at 560° C. is generated by performing heat exchange between boiler water at 250° C. and high-temperature air at 700° C. The superheated steam generated in the boiler can be supplied to the steam turbine. When the steam turbine is driven, power can be generated by a generator.

In the fourth embodiment, in addition to the cooling unit 92 and the heating unit 33, a buffer tank 94 for storing air, a blower 96 for sending air, the temperature indicator TI, the pressure indicator PI, the flow rate indicator FI, and the like are provided in the circulation line 30.

As described above, the heat generating device 90 generates a high-temperature fluid (high-temperature air) by performing heat exchange between the heat generating element 13 provided on the outer surface of the tubular body 12 and the fluid (air) flowing through the flow path 14 formed by the inner surface of the tubular body 12. The high-temperature air as a high-temperature fluid can be used to generate superheated steam in the boiler (cooling unit 92). The superheated steam generated in the boiler can be used in a steam turbine. Therefore, since the heat generating device 90 uses the heat generating element 13 as an energy source, energy can be supplied inexpensively, cleanly and safely.

Fifth Embodiment

In the fifth embodiment, high-temperature air is used to generate superheated steam in a boiler, and the superheated steam is used as a working fluid for a steam turbine to generate electric power. The same members as those in the above-described embodiments are denoted by the same reference numerals, and description thereof will be omitted.

As shown in FIG. 13, a heat generating device 100 includes one heat generating module 55, similarly to the heat generating device 90 of the fourth embodiment. The preheater 75 is provided in the circulation line 30 of the heat

generating device 100, and the air sent by the blower 96 is preheated by the preheater 75. The heat generating device 100 has the same configuration as the heat generating device 90 of the fourth embodiment except that the preheater 75 is provided in the circulation line 30.

The heat generating device 100 is connected to a heat recovery line 101. The heat recovery line 101 is connected to the cooling unit 92 as a boiler provided in the circulation line 30, and is configured to circulate boiler water to the cooling unit 92.

The heat recovery line 101 is provided with a control valve 102, a steam tank 103, a steam turbine 104, a condenser 105, a reservoir tank 106, a pump 107, a buffer tank 108, a deaerator 109, a pump 110, and a preheater 111.

The control valve 102 adjusts the flow rate and pressure of the water vapor flowing out from the cooling unit 92 as a boiler. The steam tank 103 is for temporarily storing the water vapor. The steam tank 103 is provided with the temperature indicator TI. The temperature and pressure of the water vapor stored in the steam tank 103 are, for example, 560° C. and 130 bar.

The steam tank 103 is connected to the buffer tank 108 via a preheating pipe 101a and a preheating pipe 101b. The preheating pipe 101a is connected to the preheater 111. The preheating pipe 101b is connected to the preheater 75. A part of the water vapor stored in the steam tank 103 is supplied to the preheater 111 via the preheating pipe 101a and is supplied to the preheater 75 via the preheating pipe 101b.

The steam turbine 104 is a fluid utilization device that utilizes the superheated steam stored in the steam tank 103 as a working fluid. The steam turbine 104 has a rotary shaft connected to the power generator, and rotates about the rotary shaft by being supplied with superheated steam. The power generator generates power by rotation of the steam turbine 104. The water vapor discharged from the steam turbine 104 is, for example, cooled to 32.9° C. and depressurized to 0.05 bar. The water vapor contains fine mist-like water droplets.

The steam turbine 104 is an extraction turbine configured such that a part of steam can be extracted from an extraction portion provided in the middle of the turbine. The extraction portion of the steam turbine 104 is connected to the deaerator 109 via an extraction pipe 101c. The water vapor extracted from the extraction portion of the steam turbine 104 flows through the extraction pipe 101c and is supplied to the deaerator 109. The temperature and pressure of the water vapor flowing through the extraction pipe 101c are, for example, 251° C. and 12 bar.

The condenser 105 cools and condenses the water vapor discharged from the steam turbine 104. The reservoir tank 106 is for storing boiler water condensed by the condenser 105. The pump 107 is for sending the boiler water in the reservoir tank 106 to the buffer tank 108. The temperature and pressure of the boiler water sent by the pump 107 are, for example, 32.9° C. and 1 bar.

The buffer tank 108 is for storing boiler water. The buffer tank 108 is supplied with boiler water sent from the reservoir tank 106, boiler water generated by cooling the water vapor flowing through the preheating pipe 101a by the preheater 111, and boiler water generated by cooling the water vapor flowing through the preheating pipe 101b by the preheater 75. The boiler water stored in the buffer tank 108 is sent to the deaerator 109. The temperature and pressure of the boiler water sent to the deaerator 109 are, for example, 87.5° C. and 2 bar.

The deaerator 109 degasses oxygen contained in the boiler water sent from the buffer tank 108 by using the water

vapor supplied from the extraction portion of the steam turbine 104 via the extraction pipe 101c. The deaerator 109 is provided with the temperature indicator TI and the pressure indicator PI. The pump 110 is for sending the boiler water deaerated by the deaerator 109 to the preheater 111. The temperature and pressure of the boiler water sent by the pump 110 are, for example, 120° C. and 2 bar.

The preheater 111 preheats the boiler water to be supplied to the cooling unit 92 by performing heat exchange between the water vapor flowing through the preheating pipe 101a and the boiler water supplied from the deaerator 109. The water vapor flowing through the preheating pipe 101a is cooled by heat exchange in the preheater 111, condensed, and sent to the buffer tank 108 as boiler water. The temperature and pressure of the water vapor flowing through the preheating pipe 101a are, for example, 560° C. and 130 bar. The temperature and pressure of the boiler water sent to the buffer tank 108 via the preheater 111 are, for example, 120° C. and 2 bar.

The preheater 75 preheats the air flowing into the flow path 14 by performing heat exchange between the water vapor flowing through the preheating pipe 101b and the air sent by the blower 96. The water vapor flowing through the preheating pipe 101b is cooled by heat exchange in the preheater 75, condensed, and sent to the buffer tank 108 as boiler water. The temperature and pressure of the water vapor flowing through the preheating pipe 101b are, for example, 560° C. and 130 bar. The temperature and pressure of the boiler water sent to the buffer tank 108 via the preheater 75 are, for example, 120° C. and 2 bar.

In the cooling unit 92 as a boiler, for example, heat exchange is performed between boiler water at 250° C. and 130 bar supplied from the preheater 111 and high-temperature air at 700° C. flowing out from the flow path 14, thereby generating superheated steam at 560° C. and 130 bar from the boiler water.

As described above, the heat generating device 100 generates a high-temperature fluid (high-temperature air) similarly to the heat generating device 90 of the fourth embodiment. The high-temperature air as a high-temperature fluid can be used to generate superheated steam in the boiler (cooling unit 92). The heat generating device 100 and the steam turbine 104 as a fluid utilization device constitute a heat utilization system 119. Since the heat generating device 100 and the heat utilization system 119 use the heat generating element 13 as an energy source, energy can be supplied inexpensively, cleanly, and safely.

Sixth Embodiment

While the heat generating device 100 of the fifth embodiment includes one heat generating module 55, in the sixth embodiment, a plurality of heat generating modules 55 are connected. In this example, a case where the three heat generating modules 55a to 55c are connected will be described, but the number of heat generating modules 55 is not particularly limited and can be increased or decreased so as to obtain a desired output. The same members as those in the above-described embodiments are denoted by the same reference numerals, and description thereof will be omitted.

As shown in FIG. 14, the heat generating device 120 includes the three heat generating modules 55a to 55c. Although not shown in FIG. 14, a heat generating device 120 includes the control unit 16, and the operation of each unit is controlled by the control unit 16. The gas supply unit 27 and the gas exhaust unit 28 are connected to the hollow portion 26. The heat generating device 120 has a configura-

tion in which the three heat generating modules 55a to 55c are connected in parallel by the distribution pipe 81 and the collection pipe 82, but the three heat generating modules 55a to 55c can also be connected in series.

The heat generating device 120 has the same configuration as the heat generating device 100 of the fifth embodiment except that the three heat generating modules 55a to 55c are provided, and each of the heat generating modules 55a to 55c is connected by the distribution pipe 81 and the collection pipe 82. The heat generating device 120 is connected to the heat recovery line 101 in which the steam turbine 104 and the like are provided. Therefore, the high temperature air generated by the heat generating device 120 is used to generate superheated steam in the boiler (cooling unit 92).

As described above, since the heat generating device 120 includes the three heat generating modules 55a to 55c, it is possible to achieve high output. In addition, since each of the heat generating modules 55a to 55c is detachable from the heat generating device 120, and the heat generating modules 55a to 55c can be easily replaced, the heat generating device 120 is excellent in maintainability.

The heat generating device 120 and the steam turbine 104 as a fluid utilization device constitute a heat utilization system 129. Since the heat generating device 80 and the heat utilization system 129 use the heat generating element 13 as an energy source, energy can be supplied inexpensively, cleanly, and safely.

FIG. 15 is a graph showing a state of heat exchange in the boiler (cooling unit 92) of the sixth embodiment. FIG. 15 shows the temperature drop of the high temperature air and the temperature rise of the boiler water when the pressure in the boiler is set to 130 bar and the high temperature air and the boiler water as a heating medium are in countercurrent indirect contact in the boiler. In FIG. 15, the vertical axis indicates the temperatures of boiler water and air. The horizontal axis indicates each portion in the boiler, "SH inlet" indicates a portion at the inlet of a superheater (SH) of the boiler, "SH out/EVA in" indicates a portion between the outlet of the superheater and the inlet of an evaporator (EVA), "EVA out/ECO in" indicates a portion between the outlet of the evaporator and the inlet of an economizer (ECO), and "ECO out" indicates a portion at the outlet of the economizer. "Boiler air" is high-temperature air. "Boiler steam" is boiler water or water vapor. The high-temperature air is supplied to the superheater of the boiler at 700° C. and is discharged from the economizer as air at 300° C. through heat exchange with boiler water. The boiler water is supplied to the economizer of the boiler at 250° C., heated in the economizer to 331° C., which is the saturation temperature at 130 bar, and becomes water vapor in the evaporator. This water vapor is further heated by the superheater and discharged from the boiler as superheated steam at 560° C.

FIG. 16 is a graph showing a relationship between entropy and pressure of a Rankine cycle including the heat generating device 120 and the steam turbine 104 according to the sixth embodiment. In FIG. 16, the horizontal axis indicates entropy and the vertical axis indicates pressure. FIG. 17 is a graph showing a relationship between entropy and temperature of a Rankine cycle including the heat generating device 120 and the steam turbine 104 according to the sixth embodiment. In FIG. 17, the horizontal axis indicates entropy and the vertical axis indicates temperature. FIG. 18 is a graph showing a relationship between entropy and enthalpy of a Rankine cycle including the heat generating device 120 and the steam turbine 104 according to the sixth embodiment. In FIG. 18, the horizontal axis indicates

entropy and the vertical axis indicates enthalpy. In FIG. 16 to FIG. 18, A indicates a state of the heat medium at the inlet of the steam turbine 104, B indicates a state of the heat medium at the extraction portion of the steam turbine 104, C indicates a state of the heat medium that exited the extraction portion of the steam turbine 104, D indicates a state of the heat medium at the outlet of the steam turbine 104, E indicates a state of the heat medium at the condenser 105, F indicates a state of the heat medium at the pump 107, G indicates a state of the heat medium at the outlet of the buffer tank 108, H indicates a state of the heat medium at the outlet of the deaerator 109, I indicates a state of the heat medium at the preheater 111, J indicates a state of the heat medium in which heat exchange is started in the boiler (cooling unit 92), K indicates a state of the heat medium having reached a saturation temperature in the boiler, and L indicates a state of the heat medium in the superheater in the boiler.

The present invention is not limited to the above-described embodiments, and can be appropriately modified without departing from the scope of the present invention.

The heat generating element 13 of each of the above-described embodiments has a configuration in which the multilayer film 58 including the first layer 59 and the second layer 60 is provided on the surface of the base 57, but the configuration of the heat generating element is not limited thereto. Another example of the heat generating element will be described below.

For example, as shown in FIG. 19, a heat generating element 133 includes the base 57 and a multilayer film 134. The multilayer film 134 further includes a third layer 135 in addition to the first layer 59 and the second layer 60. Description of the base 57, the first layer 59, and the second layer 60 will be omitted. The third layer 135 is made of a hydrogen storage metal, a hydrogen storage alloy, or ceramics different from those of the first layer 59 and the second layer 60. The thickness of the third layer 135 is preferably less than 1000 nm. In FIG. 19, the first layer 59, the second layer 60, and the third layer 135 are stacked on the surface of the base 57 in the order of the first layer 59, the second layer 60, the first layer 59, and the third layer 135. The first layer 59, the second layer 60, and the third layer 135 may be stacked on the surface of the base 57 in the order of the first layer 59, the third layer 135, the first layer 59, and the second layer 60. That is, the multilayer film 134 has a stacking structure in which the first layer 59 is provided between the second layer 60 and the third layer 135. The multilayer film 134 may include one or more third layers 135. A heterogeneous material interface 136 formed between the first layer 59 and the third layer 135 is permeable to hydrogen atoms in the same manner as the heterogeneous material interface 61.

The third layer 135 is made of, for example, any one of Ni, Pd, Cu, Cr, Fe, Mg, Co, an alloy thereof, SiC, CaO, Y₂O₃, TiC, and LaB₆. The alloy for forming the third layer 135 is preferably an alloy made of two or more of Ni, Pd, Cu, Cr, Fe, Mg, and Co. As the alloy for forming the third layer 135, an alloy obtained by adding an additive element to Ni, Pd, Cu, Cr, Fe, Mg, or Co may be used.

In particular, the third layer 135 is preferably made of any one of CaO, Y₂O₃, TiC, LaB₆, SrO, and BaO. In the heat generating element 133 having the third layer 135 made of any one of CaO, Y₂O₃, TiC, LaB₆, SrO, and BaO, the amount of hydrogen occlusion increases, the amount of hydrogen permeating through the heterogeneous material interface 61 and the heterogeneous material interface 136 increases, and a high output of excess heat can be achieved.

The thickness of the third layer 135 made of any one of CaO, Y₂O₃, TiC, LaB₆, SrO, and BaO is preferably 10 nm or less. Accordingly, hydrogen atoms easily permeate through the multilayer film 134. The third layer 135 made of any one of CaO, Y₂O₃, TiC, LaB₆, SrO, and BaO may not be formed into a complete film shape and may be formed into an island shape. The first layer 59 and the third layer 135 are preferably formed continuously in a vacuum state. Accordingly, between the first layer 59 and the third layer 135, no natural oxide film is formed and only the heterogeneous material interface 136 is formed.

As a combination of the first layer 59, the second layer 60, and the third layer 135, it is preferably Pd—CaO—Ni, Pd—Y₂O₃—Ni, Pd—TiC—Ni, Pd—LaB₆—Ni, Ni—CaO—Cu, Ni—Y₂O₃—Cu, Ni—TiC—Cu, Ni—LaB₆—Cu, Ni—Co—Cu, Ni—CaO—Cr, Ni—Y₂O₃—Cr, Ni—TiC—Cr, Ni—LaB₆—Cr, Ni—CaO—Fe, Ni—Y₂O₃—Fe, Ni—TiC—Fe, Ni—LaB₆—Fe, Ni—Cr—Fe, Ni—CaO—Mg, Ni—Y₂O₃—Mg, Ni—TiC—Mg, Ni—LaB₆—Mg, Ni—CaO—Co, Ni—Y₂O₃—Co, Ni—TiC—Co, Ni—LaB₆—Co, Ni—CaO—SiC, Ni—Y₂O₃—SiC, Ni—TiC—SiC, or Ni—LaB₆—SiC when types of elements are expressed as “first layer 59-third layer 135-second layer 60”.

As shown in FIG. 20, a heat generating element 143 includes the base 57 and a multilayer film 144. The multilayer film 144 further includes a fourth layer 145 in addition to the first layer 59, the second layer 60, and the third layer 135. The fourth layer 145 is made of a hydrogen storage metal, a hydrogen storage alloy, or ceramics different from those of the first layer 59, the second layer 60, and the third layer 135. The thickness of the fourth layer 145 is preferably less than 1000 nm. In FIG. 20, the first layer 59, the second layer 60, the third layer 135, and the fourth layer 145 are stacked on the surface of the base 57 in the order of the first layer 59, the second layer 60, the first layer 59, the third layer 135, the first layer 59, and the fourth layer 145. The first layer 59, the second layer 60, the third layer 135, and the fourth layer 145 may be stacked on the surface of the base 57 in the order of the first layer 59, the fourth layer 145, the first layer 59, the third layer 135, the first layer 59, and the second layer 60. That is, the multilayer film 144 has a stacking structure in which the second layer 60, the third layer 135, and the fourth layer 145 are stacked in an arbitrary order, and the first layers 59 are provided between each combination of the second layer 60, and the third layer 135, and the fourth layer 145. The multilayer film 144 may include one or more fourth layers 145. A heterogeneous material interface 146 formed between the first layer 59 and the fourth layer 145 is permeable to hydrogen atoms in the same manner as the heterogeneous material interface 61 and the heterogeneous material interface 136.

The fourth layer 145 is made of, for example, any one of Ni, Pd, Cu, Cr, Fe, Mg, Co, an alloy thereof, SiC, CaO, Y₂O₃, TiC, and LaB₆. The alloy for forming the fourth layer 145 is preferably an alloy made of two or more of Ni, Pd, Cu, Cr, Fe, Mg, and Co. As the alloy for forming the fourth layer 145, an alloy obtained by adding an additive element to Ni, Pd, Cu, Cr, Fe, Mg, or Co may be used.

In particular, the fourth layer 145 is preferably made of any one of CaO, Y₂O₃, TiC, LaB₆, SrO, and BaO. In the heat generating element 143 having the fourth layer 145 made of any one of CaO, Y₂O₃, TiC, LaB₆, SrO, and BaO, the amount of hydrogen occlusion increases, the amount of hydrogen permeating through the heterogeneous material interface 61, the heterogeneous material interface 136, and the heterogeneous material interface 146 increases, and a

high output of excess heat can be achieved. The thickness of the fourth layer **145** made of any one of CaO, Y₂O₃, TiC, LaB₆, SrO, and BaO is preferably 10 nm or less. Accordingly, hydrogen atoms easily permeate through the multilayer film **144**. The fourth layer **145** made of any one of CaO, Y₂O₃, TiC, LaB₆, SrO, and BaO may not be formed into a complete film shape and may be formed into an island shape. The first layer **59** and the fourth layer **145** are preferably formed continuously in a vacuum state. Accordingly, between the first layer **59** and the fourth layer **145**, no natural oxide film is formed and only the heterogeneous material interface **146** is formed.

As a combination of the first layer **59**, the second layer **60**, the third layer **135**, and the fourth layer **145**, it is preferably Ni—CaO—Cr—Fe, Ni—Y₂O₃—Cr—Fe, Ni—TiC—Cr—Fe, or Ni—LaB₆—Cr—Fe when types of elements are expressed as “first layer **59**—fourth layer **145**—third layer **135**—second layer **60**”.

The configurations of various multilayer films such as the multilayer film **58**, the multilayer film **134**, and the multilayer film **144**, for example, the ratio of the thicknesses of the respective layers, the number of the respective layers, and the materials may be appropriately changed in accordance with the temperature at which the multilayer film is used.

In each of the above-described embodiments, one heat generating element **13** is provided on the entire outer surface of one tubular body **12**, but as shown in FIG. **21**, a plurality of heat generating elements **13** may be provided on the outer surface of one tubular body **12** at intervals from each other. Since there is a gap between each heat generating element **13**, even when the tubular body **12** is thermally expanded, damage to each heat generating element **13** is prevented. Further, a plurality of heat generating elements **133** (see FIG. **19**) may be provided on the outer surface of one tubular body **12** at intervals from each other. A plurality of heat generating elements **143** (see FIG. **20**) may also be provided on the outer surface of one tubular body **12** at intervals from each other.

Although the external fluid line **45** has the plurality of first pipes **47** in each of the above-described embodiments, the external fluid line **45** may be configured to cover the entire outer surface of the main body **17** with one first pipe **47**. Further, one first pipe **47** may be wound spirally along the outer surface of the main body **17**.

The first ring tube **48** may have a through hole connected to the fluid inflow chamber **18**. Since the first ring pipe **48** and the fluid inflow chamber **18** are directly connected by the through hole, the second pipe **50** may be omitted.

The second ring pipe **49** may have a through hole connected to the fluid outflow chamber **19**. Since the second ring pipe **49** and the fluid outflow chamber **19** are directly connected by the through hole, the third pipe **51** may be omitted.

A fluid heated by any heat generating element among the heat generating element **13**, the heat generating element **133**, and the heat generating element **143** can be used as a heat energy source to separate carbon dioxide (CO₂) from exhaust gas discharged from a combustion device such as a boiler. CO₂ contained in the exhaust gas can be recovered by supplying a fluid heated by the heat generating element to a CO₂ separation and recovery apparatus which performs a chemical absorption method or a physical adsorption method. In the chemical absorption method, CO₂ contained in the exhaust gas is absorbed in an absorbing liquid such as an amine compound aqueous solution, and the absorbing liquid that has absorbed the CO₂ is heated to discharge the

CO₂ from the absorbing liquid. In the physical adsorption method, CO₂ contained in the exhaust gas is adsorbed on an adsorbent such as active carbon or zeolite, and the adsorbent on which the CO₂ is adsorbed is heated to desorb the CO₂ from the adsorbent. In the chemical absorption method, a fluid heated by a heat generating element can be used as a heat energy source for heating the absorbing liquid that has absorbed the CO₂. Further, in the physical adsorption method, a fluid heated by a heat generating element can be used as a heat energy source for heating the adsorbent on which the CO₂ is adsorbed.

The fluid heated by the heat generating element is used as a thermal energy source, and can be converted into methane (CH₄) by reacting CO₂ separated and recovered by a CO₂ separation and recovery device with hydrogen (H₂). By bringing a raw material gas containing CO₂ and H₂ into contact with a catalyst using the catalyst for promoting the reaction between CO₂ and H₂ (methanation reaction), CH₄ is generated from the raw material gas, but the reaction does not proceed sufficiently if the temperature of the raw material gas is low. Therefore, the methanation reaction can be allowed to proceed by using the fluid heated by a heat generating element as a heat energy source for heating the raw material gas containing CO₂ and H₂.

In an IS cycle in which hydrogen is produced from water using heat energy or an ISN cycle in which ammonia (NH₃) is produced from water and nitrogen (N₂) using heat energy, a fluid heated by heat generating element can be used as a heat energy source. In the IS cycle, water, iodine (I), and sulfur (S) are reacted to produce hydrogen iodide (HI), and the hydrogen iodide is then pyrolyzed to produce hydrogen. A fluid heated by the heat generating element can be used as a heat energy source for pyrolyzing hydrogen iodide. In the ISN cycle, nitrogen is reacted with hydrogen iodide produced in the IS cycle to produce ammonium iodide (NH₄I), and the ammonium iodide is then pyrolyzed to produce ammonia. A fluid heated by the heat generating element can be used as a heat energy source for pyrolyzing ammonium iodide.

FIG. **22** shows a heat generating element production apparatus **150** for producing the heat generating element **13** using a sputtering method. In this example, the heat generating element production apparatus **150** performs a DC (Direct Current) magnetron sputtering method as the sputtering method, and directly forms the heat generating element **13** on the outer surface of the tubular body **12**.

The heat generating element production apparatus **150** includes a load chamber **151** for carrying in the tubular body **12**, a preheating chamber **152** for preheating the tubular body **12**, a sputter etching chamber **153** for sputter etching the surface of the tubular body **12**, a base forming chamber **154** for forming the base **57** on the tubular body **12**, a first layer forming chamber **155** for forming the first layer **59** on the base **57**, a second layer forming chamber **156** for forming the second layer **60** on the base **57**, and an unload chamber **157** for carrying out the tubular body **12**. In this example, the heat generating element production apparatus **150** carries a plurality of tubular bodies **12** into the load chamber **151** and directly forms the heat generating element **13** on the outer surface of each tubular body **12**, but may carry one tubular body **12** into the load chamber **151** and directly form the heat generating element **13** on the outer surface of the tubular body **12**.

In this example, the heat generating element production apparatus **150** includes a first gate valve **161** provided between the load chamber **151** and the preheating chamber **152**, a second gate valve **162** provided between the preheat-

ing chamber 152 and the sputter etching chamber 153, a third gate valve 163 provided between the sputter etching chamber 153 and the base forming chamber 154, a fourth gate valve 164 provided between the base forming chamber 154 and the first layer forming chamber 155, a fifth gate valve 165 provided between the first layer forming chamber 155 and the second layer forming chamber 156, and a sixth gate valve 166 provided between the second layer forming chamber 156 and the unload chamber 157, wherein the load chamber 151, the preheating chamber 152, the sputter etching chamber 153, the base forming chamber 154, the first layer forming chamber 155, the second layer forming chamber 156, and the unload chamber 157 are separated from each other. Although not illustrated, the heat generating element production apparatus 150 further includes a conveyance mechanism that conveys the tubular body 12 from the load chamber 151 to the unload chamber 157, and a rotation mechanism that rotates the tubular body 12 about the central axis of the tubular body 12.

The first gate valve 161 opens and closes a first carrying in/out unit 171 between the load chamber 151 and the preheating chamber 152. The second gate valve 162 opens and closes a second carrying in/out unit 172 between the preheating chamber 152 and the sputter etching chamber 153. The third gate valve 163 opens and closes a third carrying in/out unit 173 between the sputter etching chamber 153 and the base forming chamber 154. The fourth gate valve 164 opens and closes a fourth carrying in/out unit 174 between the base forming chamber 154 and the first layer forming chamber 155. The fifth gate valve 165 opens and closes a fifth carrying in/out unit 175 between the first layer forming chamber 155 and the second layer forming chamber 156. The sixth gate valve 166 opens and closes a sixth carrying in/out unit 176 between the second layer forming chamber 156 and the unload chamber 157.

The heat generating element production apparatus 150 includes a first vacuum generation unit 181 for evacuating the load chamber 151, a second vacuum generation unit 182 for evacuating the preheating chamber 152, a third vacuum generation unit 183 for evacuating the sputter etching chamber 153, a fourth vacuum generation unit 184 for evacuating the base forming chamber 154, a fifth vacuum generation unit 185 for evacuating the first layer forming chamber 155, a sixth vacuum generation unit 186 for evacuating the second layer forming chamber 156, and a seventh vacuum generation unit 187 for evacuating the unload chamber 157. As the first to seventh vacuum generation units 181 to 187, for example, a dry pump, a turbo-molecular pump, or the like is used.

The load chamber 151 has a carry-in unit 191 for carrying in the tubular body 12. After the tubular body 12 is carried in from the carry-in unit 191, the load chamber 151 is evacuated by the first vacuum generation unit 181 in a state where the carry-in unit 191 and the first gate valve 161 are closed. After the load chamber 151 is evacuated, the first gate valve 161 is opened, and the tubular body 12 is conveyed from the load chamber 151 to the preheating chamber 152 via the first carrying in/out unit 171.

The preheating chamber 152 is evacuated to, for example, about 1E-3 Pa by the second vacuum generation unit 182 in a state where the first gate valve 161 and the second gate valve 162 are closed. The preheating chamber 152 has a heating unit 192, and the tubular body 12 is heated by the heating unit 192 while rotating the tubular body 12. The heating unit 192 removes moisture adsorbed on the surface of the tubular body 12 by heating the tubular body 12 to a surface temperature of, for example, 200 to 350° C. The

heating unit 192 is not particularly limited as long as it can heat the tubular body 12 to a desired temperature. For example, a lamp heating method, an infrared heating method, an induction heating method, or the like can be used. After the heating, the second gate valve 162 is opened, and the tubular body 12 is conveyed from the preheating chamber 152 to the sputter etching chamber 153 via the second carrying in/out unit 172.

The sputter etching chamber 153 is evacuated by the third vacuum generation unit 183 in a state where the second gate valve 162 and the third gate valve 163 are closed. The sputter etching chamber 153 has a sputter etching electrode 193, and sputter etching of the tubular body 12 is performed by the sputter etching electrode 193 while rotating the tubular body 12. By using the sputter etching electrode 193, for example, the flow rate of Ar gas is adjusted to set the Ar pressure to about 0.1 to 1 Pa, and a radio frequency (RF) of 13.56 MHz is applied to remove organic substances and metallic oxides on the surface of the tubular body 12. After the sputter etching, the third gate valve 163 is opened, and the tubular body 12 is conveyed from the sputter etching chamber 153 to the base forming chamber 154 via the third carrying in/out unit 173.

The base forming chamber 154 is evacuated by the fourth vacuum generation unit 184 in a state where the third gate valve 163 and the fourth gate valve 164 are closed. The base forming chamber 154 has a base forming sputter electrode 194, and forms the base 57 on the tubular body 12 by the base forming sputter electrode 194 while rotating the tubular body 12. The base forming sputter electrode 194 has a target material (not shown) of a hydrogen storage metal, a hydrogen storage alloy, or a proton conductor forming the base 57. The front side of the target material faces the tubular body 12. In this example, a magnet (not shown) is arranged on the rear side of the target material. By using the base forming sputter electrode 194, for example, the flow rate of Ar gas is adjusted to set the Ar pressure to about 0.1 to 1 Pa, and the DC power of about 0.1 to 500 kW/m² is applied to form the base 57 on the tubular body 12. The thickness of the base 57 can be controlled by adjusting the magnitude of the DC power and the rotation speed of the tubular body 12. After the formation of the base 57, the fourth gate valve 164 is opened, and the tubular body 12 is conveyed from the base forming chamber 154 to the first layer forming chamber 155 via the fourth carrying in/out unit 174.

The first layer forming chamber 155 is evacuated to, for example, about 1E-5 Pa by the fifth vacuum generation unit 185 in a state where the fourth gate valve 164 and the fifth gate valve 165 are closed. The first layer forming chamber 155 has a first layer deposition sputter electrode 195, and forms the first layer 59 on the base 57 by the first layer deposition sputter electrode 195 while rotating the tubular body 12. The first layer deposition sputter electrode 195 has a target material (not shown) of a hydrogen storage metal or a hydrogen storage alloy forming the first layer 59. The front side of the target material faces the base 57. In this example, a magnet (not shown) is arranged on the rear side of the target material. By using the first layer deposition sputter electrode 195, for example, the flow rate of Ar gas is adjusted to set the Ar pressure to about 0.1 to 1 Pa, and the DC power of about 0.1 to 500 kW/m² is applied to form the first layer 59 on the base 57. The thickness of the first layer 59 can be controlled by adjusting the magnitude of the DC power and the rotation speed of the tubular body 12. After the formation of the first layer 59, the fifth gate valve 165 is opened, and the tubular body 12 is conveyed from the first

layer forming chamber **155** to the second layer forming chamber **156** via the fifth carrying in/out unit **175**.

The second layer forming chamber **156** is evacuated to, for example, about $1\text{E-}5$ Pa by the sixth vacuum generation unit **186** in a state where the fifth gate valve **165** and the sixth gate valve **166** are closed. The second layer forming chamber **156** has a second layer deposition sputter electrode **196**, and forms the second layer **60** on the base **57** by the second layer deposition sputter electrode **196** while rotating the tubular body **12**. The second layer deposition sputter electrode **196** has a target material (not shown) of a hydrogen storage metal, a hydrogen storage alloy, or ceramics forming the second layer **60**. The front side of the target material faces the base **57**.

In this example, a magnet (not shown) is arranged on the rear side of the target material. By using the second layer deposition sputter electrode **196**, for example, the flow rate of Ar gas is adjusted to set the Ar pressure to about 0.1 to 1 Pa, and the DC power of about 0.1 to 500 kW/m^2 is applied to form the second layer **60** on the base **57**. When ceramics are used as the target material for forming the second layer **60**, the second layer deposition sputter electrode **196** is configured to apply RF. In the second layer forming chamber **156**, the multilayer film **58** (see FIG. 5) composed of the first layer **59** and the second layer **60** is formed on the surface of the base **57**. In this way, the heat generating element **13** is directly formed on the outer surface of the tubular body **12**. The thickness of the second layer **60** can be controlled by adjusting the magnitude of the DC power and the rotation speed of the tubular body **12**. After the formation of the second layer **60**, the sixth gate valve **166** is opened, and the tubular body **12** is conveyed from the second layer forming chamber **156** to the unload chamber **157** via the sixth carrying in/out unit **176**.

The unload chamber **157** has a carry-out unit **197** for carrying out the tubular body **12**, and the sixth vacuum generation unit **186** is opened to the atmosphere in a state where the carry-out unit **197** and the sixth gate valve **166** are closed. The tubular body **12** on which the heat generating element **13** is formed can be taken out from the unload chamber **157** in an atmospheric-pressure state via the carrying-out unit **197**.

As described above, in the heat generating element production apparatus **150**, the load chamber **151**, the preheating chamber **152**, the sputter etching chamber **153**, the base forming chamber **154**, the first layer forming chamber **155**, the second layer forming chamber **156**, and the unload chamber **157** are separated from each other by the first to sixth gate valves **161** to **166**, and thus the base **57**, the first layer **59**, and the second layer **60** can be continuously formed in a vacuum state. Therefore, in the heat generating element production apparatus **150**, the heat generating element **13** in which the natural oxide film is not formed between the first layer **59** and the second layer **60** and only the heterogeneous material interface **61** is formed can be directly formed on the outer surface of the tubular body **12**.

In FIG. 22, the heat generating element production apparatus **150** is provided with the first to seventh vacuum generation units **181** to **187** that evacuate the respective processing chambers, but the vacuum generation unit may be shared by several processing chambers. When the vacuum generation unit is shared by several processing chambers, the pressure in each processing chamber can be controlled by adjusting the flow rate of the Ar gas using, for example, an orifice valve.

The rotation speed of the tubular body **12** is set based on the thickness of a film to be etched or film-formed, the

etching rate, or the film forming rate. When the thickness of a film to be etched or film-formed is X (nm) and the etching rate or film forming rate is Y (nm/min), it is desirable that the rotation speed Z (rpm) of the tubular body **12** satisfies $Z > 10 \times (Y/X)$. This is because the heat generating element **13** can have a film thickness uniformity (variation in film thickness) of 10% or less. For example, when $X=10$ (nm) and $Y=50$ (nm/min), $Z > 50$ (rpm).

FIG. 23 shows a heat generating unit **200** in which the tubular bodies **12** formed with the heat generating elements **13** are connected to each other. The tubular bodies **12** are connected to each other by, for example, welding. The output of the heat generating unit **200** can be changed by changing the number of the tubular body **12** formed with the heat generating element **13**. Since the heat generating unit **200** has a gap between each heat generating element **13**, even when the tubular body **12** is thermally expanded, damage to each heat generating element **13** is prevented.

The heat generating element production apparatus **150** can be reduced in size as a whole by being configured to carry in a plurality of short tubular body **12** having lengths of, for example, about 50 cm to 2 m. The heat generating unit **200** may be configured by connecting short tubular bodies **12** formed with the heat generating elements **13** to each other.

The heat generating element production apparatus **150** is not limited to one that produces the heat generating element **13** having a configuration in which the multilayer film **58** is formed on the base **57**. The heat generating element production apparatus may be one for producing the heat generating element **133** having a configuration in which the multilayer film **134** is formed on the base **57** or one for producing the heat generating element **143** having a configuration in which the multilayer film **144** is formed on the base **57**.

The heat generating element production apparatus for producing the heat generating element **133** includes the first layer forming chamber **155** and the second layer forming chamber **156**, and further includes a third layer forming chamber having a third layer deposition sputter electrode for forming the third layer **135** on the base **57**. The third layer deposition sputter electrode has a target material of a hydrogen storage metal or a hydrogen storage alloy forming the third layer **135**. In the third layer deposition sputter electrode, similarly to the first layer deposition sputter electrode or the second layer deposition sputter electrode, the thickness of the third layer **135** can be controlled by adjusting the magnitude of the DC power and the rotation speed of the tubular body **12**.

The heat generating element production apparatus for producing the heat generating element **143** includes the first layer forming chamber **155**, the second layer forming chamber **156**, and the third layer forming chamber, and further includes a fourth layer forming chamber having a fourth layer deposition sputter electrode for forming the fourth layer **145** on the base **57**. The fourth layer deposition sputter electrode has a target material of a hydrogen storage metal or a hydrogen storage alloy forming the fourth layer **145**. In the fourth layer deposition sputter electrode, similarly to the first layer deposition sputter electrode or the second layer deposition sputter electrode, the thickness of the fourth layer **145** can be controlled by adjusting the magnitude of the DC power and the rotation speed of the tubular body **12**.

The thickness of the base **57** constituting the heat generating elements **13**, **133**, **143** is not particularly limited and can be appropriately changed. A heat generating element having a film shape (hereinafter referred to as a film-shaped

heat generating element) can be formed by thinning the base 57 into a film shape and providing the multilayer film 58, 134, 144 on the film-shaped base 57. Hereinafter, the film-shaped heat generating element will be described in detail.

As shown in FIG. 24, a film-shaped heat generating element 213 is wrapped around the outer surface of the tubular body 12. Although the film-shaped heat generating element 213 is spirally wound around the outer surface of the tubular body 12 without a gap in FIG. 24, it may be spirally wound around the outer surface of the tubular body 12 with a gap. In addition, the film-shaped heat generating element 213 may be spirally wound around the outer surface of the tubular body 12 such that at least a portion of the film-shaped heat generating elements 213 adjacent to each other in the direction of the central axis C of the tubular body 12 overlaps in the radial direction of the tubular body 12.

The film-shaped heat generating element 213 has the same structure as the heat generating element 13 (see FIG. 5). That is, the film-shaped heat generating element 213 includes the base 57 and the multilayer film 58. The base 57 and the multilayer film 58 constituting the film-shaped heat generating element 213 have a film shape.

The thickness of the base 57 is preferably within a range of 1 μm or more and 5000 μm or less, and more preferably within a range of 100 μm or more and 600 μm or less. The thickness of the multilayer film 58 is preferably within a range of 0.02 μm or more and 10 μm or less, and more preferably within a range of 2 μm or more and 6 μm or less. The thickness of the film-shaped heat generating element 213 is preferably within a range of 1.02 μm or more and 5010 μm or less, and more preferably within a range of 102 μm or more and 606 μm or less. The thickness of the base 57, the thickness of the multilayer film 58, and the thickness of the film-shaped heat generating element 213 are not limited to the above-described values, and can be appropriately designed so that a heat generating device using the film-shaped heat generating element 213 can obtain a desired output.

In this example, the film-shaped heat generating element 213 has the same structure as the heat generating element 13, but may have the same structure as the heat generating element 133 (see FIG. 19), that is, may have the base 57 and the multilayer film 134. Further, the film-shaped heat generating element 213 may have the same structure as the heat generating element 143 (see FIG. 20), that is, may have the base 57 and the multilayer film 144. The multilayer film 134 or the multilayer film 144 constituting the film-shaped heat generating element 213 has a film shape.

The film-shaped heat generating element 213 and the tubular body 12 are joined by, for example, spot-welding. For example, the film-shaped heat generating element 213 and the tubular body 12 are joined to each other by spot-welding the film-shaped heat generating element 213 at equal intervals in the direction of the central axis C of the tubular body 12 while winding the film-shaped heat generating element 213 around the outer surface of the tubular body 12. Although the portion to be spot-welded is heated to a high temperature, since the diameter of the portion to be spot-welded is about 1 mm and the time of the high-temperature state is several seconds, the characteristics of the film-shaped heat generating element 213 are not substantially deteriorated. Note that the place where the film-shaped heat generating element 213 and the tubular body 12 are joined is not particularly limited.

As described above, since the film-shaped heat generating element 213 has the base 57 and the multilayer film 58, it has the same effects as those of the heat generating element 13.

That is, since the film-shaped heat generating element 213 generates heat using hydrogen, it does not generate greenhouse gases such as carbon dioxide. In addition, hydrogen used to generate heat in the film-shaped heat generating element 213 can be generated from water and is therefore inexpensive. Further, the heat generation of the film-shaped heat generating element 213 is considered safe because there is no chain reaction unlike a nuclear fission reaction. Therefore, the film-shaped heat generating element 213 can be used as an inexpensive, clean, and safe energy source. Further, since the base 57 and the multilayer film 58 are film-shaped, the film-shaped heat generating element 213 is excellent in followingness to a curved surface while having flexibility.

FIG. 25 shows a film-shaped heat generating element production apparatus 215 for producing the film-shaped heat generating element 213 using a sputtering method. In this example, the film-shaped heat generating element production apparatus 215 performs a DC magnetron sputtering method as the sputtering method. In the film-shaped heat generating element production apparatus 215, a multilayer film 58 is formed on the surface of a long film-shaped base 57 while the base 57 is continuously conveyed by a roller-to-roller system.

The film-shaped heat generating element production apparatus 215 includes an unwinding chamber 217 for unwinding the long film-shaped base 57, a film forming chamber 218 for forming the multilayer film 58 on the base 57, and a winding chamber 219 for winding the base 57 on which the multilayer film 58 is formed.

In this example, the film-shaped heat generating element production apparatus 215 is constituted by a single vacuum chamber 220, and includes a first partition plate 221 that partitions the unwinding chamber 217 and the film forming chamber 218, a second partition plate 222 that partitions the film forming chamber 218 and the winding chamber 219, and a third partition plate 223 that partitions the unwinding chamber 217 and the winding chamber 219.

The vacuum chamber 220 has a first vacuum generation unit 224 for evacuating the unwinding chamber 217 and a second vacuum generation unit 225 for evacuating the film forming chamber 218. The first vacuum generation unit 224 reduces the pressure inside the unwinding chamber 217 to, for example, about $1\text{E-}4$ Pa. The second vacuum generation unit 225 reduces the pressure inside the film forming chamber 218 to a level lower than that of the unwinding chamber 217, for example, about $1\text{E-}5$ Pa. As the first vacuum generation unit 224 and the second vacuum generation unit 225, for example, a dry pump, a turbo-molecular pump, or the like is used. Sputtering gas is introduced into the vacuum chamber 220 after the pressure is reduced. The sputtering gas is an argon (Ar) gas in this example, but a known gas may be used. The pressure of Ar inside the vacuum chamber 220 can be adjusted by adjusting the flow rate of Ar gas. The shape and material of the vacuum chamber 220 are not particularly limited as long as they can withstand a reduced pressure state.

The unwinding chamber 217 includes an unwinding roller 226 around which the long film-shaped base 57 is wound, a first conveyance roller unit 227 that conveys the base 57 unwound from the unwinding roller 226, and a heating unit 228 that heats the base 57 conveyed by the first conveyance roller unit 227. The unwinding roller 226 has a motor (not shown), and is rotated by driving of the motor. The first conveyance roller unit 227 includes, for example, a free roller and a tension measuring roller.

The heating unit **228** removes moisture adsorbed on the surface of the base **57** by heating the base **57** to a surface temperature of, for example, 200 to 350° C. The heating unit **228** is not particularly limited as long as it can heat the base **57** to a desired temperature. For example, a lamp heating method, an infrared heating method, an induction heating method, or the like can be used.

The film forming chamber **218** includes a film forming roller **229** for conveying the base **57** carried out from the unwinding chamber **217**, a sputter etching electrode **230** for sputter etching the surface of the base **57**, first layer deposition sputter electrodes **231A** and **231B** for forming the first layer **59** on the base **57**, and second layer deposition sputter electrodes **232A** and **232B** for forming the second layer **60** on the base **57**.

The film forming roller **229** has a motor (not shown), and is rotated by driving of the motor. Inside the film forming roller **229**, a refrigerant whose temperature has been adjusted outside the vacuum chamber **220** is circulated. Therefore, in the film forming chamber **218**, the base **57** is controlled to a constant temperature (for example, a temperature within a range of 50 to 300° C.). The tension based on the peripheral speed difference between the film forming roller **229** and the unwinding roller **226** is measured by the tension measuring roller of the first conveyance roller unit **227**. Measurement data measured by the tension measuring roller is fed back to the unwinding roller **226**, and the peripheral speed of the unwinding roller **226** is controlled.

The sputter etching electrode **230**, the first layer deposition sputter electrodes **231A**, **231B**, and the second layer deposition sputter electrodes **232A**, **232B** are arranged at positions facing the surface of the base **57** conveyed by the film forming roller **229**. The sputter etching electrode **230**, the first layer deposition sputter electrodes **231A**, **231B**, and the second layer deposition sputter electrodes **232A**, **232B** have a shield plate on the front side facing the surface of the base **57**.

By using the sputter etching electrode **230**, for example, the flow rate of Ar gas is adjusted to set the Ar pressure to about 0.1 to 1 Pa, and RF of 13.56 MHz is applied to remove organic substances and metallic oxides on the surface of the base **57**.

The first layer deposition sputter electrode **231A** and the first layer deposition sputter electrode **231B** have the same configuration. The first layer deposition sputter electrodes **231A**, **231B** have a target material (not shown) of a hydrogen storage metal or a hydrogen storage alloy forming the first layer **59**. The front side of the target material faces the base **57**. In this example, a magnet (not shown) is arranged on the rear side of the target material. By using the first deposition sputter electrodes **231A**, **231B**, for example, the flow rate of Ar gas is adjusted to set the Ar pressure to about 0.1 to 1 Pa, and the DC power of about 0.1 to 500 kW/m² is applied to form the first layer **59** on the base **57**. The thickness of the first layer **59** can be controlled by adjusting the magnitude of the DC power and the conveyance speed of the base **57**.

The second layer deposition sputter electrode **232A** and the second layer deposition sputter electrode **232B** have the same configuration. The second layer deposition sputter electrodes **232A**, **232B** have a target material (not shown) of a hydrogen storage metal, a hydrogen storage alloy, or ceramics forming the second layer **60**. The front side of the target material faces the base **57**. In this example, a magnet (not shown) is arranged on the rear side of the target material. By using the second layer deposition sputter electrodes **232A**, **232B**, for example, the flow rate of Ar gas is

adjusted to set the Ar pressure to about 0.1 to 1 Pa, and the DC power of about 0.1 to 500 kW/m² is applied to form the second layer **60** on the base **57**. When ceramics are used as the target material for forming the second layer **60**, the second layer deposition sputter electrode **232A** and the second layer deposition sputter electrode **232B** are configured to apply RFs. The thickness of the second layer **60** can be controlled by adjusting the magnitude of the DC power and the conveyance speed of the base **57**.

In FIG. **25**, the traveling direction of the base **57** is indicated by an outline arrow. In FIG. **25**, the first layer deposition sputter electrode **231A**, the second layer deposition sputter electrode **232A**, the first layer deposition sputter electrode **231B**, and the second layer deposition sputter electrode **232B** are arranged in this order from the upstream side to the downstream side in the traveling direction of the base **57**. Therefore, the first layer deposition sputter electrode **231A** forms the first layer **59** on the surface of the base **57**. The second layer deposition sputter electrode **232A** forms the second layer **60** on the surface of the first layer **59** formed by the first layer deposition sputter electrode **231A**. The first layer deposition sputter electrode **231B** forms the first layer **59** on the surface of the second layer **60** formed by the second layer deposition sputter electrode **232A**. The second layer deposition sputter electrode **232B** forms the second layer **60** on the surface of the first layer **59** formed by the first layer deposition sputter electrode **231B**. In this way, in the film forming chamber **218**, the multilayer film **58** composed of the first layer **59** and the second layer **60** is formed on the surface of the base **57**. In the following description, the first layer deposition sputter electrode **231A** and the first layer deposition sputter electrode **231B** are referred to as the first layer deposition sputter electrode **231** when they are not distinguished from each other, and the second layer deposition sputter electrode **232A** and the second layer deposition sputter electrode **232B** are referred to as the second layer deposition sputter electrode **232** when they are not distinguished from each other. When one or more first layer deposition sputter electrodes **231** and one or more second layer deposition sputter electrodes **232** are provided, the multilayer film **58** having one or more first layers **59** and one or more second layers **60**, respectively, and having one or more heterogeneous material interfaces **61** formed therein is obtained. The number of layers of the first layer **59**, the number of layers of the second layer **60**, and the number of the heterogeneous material interfaces **61** can be changed by changing the number of the first layer deposition sputter electrodes **231** and the number of the second layer deposition sputter electrodes **232**.

The winding chamber **219** includes a second conveyance roller unit **233** that conveys the base **57** carried out from the film forming chamber **218**, and a winding roller **234** that winds the base **57** conveyed by the second conveyance roller unit **233**. The film-shaped material wound by the winding roller **234** is the film-shaped heat generating element **213**. The second conveyance roller unit **233** includes, for example, a free roller and a tension measuring roller. The winding roller **234** has a motor (not shown), and is rotated by driving of the motor. The tension based on the peripheral speed difference between the winding roller **234** and the film forming roller **229** is measured by the tension measuring roller of the second conveyance roller unit **233**. Measurement data measured by the tension measuring roller is fed back to the winding roller **234**, and the peripheral speed of the winding roller **234** is controlled. The film-shaped heat generating element **213** is obtained by returning the inside of

the vacuum chamber 220 to the atmosphere pressure and taking out the winding roller 234 from the winding chamber 219.

As described above, in the film-shaped heat generating element production apparatus 215, the first layer 59 and the second layer 60 can be continuously formed in a vacuum state on the base 57 because the first layer deposition sputter electrode 231 and the second layer deposition sputter electrode 232 are alternately arranged from the upstream side to the downstream side in the traveling direction of the long film-shaped base 57. Therefore, in the film-shaped heat generating element production apparatus 215, it is possible to produce a long film-shaped heat generating element 213 in which only the heterogeneous material interface 61 is formed without forming a natural oxide film between the first layer 59 and the second layer 60. The long film-shaped heat generating element 213 has flexibility and excellent followingness to a curved surface such as an uneven shape. Further, since the long film-shaped heat generating element 213 can be used by being cut into desired lengths, it can be applied to more various uses.

A plurality of short film-shaped heat generating elements 213 may be prepared by cutting the long film-shaped heat generating element 213 into predetermined lengths, and the plurality of short film-shaped heat generating elements 213 may be provided on the outer surface of one tubular body 12 at intervals from each other.

The film-shaped heat generating element production apparatus 215 can perform a continuous processing in which heating by the heating unit 228, sputter etching by the sputter etching electrode 230, and film formation by the first layer deposition sputter electrode 231 and the second layer deposition sputter electrode 232 are continuously performed, and a step processing in which heating by the heating unit 228, sputter etching by the sputter etching electrode 230, and film formation by the first layer deposition sputter electrode 231 and the second layer deposition sputter electrode 232 are separately performed. In the case of the continuous processing, heating, sputter etching, and film formation are continued until film formation on one long film-shaped base 57 is completed. In the case of the step processing, for example, by performing ON/OFF of the power supply or adjustment of the input power, the time for performing heating, sputter etching, and film formation can be independently set. Further, the time for film formation may be set by opening and closing a shutter for shielding the target material.

The film-shaped heat generating element production apparatus 215 is not limited to one that produces the film-shaped heat generating element 213 having a configuration in which the multilayer film 58 is formed on the base 57. The film-shaped heat generating element production apparatus may be a production apparatus for producing a film-shaped heat generating element having a configuration in which the multilayer film 134 or the multilayer film 144 is formed on the base 57.

The film-shaped heat generating element production apparatus for producing the film-shaped heat generating element having a configuration in which the multilayer film 134 is formed on the base 57 further includes a third layer deposition sputter electrode for forming the third layer 135 on the base 57 in addition to the first layer deposition sputter electrode 231 and the second layer deposition sputter electrode 232. The third layer deposition sputter electrode has a target material of a hydrogen storage metal or a hydrogen storage alloy forming the third layer 135. In the third layer deposition sputter electrode, similarly to the first layer

deposition sputter electrode 231 or the second layer deposition sputter electrode 232, the thickness of the third layer 135 can be controlled by adjusting the magnitude of the DC power and the conveyance speed of the base 57.

The film-shaped heat generating element production apparatus for producing the film-shaped heat generating element having a configuration in which the multilayer film 144 is formed on the base 57 further includes a fourth layer deposition sputter electrode for forming the fourth layer 145 on the base 57 in addition to the first layer deposition sputter electrode 231, the second layer deposition sputter electrode 232, and the third layer deposition sputter electrode. The fourth layer deposition sputter electrode has a target material of a hydrogen storage metal or a hydrogen storage alloy forming the fourth layer 145. In the fourth layer deposition sputter electrode, similarly to the first layer deposition sputter electrode 231 or the second layer deposition sputter electrode 232, the thickness of the fourth layer 145 can be controlled by adjusting the magnitude of the DC power and the conveyance speed of the base 57.

In addition to the base 57 and the multilayer film 58, a film-shaped heat generating element 243 shown in FIG. 26 further includes a passivation film 244 provided on the surface of the multilayer film 58 to protect the surface of the multilayer film 58. The passivation film 244 is made of a hydrogen-permeable material such as SiO₂ or SiN. The passivation film 244 can be formed by, for example, a chemical vapor deposition (CVD) method. Since the film-shaped heat generating element 243 has the passivation film 244, damage to the multilayer film 58 is suppressed. The passivation film 244 may be provided on the surface of the multilayer film 134 or the multilayer film 144.

REFERENCE SIGNS LIST

- 10, 70, 80, 90, 100, 120 heat generating device
 - 11 sealed container
 - 12 tubular body
 - 13, 133, 143 heat generating element
 - 14 flow path
 - 15 fluid circulation unit
 - 16 control unit
 - 26 hollow portion
 - 30 circulation line
 - 32, 92 cooling unit
 - 33 heating unit
 - 45 external fluid line
 - 55, 55a to 55c heat generating module
 - 57 base
 - 58, 134, 144 multilayer film
 - 59 first layer
 - 60 second layer
 - 61, 136, 146 heterogeneous material interface
 - 71, 104 steam turbine (fluid utilization device)
 - 79, 89, 119, 129 heat utilization system
 - 101 heat recovery line
 - 135 third layer
 - 145 fourth layer
 - 150 heat generating element production apparatus
 - 213, 243 film-shaped heat generating element
 - 215 film-shaped heat generating element production apparatus
- The invention claimed is:
1. A heat generating device comprising:
 - a hollow sealed container;
 - a tubular body provided in a hollow portion formed by an inner surface of the sealed container;

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a heat generating element provided on an outer surface of the tubular body and configured to generate heat by occluding and discharging hydrogen contained in a hydrogen-based gas supplied to the hollow portion; and a flow path formed by an inner surface of the tubular body and through which configured to allow a fluid that exchanges heat with the heat generating element to flow,

wherein

the heat generating element includes a base made of a hydrogen storage metal, a hydrogen storage alloy, or a proton conductor, and a multilayer film provided on the base; and

the multilayer film has a first layer made of a hydrogen storage metal or a hydrogen storage alloy and having a thickness of less than 1000 nm, and a second layer made of a hydrogen storage metal or a hydrogen storage alloy, which is different from that of the first layer, or ceramics and having a thickness of less than 1000 nm.

2. The heat generating device according to claim 1, further comprising:

a fluid circulation unit having a circulation line that is connected to the flow path and is configured to circulate the fluid between an inside and an outside of the tubular body;

a cooling unit that is provided in the circulation line and is configured to cool the fluid;

a heating unit that is provided in the circulation line and is configured to heat the fluid; and

a control unit that drives the cooling unit and performs temperature decrease control to decrease the temperature of the heat generating element by the cooled fluid and drives the heating unit and performs temperature increase control to increase the temperature of the heat generating element by the heated fluid.

3. The heat generating device according to claim 2, wherein the fluid circulation unit further includes an external fluid line provided on an outer surface of the sealed con-

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tainer and connected to the circulation line, and through which configured to allow a part of the fluid to flow.

4. The heat generating device according to claim 1, wherein the first layer is made of any one of Ni, Pd, Cu, Mn, Cr, Fe, Mg, Co, and an alloy thereof, and the second layer is made of any one of Ni, Pd, Cu, Mn, Cr, Fe, Mg, Co, an alloy thereof, and SiC.

5. The heat generating device according to claim 4, wherein the multilayer film has a third layer made of a hydrogen storage metal, a hydrogen storage alloy, or ceramics different from those of the first layer and the second layer and having a thickness of less than 1000 nm, in addition to the first layer and the second layer.

6. The heat generating device according to claim 5, wherein the third layer is made of any one of CaO, Y₂O₃, TiC, LaB₆, SrO, and BaO.

7. The heat generating device according to claim 6, wherein the multilayer film has a fourth layer made of a hydrogen storage metal or a hydrogen storage alloy different from those of the first layer, the second layer, and the third layer and having a thickness of less than 1000 nm, in addition to the first layer, the second layer, and the third layer.

8. The heat generating device according to claim 7, wherein the fourth layer is made of any one of Ni, Pd, Cu, Cr, Fe, Mg, Co, an alloy thereof, SiC, CaO, Y₂O₃, TiC, LaB₆, SrO, and BaO.

9. The heat generating device according to claim 1, wherein the base and the multilayer film have a film shape, and the heat generating element is wound around an outer surface of the tubular body.

10. A heat utilization system comprising:

the heat generating device according to claim 1; and

a fluid utilization device that utilizes the fluid heated by the heat generating element.

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