

US Patent & Trademark Office

Patent Public Search | Text View

United States Patent Application Publication

20250257908

Kind Code

A1

Publication Date

August 14, 2025

Inventor(s)

IWAMURA; Yasuhiro et al.

HEAT UTILIZATION SYSTEM AND HEAT GENERATING DEVICE

Abstract

A heat generating device according to the invention includes: a sealed container into which a hydrogen-based gas is supplied; and a heat generating structure accommodated in the sealed container and in which a plurality of heat generating elements that are configured to generate heat by occluding and discharging hydrogen contained in the hydrogen-based gas are radially arranged. Each of the heat generating elements 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.

Inventors: IWAMURA; Yasuhiro (Sendai-shi, JP), ITO; Takehiko (Tokyo, JP), KASAGI; Jirota (Sendai-shi, JP), YOSHINO; Hideki (Tokyo, JP), HIRANO; Shotaro (Tokyo, JP), ISE; Masahide (Tokyo, JP), IBARAKI; Tetsuharu (Tokyo, JP)

Applicant: CLEAN PLANET INC. (Tokyo, JP)

Family ID: 71077354

Appl. No.: 19/098413

Filed: April 02, 2025

Foreign Application Priority Data

JP	2018-232054	Dec. 11, 2018
JP	2019-091681	May. 14, 2019
JP	2019-150030	Aug. 19, 2019

Related U.S. Application Data

Publication Classification

Int. Cl.: **F24V30/00** (20180101); **F28D7/10** (20060101); **F28D20/00** (20060101); **F28F1/36** (20060101)

U.S. Cl.:

CPC **F24V30/00** (20180501); **F28D7/106** (20130101); **F28D20/003** (20130101); **F28F1/36** (20130101); **F28F2270/00** (20130101)

Background/Summary

TECHNICAL FIELD

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

BACKGROUND ART

[0002] 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, Non-PTL 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 heat energy source.

CITATION LIST

Non-Patent Literature

[0003] Non-PTL 1: A. Kitamura. et. al “Brief summary of latest experimental results with a mass-flow calorimetry system for anomalous heat effect of nano-composite metals under D(H)-gas charging” CURRENT SCIENCE, VOL. 108, NO. 4, p. 589-593, 2015

SUMMARY OF INVENTION

Technical Problem

[0004] However, a heat 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 heat energy source and that have not been disclosed in the related art.

[0005] Therefore, an object of the invention is to provide a novel heat utilization system and heat generating device that utilize an inexpensive, clean, and safe heat energy source.

Solution to Problem

[0006] A heat utilization system according to the invention includes: a sealed container into which a hydrogen-based gas is supplied; a heat generating structure that is accommodated in the sealed container and includes a heat generating element that is configured to generate heat by occluding and discharging hydrogen contained in the hydrogen-based gas; and a heat utilization device that utilizes, as a heat source, a heat medium heated by the heat of the heat generating element. 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. [0007] A heat generating device according to the invention includes: a sealed container into which a hydrogen-based gas is supplied; and a heat generating structure that is accommodated in the sealed container and in which a plurality of heat generating elements that are configured to generate heat by occluding and discharging hydrogen contained in the hydrogen-based gas are radially arranged. 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.

[0008] Another heat utilization system according to the invention includes: a sealed container into which a hydrogen-based gas is supplied; a heat generating structure that is accommodated in the sealed container and includes a heat generating element that is configured to generate heat by occluding and discharging hydrogen contained in the hydrogen-based gas; a combustion device that is configured to combust fuel and combustion air to generate heat; and a heat utilization device that is configured to preheat the combustion air by using the heat of the heat generating element. 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.

Advantageous Effect

[0009] According to the invention, since the heat generating element that generates heat by occluding and discharging hydrogen is utilized as a heat energy source, inexpensive, clean, and safe energy can be supplied.

Description

BRIEF DESCRIPTION OF DRAWINGS

[0010] FIG. 1 is a schematic diagram showing a heat utilization system according to a first embodiment.

[0011] FIG. 2 is a perspective view showing a structure of a heat generating module.

[0012] FIG. 3 is a cross-sectional view showing the structure of the heat generating module.

[0013] FIG. 4 is a cross-sectional view showing a structure of a heat generating element having a first layer and a second layer.

[0014] FIG. 5 is an explanatory diagram showing generation of excess heat.

[0015] FIG. 6 is a cross-sectional view of a heat generating element having a first layer, a second layer, and a third layer.

[0016] FIG. 7 is a cross-sectional view of a heat generating element having a first layer, a second layer, a third layer, and a fourth layer.

[0017] FIG. 8 is a graph showing a relationship between a ratio of layer thicknesses of a multilayer film and the excess heat.

[0018] FIG. 9 is a graph showing a relationship between the number of layers of the multilayer film and the excess heat.

[0019] FIG. 10 is a graph showing a relationship between a material of the multilayer film and the

excess heat.

[0020] FIG. **11** is an explanatory diagram showing an example of an arrangement of the heat generating element.

[0021] FIG. **12** is a schematic diagram showing a cylindrical heat generating element.

[0022] FIG. **13** is a schematic diagram showing a spiral heat generating element wound in a sparsely wound manner.

[0023] FIG. **14** is an explanatory diagram showing an example of a heat utilization device.

[0024] FIG. **15** is a schematic diagram showing a configuration of a thermal power generation plant including a heat utilization system according to a second embodiment.

[0025] FIG. **16** is a perspective view schematically showing a configuration of a heat generating device and a heat utilization device.

[0026] FIG. **17** is an explanatory diagram showing a heat generating device constituted to repeatedly perform supply and exhaust of a hydrogen-based gas.

[0027] FIG. **18** is an explanatory diagram showing a heat utilization system constituted to circulate combustion air.

[0028] FIG. **19** is a schematic diagram showing a configuration of a heat utilization system according to a third embodiment.

[0029] FIG. **20** is an explanatory diagram showing a configuration of a carbon dioxide separation and collection device.

[0030] FIG. **21** is a schematic diagram showing a configuration of a heat utilization system according to a fourth embodiment.

[0031] FIG. **22** is a perspective view of a sealed container including a fin.

[0032] FIG. **23** is a cross-sectional view of a container body of the sealed container including the fin taken in a radial direction.

[0033] FIG. **24** is a cross-sectional view of the container body of the sealed container including the fin taken in a direction orthogonal to the radial direction.

[0034] FIG. **25** is a cross-sectional view of a sealed container including a heat transfer support portion.

[0035] FIG. **26** is a cross-sectional view of the container body of the sealed container including the heat transfer support portion taken in the radial direction.

[0036] FIG. **27** is a cross-sectional view of a flat-plate-shaped heat generating element unit taken in a direction orthogonal to a thickness direction thereof.

[0037] FIG. **28** is a cross-sectional view of the flat-plate-shaped heat generating element unit taken in the thickness direction.

[0038] FIG. **29** is an explanatory diagram showing a state where the flat-plate-shaped heat generating element unit is accommodated in an accommodation container.

[0039] FIG. **30** is a plan view of a sealed container including a fin and formed by a plurality of ribs.

[0040] FIG. **31** is a side view of the sealed container including the fin and formed by the plurality of ribs.

DESCRIPTION OF EMBODIMENTS

1. First Embodiment

[0041] As shown in FIG. **1**, a heat utilization system **10** includes a heat generating device **11** and a heat utilization device **12**. The heat utilization system **10** heats a heat medium to be described later by heat generated by the heat generating device **11**, and operates the heat utilization device **12** using the heated heat medium as a heat source.

[0042] The heat generating device **11** includes a sealed container **15**, a gas exhaust unit **16**, a gas supply unit **17**, a heat generating module **18**, and a control unit **19**.

[0043] The sealed container **15** is a hollow container, and accommodates the heat generating module **18** therein. The sealed container **15** is made of stainless steel or the like. The sealed container **15** has an exhaust port **15a** connected to an exhaust pipe **16b** to be described later and a

supply port **15b** connected to a supply pipe **17b** to be described later. The sealed container **15** includes, for example, a tubular container body (not shown), an upper lid (not shown) provided at an upper end of the container body, and a lower lid (not shown) provided at a lower end of the container body. In this example, the exhaust port **15a** is formed in the upper lid, and the supply port **15b** is formed in the lower lid. Inner surfaces of the container body, the upper lid, and the lower lid form a space inside the sealed container **15**. A hydrogen-based gas, which will be described later, is supplied to the sealed container **15** through the supply pipe **17b** and the supply port **15b**.

[0044] The gas exhaust unit **16** vacuum-evacuates the inside of the sealed container **15**. The gas exhaust unit **16** includes a vacuum pump **16a**, the exhaust pipe **16b**, and an exhaust valve **16c**. The vacuum pump **16a** is formed of, for example, a turbo molecular pump and a dry pump. The exhaust pipe **16b** connects the vacuum pump **16a** and the sealed container **15**. The exhaust pipe **16b** circulates the gas inside the sealed container **15** to the vacuum pump **16a**. The exhaust valve **16c** is provided in the exhaust pipe **16b**. The exhaust valve **16c** adjusts a flow rate of the gas circulating through the exhaust pipe **16b**. The vacuum pump **16a** and the exhaust valve **16c** are electrically connected to the control unit **19**. An exhaust speed of the gas exhaust unit **16** can be controlled by, for example, adjusting a rotation speed of the turbo molecular pump.

[0045] The gas supply unit **17** supplies the hydrogen-based gas into the sealed container **15**. The gas supply unit **17** includes a gas cylinder **17a**, the supply pipe **17b**, and a supply valve **17c**. The gas cylinder **17a** is a container that stores a hydrogen-based gas at a high pressure. The supply pipe **17b** connects the gas cylinder **17a** and the sealed container **15**. The supply pipe **17b** circulates the hydrogen-based gas stored in the gas cylinder **17a** to the sealed container **15**. The supply valve **17c** is provided in the supply pipe **17b**. The supply valve **17c** adjusts the flow rate of the hydrogen-based gas circulating through the supply pipe **17b**. The supply valve **17c** is electrically connected to the control unit **19**. The hydrogen-based gas is a gas containing isotopes of hydrogen. As the hydrogen-based gas, at least one of a deuterium gas and a protium gas is used. The protium gas includes a mixture of naturally occurring protium and deuterium, that is, a mixture in which an abundance ratio of protium is 99.985% and an abundance ratio of deuterium is 0.015%. In the following description, when the protium and the deuterium are not distinguished from each other, both are referred to as “hydrogen”.

[0046] The heat generating module **18** is accommodated in the sealed container **15**. The heat generating module **18** includes a heat generating structure **20** containing a hydrogen storage metal or a hydrogen storage alloy, and a heater **21** that heats the heat generating structure **20**. The heat generating structure **20** occludes hydrogen contained in the hydrogen-based gas and is heated by the heater **21**, so that heat equal to or higher than a heating temperature of the heater **21** (hereinafter, referred to as excess heat) is generated. The heat generating module **18** brings a temperature of the heat medium, which will be described later, to a temperature within a range of, for example, 50° C. or higher and 1500° C. or lower by the excess heat. In this example, the heat generating module **18** heats the heat medium to 1500° C. The heat generating module **18** may include one or more heat generating structures **20** and one or more heaters **21**. The heat generating module **18** includes at least one heat generating structure **20** and at least one heater **21**, and the number of heat generating structures **20** and the number of heaters **21** can be appropriately changed. In the present embodiment, the heat generating module **18** includes three heat generating structures **20** and one heater **21**. A detailed structure of the heat generating module **18** will be described later with reference to other drawings.

[0047] A plurality of heat generating structures **20** are arranged in a direction in which the hydrogen-based gas flows inside the sealed container **15**. The “direction in which the hydrogen-based gas flows” inside the sealed container **15** is a direction in which a main flow of the hydrogen-based gas flows, and is, for example, a direction from the supply port **15b** of the sealed container **15** toward the exhaust port **15a**, that is, a direction from a lower side to an upper side of the sealed container **15**. The heat generating structures **20** are arranged with a gap from each other.

[0048] The heat generating structure **20** is provided with a temperature sensor **22** (see FIGS. **1** and **3**). The temperature sensor **22** is provided in each of the heat generating structures **20**. The temperature sensor **22** detects a temperature of the corresponding heat generating structure **20**. Among the three heat generating structures **20**, the lower-stage heat generating structure **20** comes into contact with the heat medium supplied from the supply port **15b**, and thus has the lowest temperature. Since the middle-stage heat generating structure **20** comes into contact with the heat medium heated by passing through the lower-stage heat generating structure **20**, the temperature of the middle-stage heat generating structure **20** is higher than that of the lower-stage heat generating structure **20**. Since the upper-stage heat generating structure **20** comes into contact with the heated heat medium by passing through the middle-stage heat generating structure **20**, the temperature of the upper-stage heat generating structure **20** is higher than that of the middle-stage heat generating structure **20**. That is, the heat generating structure **20** has a low temperature, a medium temperature, and a high temperature in the order of the lower-stage, the middle-stage, and the upper-stage. As the temperature sensor **22**, for example, a thermocouple is used. The temperature sensor **22** is electrically connected to the control unit **19**, and outputs, to the control unit **19**, a signal corresponding to the detected temperature.

[0049] The heater **21** is an electric furnace formed in a tubular shape. In this example, the heater **21** is formed in a cylindrical shape. Each heat generating structure **20** is arranged in a space formed by an inner surface of the heater **21**. The heater **21** is connected to a power supply **23**, and is driven by electric power input from the power supply **23**. The power supply **23** is electrically connected to the control unit **19**. The heating temperature of the heater **21** is, for example, preferably 300° C. or higher, more preferably 500° C. or higher, and still more preferably 600° C. or higher.

[0050] The heater **21** is provided with a temperature sensor **24**. The temperature sensor **24** detects the temperature of the heater **21**. As the temperature sensor **24**, for example, a thermocouple is used. The temperature sensor **24** is electrically connected to the control unit **19**, and outputs, to the control unit **19**, a signal corresponding to the detected temperature.

[0051] The control unit **19** controls an operation of each unit of the heat utilization system **10**. The control unit **19** mainly includes, for example, an arithmetic device (a central processing unit), and a storage unit such as a read-only memory and a random access memory. The arithmetic device executes various kinds of arithmetic processings using a program, data, and the like stored in the storage unit.

[0052] The control unit **19** is electrically connected to the vacuum pump **16a**, the exhaust valve **16c**, the supply valve **17c**, the power supply **23**, the temperature sensor **24**, and the temperature sensor **22**. For example, the control unit **19** controls the output of the excess heat by adjusting input electric power of the heater **21**, a supply amount of the hydrogen-based gas, a pressure of the sealed container **15**, and the like based on the temperature of the heat generating structure **20** detected by the temperature sensor **22**.

[0053] The heat generating device **11** supplies the hydrogen-based gas into the sealed container **15** to cause the heat generating structure **20** to occlude hydrogen contained in the hydrogen-based gas. The heat generating device **11** discharges hydrogen occluded in the heat generating structure **20** by performing vacuum evacuation of the inside of the sealed container **15** and heating of the heat generating structure **20**. In this way, the heat generating device **11** generates excess heat by occluding and discharging hydrogen in the heat generating structure **20**. That is, a heat generating method using the heat generating device **11** includes a hydrogen occluding step of occluding the hydrogen contained in the hydrogen-based gas into the heat generating structure **20** by supplying the hydrogen-based gas to the inside of the sealed container **15**, and a hydrogen discharging step of discharging the hydrogen occluded in the heat generating structure **20** by performing the vacuum evacuation of the inside of the sealed container **15** and the heating of the heat generating structure **20**. In practice, the hydrogen occluding step and the hydrogen discharging step are repeatedly performed. In the hydrogen occluding step, water or the like adhering to the heat generating

structure **20** may be removed by heating the heat generating structure **20** before the supply of the hydrogen-based gas into the sealed container **15**. In the hydrogen discharging step, for example, after the supply of the hydrogen-based gas into the sealed container **15** is stopped, the vacuum evacuation and the heating are performed.

[0054] The heat utilization device **12** utilizes, as a heat source, a heat medium heated by the heat of the heat generating structure **20**. The heat medium may be a gas or a liquid, and preferably has excellent heat conductivity and chemical stability. Examples of the gas include a helium gas, an argon gas, a hydrogen gas, a 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). Alternatively, the heat medium may be a heat medium having a mixed phase in which solid particles are dispersed in a gas or a liquid. 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. In this example, a helium gas is used as the heat medium.

[0055] The heat utilization device **12** includes an accommodation container **31**, a heat medium circulation unit **32**, a gas turbine **33**, a steam generator **34**, a steam turbine **35**, a Stirling engine **36**, and a thermoelectric converter **37**. Although the heat utilization device **12** includes the gas turbine **33**, the steam generator **34**, the steam turbine **35**, the Stirling engine **36**, and the thermoelectric converter **37** in FIG. 1, the heat utilization device **12** may include any combination of these components.

[0056] The accommodation container **31** is a hollow container, and accommodates the sealed container **15** of the heat generating device **11** therein. The accommodation container **31** is made of ceramics, stainless steel, or the like. The material of the accommodation container **31** is preferably a material having an excellent heat insulation property. The accommodation container **31** has an outflow port **31a** through which the heat medium flows out and an inflow port **31b** through which the heat medium flows in. The heat medium flowing in through the inflow port **31b** passes through a gap formed by an inner surface of the accommodation container **31** and an outer surface of the sealed container **15**, and flows out through the outflow port **31a**.

[0057] The heat medium circulation unit **32** circulates the heat medium between an inside and an outside of the accommodation container **31**. In the present embodiment, the heat medium circulation unit **32** includes a first pipe **32a** that connects the accommodation container **31** and the gas turbine **33**, a second pipe **32b** that connects the gas turbine **33** and the steam generator **34**, a third pipe **32c** that connects the steam generator **34** and the Stirling engine **36**, a fourth pipe **32d** that connects the Stirling engine **36** and the accommodation container **31**, a pump **32e** that causes the heat medium to flow from the accommodation container **31** to the first pipe **32a**, and a heat medium flow rate control unit **32f** that adjusts a flow rate of the heat medium flowing out from the accommodation container **31** to the first pipe **32a**. In this example, the pump **32e** and the heat medium flow rate control unit **32f** are provided in the first pipe **32a**. Examples of the pump **32e** include a metal bellows pump. The heat medium flow rate control unit **32f** includes a variable leak valve or the like as an adjustment valve.

[0058] The heat medium flowing out from the accommodation container **31** sequentially flows through the first pipe **32a**, the second pipe **32b**, the third pipe **32c**, and the fourth pipe **32d**, and is returned to the accommodation container **31**. That is, the heat medium circulation unit **32** functions as a heat medium circulation line through which the heat medium is circulated between the inside and the outside of the accommodation container **31**. The heat medium heated by the heat generating device **11** inside the accommodation container **31** flows through the heat medium circulation unit **32** serving as a heat medium circulation line, and is cooled sequentially via the gas turbine **33**, the steam generator **34**, the Stirling engine **36**, and the thermoelectric converter **37**. The cooled heat

medium flows into the accommodation container **31** and is heated again by the heat generating device **11**.

[0059] The gas turbine **33** is driven by the heat medium flowing out from the accommodation container **31**. A temperature of the heat medium supplied to the gas turbine **33** is preferably in a range of, for example, 600° C. or higher and 1500° C. or lower. The gas turbine **33** includes a compressor **33a** and a turbine **33b**. The compressor **33a** and the turbine **33b** are coupled to each other by a rotation shaft (not shown). The compressor **33a** generates a high-temperature and high-pressure heat medium by compressing the helium gas heated by the heat generating structure **20**. The turbine **33b** is rotated about the rotation shaft by the heat medium that has passed through the compressor **33a**.

[0060] The gas turbine **33** is connected to a power generator **38**. The power generator **38** is coupled to the rotation shaft of the gas turbine **33**, and generates power by rotation of the turbine **33b**.

[0061] The steam generator **34** generates steam by the heat of the heat medium flowing out from the gas turbine **33**. The steam generator **34** includes an internal pipe **34a** and a heat exchange unit **34b**. The internal pipe **34a** connects the second pipe **32b** and the third pipe **32c** and circulates the heat medium. The heat exchange unit **34b** is implemented by a pipe through which boiler water is circulated, and performs heat exchange between the boiler water circulating through the pipe and the heat medium flowing through the internal pipe **34a**. By the heat exchange, the steam generator **34** generates steam from the boiler water.

[0062] The steam generator **34** is connected to the steam turbine **35** via a steam pipe **34c** and a water supply pipe **34d**. The steam pipe **34c** supplies the steam generated by the heat exchange unit **34b** to the steam turbine **35**. The water supply pipe **34d** includes a condenser (not shown) and a water supply pump (not shown). The steam discharged from the steam turbine **35** is cooled by the condenser and returned to the boiler water, and the boiler water is sent to the heat exchange unit **34b** via the water supply pump.

[0063] The steam turbine **35** is driven by the steam generated by the steam generator **34**. A temperature of the steam supplied to the steam turbine **35** is preferably in a range of, for example, 300° C. or higher and 700° C. or lower. The steam turbine **35** has a rotation shaft (not shown) and is rotated about the rotation shaft.

[0064] The steam turbine **35** is connected to a power generator **39**. The power generator **39** is coupled to the rotation shaft of the steam turbine **35**, and generates power by rotation of the steam turbine **35**.

[0065] The Stirling engine **36** is driven by the heat medium flowing out from the steam generator **34**. The temperature of the heat medium supplied to the Stirling engine **36** is preferably in a range of, for example, 300° C. or higher and 1000° C. or lower. In this example, the Stirling engine **36** is a displacer type Stirling engine. The Stirling engine **36** includes a cylinder portion **36a**, a displacer piston **36b**, a power piston **36c**, a flow path **36d**, and a crank portion **36e**.

[0066] The cylinder portion **36a** is formed into a cylindrical shape, and one end thereof is closed and the other end thereof is open. The displacer piston **36b** is provided inside the cylinder portion **36a**. The power piston **36c** is provided inside the cylinder portion **36a** at the other end side of the displacer piston **36b**. The displacer piston **36b** and the power piston **36c** can reciprocate in an axial direction of the cylinder portion **36a**.

[0067] An expansion space **42** and a compression space **43** partitioned by the displacer piston **36b** are provided inside the cylinder portion **36a**. The expansion space **42** is provided at one end side of the cylinder portion **36a** with respect to the compression space **43**. A working fluid is sealed in the expansion space **42** and the compression space **43**. Examples of the working fluid include a helium gas, a hydrogen-based gas, and air. In this example, a helium gas is used as the working fluid.

[0068] The flow path **36d** is provided outside the cylinder portion **36a**, and connects the expansion space **42** and the compression space **43**. The flow path **36d** circulates the working fluid between the expansion space **42** and the compression space **43**.

[0069] The flow path **36d** includes a high temperature portion **45**, a low temperature portion **46**, and a regenerator **47**. The working fluid in the expansion space **42** sequentially passes through the high temperature portion **45**, the regenerator **47**, and the low temperature portion **46**, and flows into the compression space **43**. The working fluid in the compression space **43** sequentially passes through the low temperature portion **46**, the regenerator **47**, and the high temperature portion **45**, and flows into the expansion space **42**.

[0070] The high temperature portion **45** is a heat exchanger for heating the working fluid. A heat transfer pipe **48** is provided outside the high temperature portion **45**. The heat transfer pipe **48** connects the third pipe **32c** and the fourth pipe **32d**, and circulates the heat medium from the third pipe **32c** to the fourth pipe **32d**. When the heat medium flows from the third pipe **32c** to the heat transfer pipe **48**, the heat of the heat medium is transferred to the high temperature portion **45**, and the working fluid passing through the high temperature portion **45** is heated.

[0071] The low temperature portion **46** is a heat exchanger for cooling the working fluid. A cooling pipe **49** is provided outside the low temperature portion **46**. The cooling pipe **49** is connected to a cooling medium supply unit (not shown). The cooling pipe **49** circulates a cooling medium supplied from the cooling medium supply unit. When the cooling medium flows through the cooling pipe **49**, the heat of the working fluid passing through the low temperature portion **46** is taken by the cooling medium, and the working fluid is cooled. The cooling medium is, for example, water.

[0072] The regenerator **47** is a heat exchanger for storing heat. The regenerator **47** is provided between the high temperature portion **45** and the low temperature portion **46**. When the working fluid moves from the expansion space **42** to the compression space **43**, the regenerator **47** receives and accumulates the heat from the working fluid that has passed through the high temperature portion **45**. When the working fluid moves from the compression space **43** to the expansion space **42**, the regenerator **47** supplies the accumulated heat to the working fluid that has passed through the low temperature portion **46**.

[0073] The crank portion **36e** is provided at the other end of the cylinder portion **36a**. The crank portion **36e** includes, for example, a crankshaft rotatably supported by a crankcase, a rod connected to the displacer piston **36b**, a rod connected to the power piston **36c**, and a coupling member that couples the rod and the crankshaft. The crank portion **36e** converts reciprocating motions of the displacer piston **36b** and the power piston **36c** into a rotational motion of the crankshaft.

[0074] The Stirling engine **36** is connected to a power generator **40**. The power generator **40** is coupled to the crankshaft of the Stirling engine **36**, and generates power by rotation of the crankshaft.

[0075] The thermoelectric converter **37** converts the heat of the heat medium circulating through the fourth pipe **32d** into electric power by utilizing a Seebeck effect. The thermoelectric converter **37** generates electric power by the heat medium of, for example, 300° C. or lower. The thermoelectric converter **37** is formed into a tubular shape and covers an outer periphery of the fourth pipe **32d**.

[0076] The thermoelectric converter **37** includes a thermoelectric conversion module **37a** provided on an inner surface thereof and a cooling unit **37b** provided on an outer surface thereof. The thermoelectric conversion module **37a** includes a heat reception substrate facing the fourth pipe **32d**, a heat reception side electrode provided on the heat reception substrate, a heat dissipation substrate facing the cooling unit **37b**, a heat dissipation side electrode provided on the heat dissipation substrate, p-type thermoelectric elements each made of a p-type semiconductor, and n-type thermoelectric elements each made of an n-type semiconductor. In this example, in the thermoelectric conversion module **37a**, the p-type thermoelectric elements and the n-type thermoelectric elements are alternately arranged, and a p-type thermoelectric element and an n-type thermoelectric element adjacent to each other are electrically connected to each other via the heat reception side electrode and the heat dissipation side electrode. A lead is electrically connected to a

p-type thermoelectric element provided at one end of the thermoelectric conversion module **37a** and an n-type thermoelectric element provided at the other end of the thermoelectric conversion module **37a** via the heat dissipation side electrode. The cooling unit **37b** is implemented by, for example, a pipe through which cooling water is circulated. Accordingly, the thermoelectric converter **37** generates electric power corresponding to a temperature difference generated between the inner surface and the outer surface.

[0077] The structure of the heat generating module **18** will be described in detail with reference to FIGS. **2** and **3**. In addition to the heat generating structure **20** and the heater **21**, the heat generating module **18** includes a core tube **50**, a shaft portion **51**, and a support portion **52**. The core tube **50** is formed in a tubular shape. In this example, the core tube **50** has a cylindrical shape. The core tube **50** is made of, for example, mullite and alumina. The core tube **50** is provided in a space formed by the inner surface of the heater **21**. The heat generating structure **20** is provided inside the core tube **50**.

[0078] The shaft portion **51** is formed in a tubular shape. In this example, the shaft portion **51** has a cylindrical shape. For example, one end of the shaft portion **51** is fixed to the upper lid of the sealed container **15**, and the other end of the shaft portion **51** is fixed to the lower lid of the sealed container **15**. The temperature sensor **22** is provided inside the shaft portion **51** (see FIGS. **1** and **3**).

[0079] The support portion **52** is formed in a tubular shape. In this example, the support portion **52** has a cylindrical shape. The shaft portion **51** is inserted into the support portion **52**. In the present embodiment, four support portions **52** are arranged at equal intervals along the longitudinal direction (axial direction) of the shaft portion **51**. Each support portion **52** is fixed to the shaft portion **51** using a screw **53**. The support portion **52** supports the heat generating structure **20**. The heat generating structure **20** is fixed to the shaft portion **51** via the support portion **52**.

[0080] The heat generating structure **20** includes a heat generating element **55** that generates heat by occluding and discharging hydrogen contained in the hydrogen-based gas, a holder **56** that holds the heat generating element **55**, and a frame **57** that forms an outer frame. The heat generating structure **20** includes at least one heat generating element **55**, and the number of heat generating elements **55** can be appropriately changed.

[0081] The heat generating element **55** is formed in a plate shape. In this example, the heat generating element **55** has a quadrangular shape. The heat generating element **55** is arranged upright along a direction in which the hydrogen-based gas flows inside the sealed container **15**. Accordingly, for example, when the hydrogen occluded in the heat generating structure **20** is discharged, the hydrogen-based gas inside the sealed container **15** smoothly flows from the supply port **15b** to the exhaust port **15a** without being blocked by the heat generating element **55**.

[0082] In the present embodiment, a plurality of heat generating elements **55** are radially arranged around the shaft portion **51**. In this example, 16 heat generating elements **55** are used. The plurality of heat generating elements **55** are heated by the heat of the heater **21** and the heat of the adjacent heat generating elements **55**. As a result, it is possible to reduce an input power supply of the heater **21** necessary to maintain a predetermined temperature. A detailed structure of the heat generating element **55** will be described later with reference to other drawings.

[0083] The holder **56** is formed in a rod shape having a longitudinal direction. In this example, the holder **56** has a square rod shape. The holder **56** is arranged such that the longitudinal direction thereof is orthogonal to the direction in which the hydrogen-based gas flows inside the sealed container **15**. In the present embodiment, a plurality of holders **56** are arranged radially around the shaft portion **51**. One end of the holder **56** in the longitudinal direction is arranged at a position farther from the shaft portion **51** than the other end.

[0084] A groove **60** extending in the longitudinal direction of the holder **56** is formed in a surface of the holder **56**. An edge portion of the heat generating element **55** is inserted into the groove **60**. In this example, the groove **60** is formed in an intermediate portion from the other end to one end of the holder **56**. That is, the groove **60** does not penetrate in the longitudinal direction of the holder

56, and one end side of the holder **56** is a dead end. Therefore, the heat generating element **55** inserted into the groove **60** is restricted from moving to one end side of the holder **56**, and is prevented from falling off from the holder **56**.

[0085] In the present embodiment, one heat generating element **55** is held by a pair of holders **56** arranged on an upstream side and a downstream side of the hydrogen-based gas flowing inside the sealed container **15**. In this example, 16 pairs of holders **56** are used to hold the 16 heat generating elements **55**. The pair of holders **56** is arranged such that surfaces on which the grooves **60** are formed face each other.

[0086] The frame **57** is coupled to the holder **56**. In the present embodiment, a pair of frames **57** arranged on the upstream side and the downstream side of the hydrogen-based gas flowing inside the sealed container **15** is coupled to a pair of holders **56**. The frame **57** includes an inner frame **57a** and an outer frame **57b**. The inner frame **57a** and the outer frame **57b** are coupled to the holder **56** using screws **61**.

[0087] The inner frame **57a** is formed in a plate shape. In this example, the inner frame **57a** has a disc shape. An opening **62** into which the shaft portion **51** is inserted is formed at the center of the inner frame **57a**. The opening **62** has, for example, a circular shape. A diameter of the opening **62** of the inner frame **57a** is equal to or smaller than an outer diameter of the support portion **52**. Therefore, in a state where the shaft portion **51** is inserted into the opening **62**, the inner frame **57a** comes into contact with an end portion of the support portion **52**, and a movement of the inner frame **57a** in the longitudinal direction is restricted.

[0088] The outer frame **57b** is formed in a frame shape. In this example, the outer frame **57b** has a ring shape. The outer frame **57b** is arranged at a position farther from the shaft portion **51** than the inner frame **57a**, and a gap is formed between the outer frame **57b** and the inner frame **57a**. The hydrogen-based gas flows through the gap formed between the outer frame **57b** and the inner frame **57a**. Accordingly, the hydrogen-based gas inside the sealed container **15** smoothly flows from the supply port **15b** to the exhaust port **15a**. Openings may be formed in the inner frame **57a** and the outer frame **57b** to allow the hydrogen-based gas to flow more smoothly.

[0089] A detailed structure of the heat generating element **55** will be described with reference to FIG. **4**. As shown in FIG. **4**, the heat generating element **55** includes a base **66** and a multilayer film **67**.

[0090] The base **66** is made of a hydrogen storage metal, a hydrogen storage alloy, or a proton conductor. Examples of the hydrogen storage metal include Ni, Pd, V, Nb, Ta, and Ti. Examples of the hydrogen storage alloy include LaNi.sub.5, CaCu.sub.5, MgZn.sub.2, ZrNi.sub.2, ZrCr.sub.2, TiFe, TiCo, Mg.sub.2Ni, and Mg.sub.2Cu. Examples of the proton conductor include a BaCeO.sub.3-based conductor (for example, Ba(Ce.sub.0.95Y.sub.0.05)O.sub.3-6), a SrCeO.sub.3-based conductor (for example, Sr(Ce.sub.0.95Y.sub.0.05)O.sub.3-6), a CaZrO.sub.3-based conductor (for example, CaZr.sub.0.95Y.sub.0.05O.sub.3-α), a SrZrO.sub.3-based conductor (for example, SrZr.sub.0.9Y.sub.0.1O.sub.3-α), β Al.sub.2O.sub.3, and β Ga.sub.2O.sub.3.

[0091] The multilayer film **67** is provided on the base **66**. Although the multilayer film **67** is provided only on a surface of the base **66** in FIG. **4**, the multilayer film **67** may be provided on both surfaces of the base **66**. In the present embodiment, the heat generating structure **20** includes the heat generating element **55** in which the multilayer film **67** is provided on both surfaces of the base **66**. When the heat generating structure **20** is formed by the heat generating element **55** in which the multilayer film **67** is provided only on the surface of the base **66**, it is preferable that the two heat generating elements **55** are arranged so that the base **66** faces each other and held by the pair of holders **56**. Accordingly, the multilayer films **67** of the heat generating elements **55** are arranged on both surfaces of the heat generating structure **20**.

[0092] The multilayer film **67** has a first layer **71** made of a hydrogen storage metal or a hydrogen storage alloy, and a second layer **72** made of a hydrogen storage metal or a hydrogen storage alloy, which is different from that of the first layer **71**, or ceramics. A heterogeneous material interface **73**

to be described later is formed between the base **66** and the first layer **71** and the second layer **72**. In FIG. **4**, the multilayer film **67** is formed by alternately stacking the first layer **71** and the second layer **72** in order on the surface of the base **66**. The first layer **71** and the second layer **72** each have five layers. The number of layers of each of the first layer **71** and the second layer **72** may be changed as appropriate. The multilayer film **67** may be formed by alternately stacking the second layer **72** and the first layer **71** in order on the surface of the base **66**. The multilayer film **67** preferably has one or more first layers **71** and one or more second layers **72**, and one or more heterogeneous material interfaces **73** are preferably formed.

[0093] The first layer **71** is made of, for example, any one of Ni, Pd, Cu, Mn, Cr, Fe, Mg, Co, and an alloy thereof. An alloy for forming the first layer **71** is preferably an alloy made of two or more of Ni, Pd, Cu, Mn, Cr, Fe, Mg, and Co. The alloy for forming the first layer **71** may be an alloy obtained by adding an additive element to Ni, Pd, Cu, Mn, Cr, Fe, Mg, and Co.

[0094] The second layer **72** is made of, for example, any one of Ni, Pd, Cu, Mn, Cr, Fe, Mg, Co, an alloy thereof, and SiC. An alloy for forming the second layer **72** is preferably an alloy made of two or more of Ni, Pd, Cu, Mn, Cr, Fe, Mg, and Co. The alloy for forming the second layer **72** may be an alloy obtained by adding an additive element to Ni, Pd, Cu, Mn, Cr, Fe, Mg, and Co.

[0095] A combination of the first layer **71** and the second layer **72** is preferably Pd—Ni, Ni—Cu, Ni—Cr, Ni—Fe, Ni—Mg, and Ni—Co when types of elements are expressed as “first layer **71**-second layer **72** (second layer **72**-first layer **71**)”. When the second layer **72** is made of ceramics, the “first layer **71**-second layer **72**” is preferably Ni—SiC.

[0096] As shown in FIG. **5**, hydrogen atoms permeate through the heterogeneous material interface **73**. FIG. **5** is a schematic diagram showing a state where the hydrogen atoms in a metal lattice of the first layer **71** permeate through the heterogeneous material interface **73** and move to a metal lattice of the second layer **72** when the first layer **71** and the second layer **72** each made of a hydrogen storage metal having a face-centered cubic structure are made to occlude hydrogen and then the first layer **71** and the second layer **72** are heated.

[0097] The heat generating element **55** occludes hydrogen by the base **66** and the multilayer film **67** when the hydrogen-based gas is supplied to the sealed container **15**. Even when the supply of the hydrogen-based gas to the sealed container **15** is stopped, the heat generating element **55** maintains a state where hydrogen is occluded in the base **66** and the multilayer film **67**. In the heat generating element **55**, when heating is started by the heater **21**, hydrogen occluded in the base **66** and the multilayer film **67** is discharged, and quantum diffusion occurs while hopping the inside of the multilayer film **67**. It is known that hydrogen is light and hops in a manner of quantum diffusion at a site (octahedral site or tetrahedral site) occupied by hydrogen of a certain substance A and substance B. When the heat generating element **55** is heated by the heater **21** in a vacuum state, hydrogen permeates through the heterogeneous material interface **73** in a manner of quantum diffusion, and generates excess heat equal to or higher than the heating temperature of the heater **21**.

[0098] A thickness of each of the first layer **71** and the second layer **72** is preferably less than 1000 nm. When the thickness of each of the first layer **71** and the second layer **72** is 1000 nm or more, hydrogen is less likely to permeate through the multilayer film **67**. When the thickness of each of the first layer **71** and the second layer **72** is less than 1000 nm, a nano-structure that does not exhibit a bulk property can be maintained. The thickness of each of the first layer **71** and the second layer **72** is more preferably less than 500 nm. When the thickness of each of the first layer **71** and the second layer **72** is less than 500 nm, a nano-structure that does not exhibit a bulk property at all can be maintained.

[0099] An example of a method for producing the heat generating element **55** will be described. The plate-shaped base **66** is prepared, an evaporation device is used to make a hydrogen storage metal or a hydrogen storage alloy for forming the first layer **71** or the second layer **72** into a gas phase state, and then the first layer **71** and the second layer **72** are alternately formed on the base **66**

by aggregation or adsorption, so that the heat generating element 55 is formed. The first layer 71 and the second layer 72 are preferably formed continuously in a vacuum state. Accordingly, between the first layer 71 and the second layer 72, no natural oxide film is formed and only the heterogeneous material interface 73 is formed. The evaporation device may be a physical evaporation device in which the hydrogen storage metal or the hydrogen storage alloy is evaporated by a physical method. The physical evaporation device is preferably a sputtering device, a vacuum evaporation device, and a chemical vapor deposition (CVD) device. Alternatively, the hydrogen storage metal or the hydrogen storage alloy may be deposited on the base 66 by an electroplating method, to alternately form the first layer 71 and the second layer 72.

[0100] Since the heat generating element 55 generates heat using hydrogen, it does not generate greenhouse gases such as carbon dioxide. Hydrogen used is generated from water and is thus inexpensive. Unlike a nuclear fission reaction, heat generation of the heat generating element 55 is safe since there is no chain reaction. Therefore, since the heat utilization system 10 and the heat generating device 11 utilize the heat generating element 55 as a heat energy source, inexpensive, clean, and safe energy can be supplied.

[0101] The invention is not limited to the first embodiment described above, and can be modified as appropriate without departing from the scope of the invention.

[0102] In the first embodiment, although the multilayer film 67 of the heat generating element 55 includes the first layer 71 and the second layer 72, the structure of the multilayer film 67 is not limited thereto.

[0103] For example, as shown in FIG. 6, in a heat generating element 75, the multilayer film 67 provided on the base 66 further has a third layer 77 in addition to the first layer 71 and the second layer 72. The third layer 77 is made of a hydrogen storage metal, a hydrogen storage alloy, or ceramics different from those of the first layer 71 and the second layer 72. A thickness of the third layer 77 is preferably less than 1000 nm. In FIG. 6, the first layer 71, the second layer 72, and the third layer 77 are stacked on the surface of the base 66 in order of the first layer 71, the second layer 72, the first layer 71, and the third layer 77. The first layer 71, the second layer 72, and the third layer 77 may be stacked on the surface of the base 66 in order of the first layer 71, the third layer 77, the first layer 71, and the second layer 72. That is, the multilayer film 67 has a stacking structure in which the first layer 71 is provided between the second layer 72 and the third layer 77. The multilayer film 67 preferably has one or more third layers 77. Similar to the heterogeneous material interface 73, hydrogen atoms permeate through a heterogeneous material interface 78 formed between the first layer 71 and the third layer 77. The heat generating element 75 can be used instead of the heat generating element 55. That is, the heat generating structure 20 may include the heat generating element 75.

[0104] The third layer 77 is made of, for example, any one of Ni, Pd, Cu, Cr, Fe, Mg, Co, an alloy thereof, SiC, CaO, Y.sub.2O.sub.3 , TiC, LaB.sub.6 , SrO, and BaO. An alloy for forming the third layer 77 is preferably an alloy made of two or more of Ni, Pd, Cu, Cr, Fe, Mg, and Co. The alloy for forming the third layer 77 may be an alloy obtained by adding an additive element to Ni, Pd, Cu, Cr, Fe, Mg, and Co.

[0105] In particular, the third layer 77 is preferably made of any one of CaO, Y.sub.2O.sub.3 , TiC, LaB.sub.6 , SrO, and BaO. In the heat generating element 75 having the third layer 77 made of any one of CaO, Y.sub.2O.sub.3 , TiC, LaB.sub.6 , SrO, and BaO, an occluding amount of hydrogen is increased, an amount of hydrogen permeating through the heterogeneous material interfaces 73 and 78 is increased, and a high output of excess heat can be achieved. The thickness of the third layer 77 made of any one of CaO, Y.sub.2O.sub.3 , TiC, LaB.sub.6 , SrO, and BaO is preferably 10 nm or less. Accordingly, hydrogen atoms easily permeate through the multilayer film 67. The third layer 77 made of any one of CaO, Y.sub.2O.sub.3 , TiC, LaB.sub.6 , SrO, and BaO may not be formed into a complete film shape and may be formed into an island shape. The first layer 71 and the third layer 77 are preferably formed continuously in a vacuum state. Accordingly, between the first layer

71 and the third layer **77**, no natural oxide film is formed and only the heterogeneous material interface **78** is formed.

[0106] A combination of the first layer **71**, the second layer **72**, and the third layer **77** is preferably Pd—CaO—Ni, Pd—Y.sub.2O.sub.3—Ni, Pd—TiC—Ni, Pd—LaB.sub.6—Ni, Ni—CaO—Cu, Ni—Y.sub.2O.sub.3—Cu, Ni—TiC—Cu, Ni—LaB.sub.6—Cu, Ni—Co—Cu, Ni—CaO—Cr, Ni—Y.sub.2O.sub.3—Cr, Ni—TiC—Cr, Ni—LaB.sub.6—Cr, Ni—CaO—Fe, Ni—Y.sub.2O.sub.3—Fe, Ni—TiC—Fe, Ni—LaB.sub.6—Fe, Ni—Cr—Fe, Ni—CaO—Mg, Ni—Y.sub.2O.sub.3—Mg, Ni—TiC—Mg, Ni—LaB.sub.6—Mg, Ni—CaO—Co, Ni—Y.sub.2O.sub.3—Co, Ni—TiC—Co, Ni—LaB.sub.6—Co, Ni—CaO—SiC, Ni—Y.sub.2O.sub.3—SiC, Ni—TiC—SiC, and Ni—LaB.sub.6—SiC when types of elements are expressed as “first layer **71**-third layer **77**-second layer **72**”.

[0107] The heat generating structure **20** may include a heat generating element **80** shown in FIG. 7 instead of the heat generating element **55** or the heat generating element **75**. As shown in FIG. 7, in the heat generating element **80**, the multilayer film **67** provided on the base **66** further has a fourth layer **82** in addition to the first layer **71**, the second layer **72**, and the third layer **77**. The fourth layer **82** is made of a hydrogen storage metal, a hydrogen storage alloy, or ceramics different from those of the first layer **71**, the second layer **72**, and the third layer **77**. A thickness of the fourth layer **82** is preferably less than 1000 nm. In FIG. 7, the first layer **71**, the second layer **72**, the third layer **77**, and the fourth layer **82** are stacked on the surface of the base **66** in order of the first layer **71**, the second layer **72**, the first layer **71**, the third layer **77**, the first layer **71**, and the fourth layer **82**. The first layer **71**, the second layer **72**, the third layer **77**, and the fourth layer **82** may be stacked on the surface of the base **66** in order of the first layer **71**, the fourth layer **82**, the first layer **71**, the third layer **77**, the first layer **71**, and the second layer **72**. That is, the multilayer film **67** has a stacking structure in which the second layer **72**, the third layer **77**, and the fourth layer **82** are stacked in any order and the first layer **71** is provided between the second layer **72** and the third layer **77**, between the third layer **77** and the fourth layer **82**, and between the second layer **72** and the fourth layer **82**. The multilayer film **67** preferably has one or more fourth layers **82**. Similar to the heterogeneous material interface **73** and the heterogeneous material interface **78**, hydrogen atoms permeate through a heterogeneous material interface **83** formed between the first layer **71** and the fourth layer **82**. The heat generating element **80** can be used instead of the heat generating element **55**. That is, the heat generating structure **20** may include the heat generating element **80**.

[0108] The fourth layer **82** is made of, for example, any one of Ni, Pd, Cu, Cr, Fe, Mg, Co, an alloy thereof, SiC, CaO, Y.sub.2O.sub.3, TiC, LaB.sub.6, SrO, and BaO. An alloy for forming the fourth layer **82** is preferably an alloy made of two or more of Ni, Pd, Cu, Cr, Fe, Mg, and Co. The alloy for forming the fourth layer **82** may be an alloy obtained by adding an additive element to Ni, Pd, Cu, Cr, Fe, Mg, and Co.

[0109] In particular, the fourth layer **82** is preferably made of any one of CaO, Y.sub.2O.sub.3, TiC, LaB.sub.6, SrO, and BaO. In the heat generating element **80** having the fourth layer **82** made of any one of CaO, Y.sub.2O.sub.3, TiC, LaB.sub.6, SrO, and BaO, an occluding amount of hydrogen is increased, an amount of hydrogen permeating through the heterogeneous material interfaces **73**, **78**, and **83** is increased, and a high output of excess heat can be achieved. The thickness of the fourth layer **82** made of any one of CaO, Y.sub.2O.sub.3, TiC, LaB.sub.6, SrO, and BaO is preferably 10 nm or less. Accordingly, hydrogen atoms easily permeate through the multilayer film **67**. The fourth layer **82** made of any one of CaO, Y.sub.2O.sub.3, TiC, LaB.sub.6, SrO, and BaO may not be formed into a complete film shape and may be formed into an island shape. The first layer **71** and the fourth layer **82** are preferably formed continuously in a vacuum state. Accordingly, between the first layer **71** and the fourth layer **82**, no natural oxide film is formed and only the heterogeneous material interface **83** is formed.

[0110] A combination of the first layer **71**, the second layer **72**, the third layer **77**, and the fourth layer **82** is preferably Ni—CaO—Cr—Fe, Ni—Y.sub.2O.sub.3—Cr—Fe, Ni—TiC—Cr—Fe, and Ni—LaB.sub.6—Cr—Fe when types of elements are expressed as “first layer **71**-fourth layer **82**-

third layer 77-second layer 72”.

[0111] A configuration of the multilayer film 67 such as a ratio of layer thicknesses, the number of layers of each layer, and a material may be appropriately changed according to a temperature to be used. Hereinafter, an example of the configuration of the multilayer film 67 corresponding to a temperature will be described after describing a “relationship between a ratio of layer thicknesses of the multilayer film and the excess heat”, a “relationship between the number of layers of the multilayer film and the excess heat”, and a “relationship between a material of the multilayer film and the excess heat”.

[0112] First, the “relationship between a ratio of layer thicknesses of the multilayer film and the excess heat” will be described. A relationship between a ratio of the thickness of the second layer 72 to the thickness of the first layer 71 and the excess heat was examined using the heat generating element 55 including the base 66 made of Ni and the multilayer film 67 having the first layer 71 made of Cu and the second layer 72 made of Ni. Hereinafter, the ratio of layer thicknesses of the multilayer film 67 is referred to as Ni:Cu.

[0113] Eight types of heat generating elements 55, in which the multilayer films 67 were formed under the same conditions except for the ratio Ni:Cu, were prepared and used as Examples 1 to 8. The multilayer film 67 was provided only on the surface of the base 66. Ratios Ni:Cu in the heat generating elements 55 according to Examples 1 to 8 are respectively 7:1, 14:1, 4.33:1, 3:1, 5:1, 8:1, 6:1, and 6.5:1. In each of the heat generating elements 55 according to Examples 1 to 8, the multilayer film 67 is formed by repeating a stacking configuration having the first layer 71 and the second layer 72. In each of the heat generating elements 55 according to Examples 1 to 8, the number of layers in the stacking configuration of the multilayer film 67 (hereinafter, referred to as the number of layers of the multilayer film) was 5. The thickness of the entire multilayer film 67 in each of the heat generating elements 55 according to Examples 1 to 8 was substantially the same. An experimental heat generating device (not shown) for examining the relationship between the ratio of the thickness of each layer of the multilayer film 67 and the excess heat was prepared, and each of the heat generating elements 55 according to Examples 1 to 8 was introduced into the experimental heat generating device.

[0114] The experimental heat generating device will be described. The experimental heat generating device includes a sealed container, two heat generating elements provided inside the sealed container, and a heater that heats the heat generating elements. The heat generating element is formed into a plate shape. The heater is a ceramic heater formed into a plate shape, and includes a built-in thermocouple. The heater is provided between the two heat generating elements. The two heat generating elements 55 has the same configuration, that is, Ni:Cu is the same. The sealed container is connected to a hydrogen-based gas supply path and an exhaust path. The hydrogen-based gas supply path connects a gas cylinder that stores a hydrogen-based gas and the sealed container. The hydrogen-based gas supply path is provided with an adjustment valve or the like for adjusting a supply amount of the hydrogen-based gas stored in the gas cylinder to the sealed container. The exhaust path connects a dry pump for vacuum evacuating an inside of the sealed container and the sealed container. The exhaust path is provided with an adjustment valve for adjusting an exhaust amount of the gas. In the experimental heat generating device, a protium gas (manufactured by Numata Oxygen Co., grade 2, purity: 99.999 vol % or more) was used as a hydrogen-based gas.

[0115] Each of the heat generating elements 55 according to Examples 1 to 8 was provided inside the sealed container of the experimental heat generating device, and the hydrogen occluding step and the hydrogen discharging step were repeated. That is, in the experimental heat generating device, a hydrogen occluding step of occluding hydrogen contained in the hydrogen-based gas in the heat generating element 55 by supplying the hydrogen-based gas to the inside of the sealed container, and a hydrogen discharging step of discharging hydrogen stored in the heat generating element 55 by performing the vacuum evacuation of the inside of the sealed container and heating

of the heat generating element 55 were repeatedly performed. In the hydrogen occluding step, the hydrogen-based gas was supplied into the sealed container at about 50 Pa. The time for occluding hydrogen in the heat generating element 55 was about 64 hours. Before the hydrogen occluding step, first, the inside of the sealed container was baked by a heater at about 200° C. or higher for 36 hours to remove water and the like adhered to a front surface of the heat generating element 55. Hydrogen discharging steps were performed with input electric power of the heater of 9 W, 18 W, and 27 W, and hydrogen occluding steps were performed between the hydrogen discharging steps. Then, the temperature of the heat generating element 55 in each of the hydrogen discharging steps was measured using the thermocouple built in the heater. Results are shown in FIG. 8. FIG. 8 is a graph obtained by fitting measured data by a predetermined method. In FIG. 8, a horizontal axis indicates a heater temperature and a vertical axis indicates electric power of excess heat. The heater temperature is the temperature of the heat generating element 55 at predetermined input electric power. In FIG. 8, Example 1 was expressed as “Ni:Cu=7:1”, Example 2 was expressed as “Ni:Cu=14:1”, Example 3 was expressed as “Ni:Cu=4.33:1”, Example 4 was expressed as “Ni:Cu=3:1”, Example 5 was expressed as “Ni:Cu=5:1”, Example 6 was expressed as “Ni:Cu=8:1”, Example 7 was expressed as “Ni:Cu=6:1”, and Example 8 was expressed as “Ni:Cu=6.5:1”.

[0116] From FIG. 8, it was confirmed that the excess heat was generated in all of the heat generating elements 55 according to Examples 1 to 8. When comparing the heat generating elements 55 according to Examples 1 to 8 at a heater temperature of 700° C. or higher, it is found that the heat generating element 55 according to Example 1 generates the largest excess heat. When comparing the heat generating element according to Example 3 with the heat generating elements 55 according to Examples 1, 2, 4 to 8, it is found that the heat generating element according to Example 3 generates excess heat in a wide range in which the heater temperature is 300° C. or higher and 1000° C. or lower. It is found that the excess heat increases as the heater temperature increases in the heat generating elements 55 according to Examples 1, 3 to 8 in which Ni:Cu of the multilayer film 67 is 3:1 to 8:1. It is found that the excess heat decreases at a heater temperature of 800° C. or higher in the heat generating element 55 according to Example 2 in which Ni:Cu of the multilayer film 67 is 14:1. Thus, it is considered that the excess heat does not simply increase with respect to the ratio Ni:Cu due to a quantum effect of hydrogen in the multilayer film 67.

[0117] Next, the “relationship between the number of layers of the multilayer film and the excess heat” will be described. A relationship between the number of layers of the multilayer film 67 and the excess heat was examined by using the heat generating element 55 including the base 66 made of Ni and the multilayer film 67 having the first layer 71 made of Cu and the second layer 72 made of Ni.

[0118] Eight types of heat generating elements 55, in which the multilayer films 67 were produced under the conditions same as the conditions for producing the heat generating element 55 according to Example 1 except for the number of layers, were prepared and used as Examples 9 to 16. The number of layers of the multilayer films 67 of the heat generating elements 55 according to Examples 1, 9 to 16 is respectively 5, 3, 7, 6, 8, 9, 12, 4, and 2.

[0119] Each of the heat generating elements 55 according to Examples 1, 9 to 16 was provided inside a sealed container of an experimental heat generating device. The experimental heat generating device is the same as the device used to examine the above-described “relationship between a ratio of layer thicknesses of the multilayer film and the excess heat”. In the experimental heat generating device, the temperature of each of the heat generating elements 55 during the hydrogen discharging step was measured by the same method as that for the above-described “relationship between a ratio of layer thicknesses of the multilayer film and the excess heat”. Results are shown in FIG. 9. FIG. 9 is a graph obtained by fitting measured data by a predetermined method. In FIG. 9, a horizontal axis indicates a heater temperature and a vertical axis indicates electric power of excess heat. In FIG. 9, based on the thickness of each layer,

Example 1 was expressed as “Ni.sub.0.875Cu.sub.0.125 5 layers”, Example 9 was expressed as “Ni.sub.0.875Cu.sub.0.125 3 layers”, Example 10 was expressed as “Ni.sub.0.875Cu.sub.0.125 7 layers”, Example 11 was expressed as “Ni.sub.0.875Cu.sub.0.125 6 layers”, Example 12 was expressed as “Ni.sub.0.875Cu.sub.0.125 8 layers”, Example 13 was expressed as “Ni.sub.0.875Cu.sub.0.125 9 layers”, Example 14 was expressed as “Ni.sub.0.875Cu.sub.0.125 12 layers”, Example 15 was expressed as “Ni.sub.0.875Cu.sub.0.125 4 layers”, and Example 16 was expressed as “Ni.sub.0.875Cu.sub.0.125 2 layers”.

[0120] From FIG. 9, it was confirmed that the excess heat was generated in all of the heat generating elements 55 according to Examples 1, 9 to 16. When comparing the heat generating elements 55 according to Examples 1, 9 to 16 at a heater temperature of 840° C. or higher, it is found that the heat generating element 55 according to Example 11 in which the number of layers of the multilayer film 67 is 6 generates the largest excess heat and the heat generating element 55 according to Example 12 in which the number of layers of the multilayer film 67 is 8 generates the smallest excess heat. Thus, it is considered that the excess heat does not simply increase with respect to the number of layers of the multilayer film 67 since a wavelength of a behavior of a hydrogen wave in the multilayer film 67 is in a nanometer order and interferes with the multilayer film 67.

[0121] Next, the “relationship between a material of the multilayer film and the excess heat” will be described. The relationship between a type of a material for forming the third layer 77 and the excess heat was examined using the heat generating element 75 including the multilayer film 67 having the first layer 71 made of Ni, the second layer 72 made of Cu, and the third layer 77 made of a hydrogen storage metal, a hydrogen storage alloy, or ceramics different from the materials of the first layer 71 and the second layer 72.

[0122] Nine types of heat generating elements 75, in which the multilayer films 67 were formed under the same conditions except for types of the material for forming the third layer 77, were prepared and used as Examples 17 to 25. The types of the material for forming the third layer 77 in the heat generating elements 75 according to Examples 17 to 25 are respectively CaO, SiC, Y.sub.2O.sub.3, TiC, Co, LaB.sub.6, ZrC, TiB.sub.2, and CaOZrO.

[0123] Each of the heat generating elements 75 according to Examples 17 to 25 was provided inside a sealed container of an experimental heat generating device. The experimental heat generating device is the same as the device used to examine the above-described “relationship between a ratio of layer thicknesses of the multilayer film and the excess heat”. In the experimental heat generating device, the temperature of each of the heat generating elements 75 during the hydrogen discharging step was measured by the same method as that for the above-described “relationship between a ratio of layer thicknesses of the multilayer film and the excess heat”. Results are shown in FIG. 10. FIG. 10 is a graph obtained by fitting measured data by a predetermined method. In FIG. 10, a horizontal axis indicates a heater temperature and a vertical axis indicates electric power of excess heat. In FIG. 10, based on the thickness of each layer, Example 17 was expressed as “Ni.sub.0.793CaO.sub.0.113Cu.sub.0.094”, Example 18 was expressed as “Ni.sub.0.793SiC.sub.0.113Cu.sub.0.094”, Example 19 was expressed as “Ni.sub.0.793Y.sub.2O.sub.30.113Cu.sub.0.094”, Example 20 was expressed as “Ni.sub.0.793TiC.sub.0.113Cu.sub.0.094”, Example 21 was expressed as “Ni.sub.0.793Co.sub.0.113Cu.sub.0.094”, Example 22 was expressed as “Ni.sub.0.793LaB.sub.60.113Cu.sub.0.094”, Example 23 was expressed as “Ni.sub.0.793ZrC.sub.0.113Cu.sub.0.094”, Example 24 was expressed as “Ni.sub.0.793TiB.sub.20.113Cu.sub.0.094”, and Example 25 was expressed as “Ni.sub.0.793CaOZrO.sub.0.113Cu.sub.0.094”.

[0124] From FIG. 10, it was confirmed that the excess heat was generated in all of the heat generating elements 75 according to Examples 17 to 25. In particular, when comparing Example 17 in which the material for forming the third layer 77 is CaO, Example 20 in which the material for

forming the third layer 77 is TiC, and Example 22 in which the material for forming the third layer 77 is LaB.sub.6 with Examples 18, 19, 21, 23 to 25, it is found that the excess heat increases in a substantially linear manner in a wide range in which the heater temperature is 400° C. or higher and 1000° C. or lower. Materials for forming the third layers 77 in Examples 17, 20, and 22 have a work function smaller than those of the materials in Examples 18, 19, 21, 23 to 25. Therefore, it is found that the type of the material for forming the third layer 77 preferably has a small work function. Based on the results, an electron density in the multilayer film 67 may contribute to a reaction that generates excess heat.

[0125] An example of the structure of the multilayer film 67 according to the temperature of the heat generating structure 20 will be described. For example, regarding the upper-stage, middle-stage, and lower-stage heat generating structures 20 shown in FIGS. 2 and 3, in consideration of the above-described “relationship between a ratio of layer thicknesses of the multilayer film and the excess heat”, in the lower-stage heat generating structure 20 that is set to a low temperature (for example, in a range of 50° C. or higher and 500° C. or lower), the ratio of layer thicknesses of the multilayer film 67 is preferably in a range of 2:1 or more and 5:1 or less. In the middle-stage heat generating structure 20 at a medium temperature (for example, in a range of 500° C. or higher and 800° C. or lower), the ratio of layer thicknesses of the multilayer film 67 is preferably in a range of 5:1 or more and 6:1 or less. In the upper-stage heat generating structure 20 at a high temperature (for example, in a range of 800° C. or higher and 1500° C. or lower), the ratio of layer thicknesses of the multilayer film 67 is preferably in a range of 6:1 or more and 12:1 or less.

[0126] In consideration of the above-described “relationship between the number of layers of the multilayer film and the excess heat”, in each of the heat generating structures 20 that are set to a low temperature, a medium temperature, and a high temperature, the number of layers of the first layer 71 of the multilayer film 67 is preferably in a range of 2 layers or more and 18 layers or less, and the number of layers of the second layer 72 is preferably in a range of 2 layers or more and 18 layers or less.

[0127] When the heat generating element 75 is used in place of the heat generating element 55 in the upper-stage, middle-stage, and lower-stage heat generating structures 20 shown in FIGS. 2 and 3, in consideration of the above-described “relationship between the material of the multilayer film and the excess heat”, the first layer 71 is preferably made of Ni, the second layer 72 is preferably made of Cu, and the third layer 77 is preferably made of Y.sub.2O.sub.3 in the lower-stage heat generating structure 20 which is set to a low temperature. In the middle-stage heat generating structure 20 that is set to a medium temperature, the first layer 71 is preferably made of Ni, the second layer 72 is preferably made of Cu, and the third layer 77 is preferably made of TiC. In the upper-stage heat generating structure 20 that is set to a high temperature, the first layer 71 is preferably made of Ni, the second layer 72 is preferably made of Cu, and the third layer 77 is preferably made of CaO or LaB.sub.6.

[0128] In the first embodiment, the heat generating structure 20 has a configuration in which the plurality of heat generating elements 55 are radially arranged, whereas the arrangement of the heat generating elements 55 may be appropriately changed.

[0129] For example, as shown in FIG. 11, a plurality of heat generating elements 55 are arranged in a line with a gap therebetween. In this case, it is preferable that the heater 21 has a square tubular shape. Accordingly, space saving can be achieved. The plurality of heat generating elements 55 are heated by the heat of the heater 21 and the heat of the adjacent heat generating elements 55.

Accordingly, it is possible to reduce the input power supply of the heater 21 necessary to maintain the predetermined temperature.

[0130] An arrangement direction of the plurality of heat generating elements 55 is preferably a direction perpendicular to the direction in which the hydrogen-based gas flows inside the sealed container 15. In this case, the plurality of heat generating elements 55 are arranged upright along the direction in which the hydrogen-based gas flows inside the sealed container 15. Accordingly,

for example, when the hydrogen occluded in the heat generating structure **20** is discharged, the hydrogen-based gas inside the sealed container **15** smoothly flows from the supply port **15b** to the exhaust port **15a** without being blocked by the heat generating element **55**.

[0131] In the first embodiment, the heat generating element **55** is formed in a plate shape, whereas the shape of the heat generating element **55** may be appropriately changed.

[0132] As shown in FIG. **12**, a heat generating element **85** is formed in a cylindrical shape. The heat generating structure **20** shown in FIG. **12** includes the heat generating element **85** instead of the heat generating element **55**. In FIG. **12**, the heat generating element **85** has a cylindrical shape, whereas the heat generating element **85** may have a square tubular shape. By forming the heat generating element **85** in a cylindrical shape, the hydrogen-based gas flows through the gap formed between the inner surface of the heater **21** and an outer surface of the heat generating element **85** and through the inside of the heat generating element **85**. An axial direction of the heat generating element **85** is preferably parallel to the direction in which the hydrogen-based gas flows inside the sealed container **15**. Accordingly, for example, when the hydrogen occluded in the heat generating structure **20** is discharged, the hydrogen-based gas inside the sealed container **15** smoothly flows from the supply port **15b** to the exhaust port **15a** without being blocked by the heat generating element **85**.

[0133] As shown in FIG. **13**, a heat generating element **86** is formed in a spiral shape by being wound in a sparsely wound manner. The heat generating structure **20** shown in FIG. **13** includes the heat generating element **86** instead of the heat generating element **55**. By sparsely winding the heat generating element **86**, the hydrogen-based gas flows through the gap formed inside the heat generating element **86**. The number of turns of the heat generating element **86** may be appropriately changed. For example, by increasing the number of turns of the heat generating element **86**, a contact area between the heat generating element **86** and the hydrogen-based gas increases, so that the output of excess heat can be increased. Therefore, in the heat generating element **86** formed in a spiral shape, the output of excess heat can be adjusted in accordance with the number of turns.

[0134] The heat generating element is not limited to a plate shape, tubular shape, or spiral shape, and may be, for example, a powder made of a hydrogen storage metal or a hydrogen storage alloy.

[0135] In the first embodiment, one heater **21** is used to heat the three heat generating structures **20**, whereas a plurality of heaters **21** may be used. For example, the three heat generating structures **20** are heated by using three heaters **21**. In this case, the control unit **19** may control the output of the excess heat for each of the heat generating structures **20** by adjusting the input electric power of each of the heaters **21** based on the temperature detected by the temperature sensor **22** provided in each of the heat generating structures **20**. For example, the control unit **19** increases the output of the excess heat of the lower-stage heat generating structure **20** by increasing the input electric power of the heater **21** corresponding to the lower-stage heat generating structure **20**. The control unit **19** reduces the input electric power of the heater **21** corresponding to the upper-stage heat generating structure **20** to reduce the output of the excess heat of the upper-stage heat generating structure **20**. Accordingly, the output of the excess heat of the plurality of heat generating structures **20** as a whole is controlled.

[0136] In the first embodiment, the heat utilization device **12** includes the accommodation container **31**, the heat medium circulation unit **32**, the gas turbine **33**, the steam generator **34**, the steam turbine **35**, the Stirling engine **36**, and the thermoelectric converter **37**, whereas the configuration of the heat utilization device **12** is not limited thereto. For example, when a hydrogen-based gas is used as the heat medium, the accommodation container **31** can be omitted in the heat utilization device **12** by connecting the heat medium circulation unit **32** to the sealed container **15** of the heat generating device **11**.

[0137] As shown in FIG. **14**, the heat utilization device **12** includes the accommodation container **31**, the heat medium circulation unit **32**, and the steam turbine **35**, and may use water as the heat medium. In FIG. **14**, the gas exhaust unit **16**, the gas supply unit **17**, the control unit **19**, and the

like of the heat generating device **11** are not shown. Water is supplied into the accommodation container **31**. A space is formed above a water surface in the accommodation container **31**. In the accommodation container **31**, heat exchange is performed between water and the heat generating structure **20**, and water is boiled to generate steam. The heat medium circulation unit **32** includes a steam pipe **32g** and a water supply pipe **32h** instead of the first pipe **32a**, the second pipe **32b**, the third pipe **32c**, the fourth pipe **32d**, the pump **32e**, and the heat medium flow rate control unit **32f**. The steam pipe **32g** supplies the steam generated in the accommodation container **31** to the steam turbine **35**. The water supply pipe **32h** includes a condenser (not shown) and a water supply pump (not shown). The steam discharged from the steam turbine **35** is cooled by the condenser and returned to water, and the water is supplied to the accommodation container **31** via the water supply pump.

[0138] The heat utilization device **12** may only include the accommodation container **31** and the heat medium circulation unit **32**. The heat medium flowing through the heat medium circulation unit **32** is used for various purposes such as household heating, a household water heater, an automobile heater, an agricultural heating machine, a road heater, a seawater desalination heat source, and a geothermal power generation auxiliary heat source.

[0139] In the first embodiment, the gas turbine **33** is connected to the power generator **38** and is used as power for power generation, whereas the gas turbine **33** may be used as a motor without being connected to the power generator **38**. Similarly, the steam turbine **35** may be used as a motor without being connected to the power generator **39**. The Stirling engine **36** may be used as a motor without being connected to the power generator **40**.

2. Second Embodiment

[0140] Heat generated by a heat generating element can be used for preheating combustion air in a combustion device that combusts fuel and the combustion air to generate heat. Examples of the combustion device include a boiler, a rotary kiln, a metal heat treatment furnace, a heating furnace for metal processing, a hot air furnace, a firing furnace for ceramic, a petroleum refining tower, a dry distillation furnace, and a drying furnace. Hereinafter, a case where the combustion air to be supplied to the boiler as the combustion device is preheated using the heat generated by the heat generating element will be described.

[0141] FIG. **15** is a schematic diagram showing a configuration of a thermal power generation plant **91** including a heat utilization system **90**. Hereinafter, the thermal power generation plant **91** will be described.

[0142] The thermal power generation plant **91** includes a boiler **92**, the steam turbine **35**, and the power generator **39**. In the thermal power generation plant **91**, steam generated in the boiler **92** is supplied to the steam turbine **35** through a steam pipe **34g**, and the steam rotates the steam turbine **35** to drive the power generator **39** connected to the rotation shaft of the steam turbine **35** to generate power. The steam rotating the steam turbine **35** is sent to a water supply pipe **34h**, cooled by a condenser (not shown), and returned to water. The water generated by the condenser is sent to the boiler **92** by a water supply pump (not shown).

[0143] In the boiler **92**, the fuel and the combustion air are burnt to generate the heat, and the steam is generated from the water by the heat. The boiler **92** includes a furnace **93**, a burner **94**, a fuel supply line **95**, and an air supply line **96**.

[0144] The furnace **93** is a tubular hollow body that causes the fuel and the combustion air to react with each other and to combust. The furnace **93** may have various shapes such as a cylindrical shape and a square tubular shape. Water is supplied to the furnace **93** from a water supply pump (not shown) provided in the water supply pipe **34h**.

[0145] The burner **94** is constituted to supply the fuel and the combustion air into the furnace **93** from the outside of the furnace **93**. The burner **94** is provided in a lower portion of the furnace **93**. The burner **94** burns the fuel to generate a high-temperature combustion gas. Water in the boiler **92** is evaporated by the heat of the combustion gas, and high-temperature and high-pressure steam is

generated. The combustion gas passes through a flue **97** provided above the furnace **93**, and is discharged as an exhaust gas from a chimney **98** to the atmosphere.

[0146] The fuel supply line **95** supplies the fuel to the burner **94**. As the fuel, fossil fuel such as coal, natural gas, petroleum, liquefied natural gas (LNG), and liquefied petroleum gas (LPG) is used. Coal is pulverized coal pulverized in advance. The natural gas is a shear gas or the like, and includes fuel derived from a natural gas such as methane hydrate. Examples of the petroleum include heavy oil and light oil. Biomass (woody chip or the like) may be used as the fuel. When the pulverized coal is used as the fuel, the fuel supply line **95** supplies a mixed gas obtained by mixing the pulverized coal with a carrier gas such as air to the burner **94**. When the coal, the woody chip, or the like is used as the fuel, a fluidized bed boiler or a fixed bed boiler (a stoker furnace or the like) may be used. In this case, the fuel may be supplied into the furnace and only the preheated air may be blown from the burner or the like.

[0147] The air supply line **96** supplies the combustion air to the burner **94**. The air supply line **96** takes in outside air from the outside of the boiler **92** by a forced draft fan (not shown) or the like.

[0148] The air supply line **96** includes a heat exchanger **99**. The heat exchanger **99** is provided in the flue **97**. The heat exchanger **99** performs heat exchange between the outside air taken into the air supply line **96** from the outside of the boiler **92** and the exhaust gas circulating through the flue **97**. The outside air taken into the air supply line **96** is preheated by the heat exchanger **99** to generate preheated air. The preheated air generated in the heat exchanger **99** is supplied to a heat utilization device **102** to be described later.

[0149] Next, the heat utilization system **90** will be described. The heat utilization system **90** includes a heat generating device **101**, the boiler **92**, and the heat utilization device **102**. The heat utilization system **90** heats the preheated air supplied to the heat utilization device **102** by using the heat generated by a heat generating element **105** (see FIG. **16**) of the heat generating device **101**.

[0150] As shown in FIG. **16**, the heat generating device **101** includes a plurality of heat generating element units **103**. FIG. **16** is a perspective view schematically showing configurations of the heat generating device **101** and the heat utilizing device **102**. In FIG. **16**, a part of one heat generating element unit **103** is cut out and the inside thereof is shown. The heat generating element units **103** are arranged with a gap therebetween. Each of the heat generating element units **103** is detachably supported by a support body (not shown). The number of the heat generating element units **103** is not particularly limited, and can be appropriately changed so as to obtain a desired output. In FIG. **16**, nine heat generating element units **103** are used.

[0151] The heat generating element unit **103** includes a sealed container **104** to which a hydrogen-based gas is supplied, and a heat generating structure **106** that is accommodated in the sealed container **104** and includes a heat generating element **105** that generates heat by occluding and discharging hydrogen contained in the hydrogen-based gas.

[0152] The sealed container **104** is a tubular hollow body. The sealed container **104** may have various shapes such as a cylindrical shape and a square tubular shape. The sealed container **104** has a cylindrical shape in this example. A plurality of heat generating structures **106** are arranged in the sealed container **104**.

[0153] The heat generating element **105** may have the same configuration as, for example, the heat generating element **55** (see FIG. **4**), the heat generating element **85** (see FIG. **12**), and the heat generating element **86** (see FIG. **13**). In this example, the shape of the heat generating element **105** is a plate shape similar to the heat generating element **55**. A plurality of heat generating elements **105** are radially arranged to constitute the heat generating structure **106**.

[0154] The heat generating element **105** occludes hydrogen contained in the hydrogen-based gas in the sealed container **104**. The heat generating element **105** generates heat by the movement of the occluded hydrogen due to a temperature difference between the temperature of the heat generating element **105** and the temperature of the preheated air supplied to the heat utilization device **102**.

For example, when the temperature of the heat generating element **105** is normal temperature (for

example, 25° C.) and the temperature of the preheated air supplied to the heat utilization device **102** is, for example, 250° C., at the start of the operation of the heat utilization device **102**, the temperature difference occurs between the heat generating element **105** and the preheated air, and thus the heat generating element **105** starts to generate heat. Thereafter, the temperature of the heat generating element **105** is increased to, for example, 500° C. to 800° C., and the temperature difference between the heated heat generating element **105** and the preheated air is generated, so that the heat generation of the heat generating element **105** is continued. In this way, the heat generating device **101** generates heat by the temperature difference between the heat generating element **105** and the preheated air without repeatedly supplying and exhausting the hydrogen-based gas.

[0155] The heat utilization device **102** includes a case **108** that accommodates the heat generating device **101**, an air inlet **109** that is connected to the heat exchanger **99**, and an air outlet **110** that is connected to the burner **94**. The preheated air generated in the heat exchanger **99** is supplied through the air inlet **109** into the case **108**, and is heated by the heat of the heat generating element **105** when passing through the gap formed between the heat generating element units **103**. The preheated air heated by the heat generating element **105** is discharged as combustion air through the air outlet **110**. In this way, the heat utilization device **102** functions as an air preheater that preheats the combustion air by using the heat of the heat generating element **105**.

[0156] As described above, the heat utilization system **90** is applied to the thermal power generation plant **91**, and preheats the combustion air by using the heat of the heat generating element **105**. Therefore, combustion efficiency in the boiler **92** can be improved and the amount of the fuel to be used can be reduced.

[0157] In the heat utilization system **90**, since each of the heat generating element units **103** is detachable, each of the heat generating element units **103** can be individually replaced. Therefore, the heat generation of the heat generating device **101** can be stabilized by removing the heat generating element unit **103** that no longer generates heat and replacing the heat generating element unit **103** with a new heat generating element unit **103**. Further, all of the heat generating element units **103** can be replaced at the same time.

[0158] The heat generating device **101** may be constituted such that the supply and the exhaust of the hydrogen-based gas are repeatedly performed. As shown in FIG. **17**, the heat generating device **101** further includes, in addition to the plurality of heat generating element units **103**, a hydrogen-based gas supply and exhaust header **120** connected to each sealed container **104**, and a hydrogen pipe **121** connected to the hydrogen-based gas supply and exhaust header **120**. The hydrogen pipe **121** is connected to a gas supply unit and a gas exhaust unit (both not shown). The gas supply unit supplies the hydrogen-based gas into the sealed container **104** via the hydrogen-based gas supply and exhaust header **120** and the hydrogen pipe **121**. The gas exhaust unit vacuum-evacuates the inside of the sealed container **104** via the hydrogen-based gas supply and exhaust header **120** and the hydrogen pipe **121**. By repeatedly supplying and exhausting the hydrogen-based gas, it is possible to reliably cause the heat generating element **105** to generate heat.

[0159] The structure of the heat generating element unit **103** shown in FIG. **16** is an example. That is, the heat generating element unit **103** is not limited to the case where the heat generating element unit **103** includes the heat generating structure **106** in which the plurality of heat generating elements **105** are radially arranged. The arrangement of the plurality of heat generating elements **105** is not limited to a radial arrangement, and can be appropriately changed.

[0160] The heat utilization system **90** may be constituted to circulate the combustion air discharged from the heat utilization device **102**. As shown in FIG. **18**, the heat utilization system **90** further includes a combustion air circulation line **125** in which the combustion air circulates, a flow rate variable circulation fan **126** that is provided in the combustion air circulation line **125**, and a circulation flow rate control unit **127** that drives the flow rate variable circulation fan **126** and controls a circulation flow rate of the combustion air.

[0161] The air supply line **96** is provided with a temperature sensor **128** that measures the temperature of the combustion air supplied to the heat utilization device **102**, and a temperature sensor **129** that measures the temperature of the combustion air discharged from the heat utilization device **102**. The heat utilization device **102** is provided with a temperature sensor **130** that measures the temperature of the heat generating element **105** of the heat generating element unit **103** or the temperature of a specific portion enabling estimation of the temperature of the heat generating element **105**. The circulation flow rate control unit **127** is electrically connected to the temperature sensors **128** to **130**, and controls the circulation flow rate of the combustion air by driving the flow rate variable circulation fan **126** based on the temperatures detected by the temperature sensors **128** to **130**.

[0162] For example, the circulation flow rate control unit **127** decreases the temperature of the heat generating element **105** by increasing the circulation flow rate of the combustion air when the temperature of the heat generating element **105** exceeds a predetermined temperature. The circulation flow rate control unit **127** increases the temperature of the heat generating element **105** by decreasing the circulation flow rate of the combustion air when the temperature of the heat generating element **105** is equal to or lower than the predetermined temperature.

[0163] A flow rate sensor (not shown) that measures the flow rate of the combustion air may be provided in the air supply line **96** or the combustion air circulation line **125**, and the circulation flow rate of the combustion air may be controlled based on the temperature and the flow rate of the combustion air.

[0164] The air supply line **96** may be provided with a heater (not shown) for heating the combustion air. The heater can increase the temperature of the heat generating element **105**. When the temperature of the heat generating element **105** increases to the predetermined temperature, the heat generating element **105** starts to generate heat. The heater is operated, for example, when the operation of the heat utilization system **90** is started or when the temperature of the heat generating element **105** decreases.

[0165] The heat utilization device **102** is not limited to the case where the preheated air generated in the heat exchanger **99** is heated by using the heat of the heat generating element **105**. For example, the heat utilization device **102** may heat the outside air taken into the air supply line **96** from the outside of the boiler **92**. In this case, the outside air heated by the heat of the heat generating element **105** may be used as the combustion air without providing the heat exchanger **99**.

[0166] The combustion air may be mixed with the exhaust gas. For example, the flue **97** is branched and connected to the air supply line **96**, and the exhaust gas is recirculated, so that the exhaust gas can be mixed with the combustion air. The heat utilization device **102** may preheat the combustion air mixed with the exhaust gas.

[0167] The heat utilization device **102** may preheat water generated by a condenser (not shown) by rotating the steam turbine **35** in addition to or instead of preheating the combustion air used in the boiler **92** as a combustion device. By returning the preheated water to the boiler **92**, the combustion efficiency in the boiler **92** is increased, and the amount of fuel to be used can be reduced.

3. Third Embodiment

[0168] Exhaust gas discharged from a combustion device such as the boiler **92** according to the second embodiment usually contains carbon dioxide (CO.sub.2). As a technique for collecting CO.sub.2 from the exhaust gas, carbon dioxide capture and storage (CCS) is known. The CCS is a technique of separating and collecting CO.sub.2 from the exhaust gas and storing the collected CO.sub.2 in the ground or the like to reduce the amount of CO.sub.2 discharging to an atmosphere. Examples of a method for collecting CO.sub.2 include a chemical absorption method and a physical adsorption method. In the chemical absorption method, CO.sub.2 contained in the exhaust gas is absorbed by an absorption liquid such as an amine compound aqueous solution, and CO.sub.2 is discharged from the absorption liquid by heating the absorption liquid that has

adsorbed CO.sub.2. In the physical adsorption method, CO.sub.2 contained in the exhaust gas is adsorbed to an adsorbent such as activated carbon or zeolite, and CO.sub.2 is desorbed from the adsorbent by heating the adsorbent to which CO.sub.2 is adsorbed.

[0169] In the third embodiment, a heat medium heated by heat generated by a heat generating element is used as a heat source for heating the absorption liquid that has absorbed CO.sub.2 in the chemical absorption method. Hereinafter, a case where the chemical absorption method is performed will be described. However, the heat medium heated by the heat generated by the heat generating element can also be used as a heat source for heating the adsorbent to which CO.sub.2 is adsorbed in the physical adsorption method.

[0170] As shown in FIG. 19, a heat utilization system 140 includes the heat generating device 101 (see FIG. 16), a boiler 142, and a carbon dioxide separation and collection device 143. Since the heat generating device 101 has the same configuration as that of the second embodiment, the description thereof will be omitted.

[0171] The boiler 142 is an example of a combustion device that generates heat by combusting fuel and combustion air. The exhaust gas discharged from the boiler 142 contains carbon dioxide (CO.sub.2). The boiler 142 may have, for example, the same configuration as that of the boiler 92 according to the second embodiment.

[0172] The carbon dioxide separation and collection device 143 separates and collects CO.sub.2 contained in the exhaust gas discharged from the boiler 142 as a combustion device by using, as a heat source, the heat medium heated by the heat of the heat generating element 105 (see FIG. 16) of the heat generating device 101. In this example, a case where the chemical absorption method is performed as a method of collecting CO.sub.2 will be described.

[0173] As shown in FIG. 20, the carbon dioxide separation and collection device 143 includes an absorption tower 145, a regeneration tower 146, and a reboiler 147. The absorption tower 145 includes an absorption unit 148 that causes the absorption liquid to absorb CO.sub.2 contained in the exhaust gas discharged from the boiler 142. The absorption tower 145 supplies the absorption liquid having CO.sub.2 absorbed in the absorption unit 148 to the regeneration tower 146. The absorption liquid that has absorbed CO.sub.2 is referred to as a rich liquid. In FIG. 20, the rich liquid is denoted by reference numeral 149. The regeneration tower 146 includes a regeneration unit 150 that discharges CO.sub.2 from the absorption liquid supplied from the absorption tower 145 to regenerate the absorption liquid. The regeneration tower 146 supplies the absorption liquid from which CO.sub.2 is discharged in the regeneration unit 150 to the absorption tower 145. The absorption liquid from which CO.sub.2 is discharged is referred to as a lean liquid. In FIG. 20, the lean liquid is denoted by reference numeral 151.

[0174] In the carbon dioxide separation and collection device 143, the rich liquid 149 is sent from the absorption tower 145 to the regeneration tower 146, and the lean liquid 151 is returned from the regeneration tower 146 to the absorption tower 145. In this way, the carbon dioxide separation and collection device 143 is constituted to circulate the absorption liquid. Although not shown, a rich liquid delivery pump for delivering the rich liquid 149 from the absorption tower 145 to the regeneration tower 146, a lean liquid delivery pump for delivering the lean liquid 151 from the regeneration tower 146 to the absorption tower 145, and the like are provided between the absorption tower 145 and the regeneration tower 146.

[0175] The absorption tower 145 further includes a lean liquid supply nozzle 152 constituted to discharge the lean liquid 151 supplied from the regeneration tower 146. The lean liquid supply nozzle 152 is provided above the absorption unit 148, and drops the lean liquid 151 toward the absorption unit 148.

[0176] The exhaust gas containing CO.sub.2 is supplied from the boiler 142 to a lower portion of the absorption unit 148 of the absorption tower 145. The exhaust gas supplied to the absorption tower 145 rises toward the absorption unit 148.

[0177] In the absorption unit 148, the exhaust gas containing CO.sub.2 comes into contact with the

lean liquid **151**. The absorption unit **148** causes CO.sub.2 contained in the exhaust gas to be absorbed by the lean liquid **151**, thereby causing the lean liquid **151** to become the rich liquid **149**. The rich liquid **149** is discharged from the bottom of the absorption tower **145** and supplied to the regeneration tower **146**. CO.sub.2 is removed from the exhaust gas in contact with the lean liquid **151**. The exhaust gas after the removal of CO.sub.2 is discharged from the top portion of the absorption tower **145** to the atmosphere.

[0178] The regeneration tower **146** further includes a rich liquid supply nozzle **153** constituted to discharge the rich liquid **149** supplied from the absorption tower **145**. The rich liquid supply nozzle **153** is provided above the regeneration unit **150**, and drops the rich liquid **149** toward the regeneration unit **150**.

[0179] The reboiler **147** is coupled to the regeneration tower **146**. The reboiler **147** heats the lean liquid **151** in the regeneration tower **146** and generates absorption liquid steam **154** by evaporating the lean liquid **151**.

[0180] The reboiler **147** includes an accommodation container **147a** that accommodates the heat generating device **101**, and a heat medium circulation unit **147b** that circulates the heat medium between the inside and the outside of the accommodation container **147a**. The heat medium is heated by passing through a gap formed by an inner surface of the accommodation container **147a** and an outer surface of the sealed container **104** (see FIG. **16**) of the heat generating device **101**. The reboiler **147** heats the lean liquid **151** by using, as a heat source, the heat medium heated by the heat of the heat generating element **105** (see FIG. **16**) of the heat generating device **101**.

[0181] Although not shown, the heat medium circulation unit **147b** is provided with a flow rate variable fan and a flow rate control unit. The reboiler **147** adjusts the temperature of the heat medium to a predetermined temperature by driving the flow rate variable fan and controlling the flow rate of the heat medium by the flow rate control unit. In this example, the temperature of the heat medium is adjusted such that the lean liquid **151** evaporates to become the absorption liquid steam **154**.

[0182] The absorption liquid steam **154** generated in the reboiler **147** is supplied to a lower portion of the regeneration unit **150** of the regeneration tower **146**. The absorption liquid steam **154** supplied to the regeneration tower **146** rises toward the regeneration unit **150**.

[0183] In the regeneration unit **150**, the absorption liquid steam **154** and the rich liquid **149** come into contact with each other. The regeneration unit **150** heats the rich liquid **149** by the absorption liquid steam **154** and discharges CO.sub.2 from the rich liquid **149**, so that the rich liquid **149** becomes the lean liquid **151**. That is, the rich liquid **149** is regenerated into the lean liquid **151**. The lean liquid **151** is discharged from the bottom of the regeneration tower **146**, a part of which is supplied to the absorption tower **145**, and a remaining part of which is supplied to the reboiler **147**. The absorption liquid steam **154** in contact with the rich liquid **149** is discharged from the top portion of the regeneration tower **146** together with CO.sub.2 discharged from the rich liquid **149**.

[0184] A heat exchanger **155** is provided between the absorption tower **145** and the regeneration tower **146**. The heat exchanger **155** performs heat exchange between the rich liquid **149** supplied from the absorption tower **145** to the regeneration tower **146** and the lean liquid **151** supplied from the regeneration tower **146** to the absorption tower **145**. Accordingly, the rich liquid **149** is heated, and the lean liquid **151** is cooled.

[0185] The carbon dioxide separation and collection device **143** further includes, for example, a separation drum (not shown), and introduces the absorption liquid steam **154** and CO.sub.2 discharged from the top portion of the regeneration unit **150** into the separation drum. The absorption liquid steam **154** and CO.sub.2 introduced into the separation drum are separated into water and CO.sub.2 by cooling the absorption liquid steam **154** to become water. In this way, the carbon dioxide separation and collection device **143** can separate and collect CO.sub.2 from the exhaust gas of the boiler **142**. The carbon dioxide separation and collection device **143** is a heat utilization device that uses, as a heat source, the heat medium heated by the heat of the heat

generating element **105** (see FIG. **16**) of the heat generating device **101** for the separation and collection of CO.sub.2 described above.

[0186] As described above, since the heat utilization system **140** uses the heat generating element **105** as the heat source for separating and collecting CO.sub.2 contained in the exhaust gas discharged from the boiler **142** as a combustion device, the amount of CO.sub.2 discharging into the atmosphere can be reduced.

4. Fourth Embodiment

[0187] Carbon dioxide (CO.sub.2) separated and collected by the carbon dioxide separation and collection device **143** or the like according to the third embodiment can be converted into methane (CH.sub.4) by reacting with hydrogen (H.sub.2). CH.sub.4 is generated from a raw material gas containing CO.sub.2 and H.sub.2 by bringing the raw material gas into contact with a catalyst using a catalyst that causes a reaction (methanation reaction) between CO.sub.2 and H.sub.2 to proceed. However, when a temperature of the raw material gas is low, the reaction does not sufficiently proceed. In the fourth embodiment, the raw material gas containing CO.sub.2 and H.sub.2 is heated by using, as a heat source, the heat medium heated by the heat generated by the heat generating element.

[0188] As shown in FIG. **21**, a heat utilization system **160** includes the heat generating device **101** (see FIG. **16**) and a methane production device **162**. Since the heat generating device **101** has the same configuration as that of the second embodiment, the description thereof will be omitted.

[0189] The methane production device **162** includes a reactor **163**, a raw material gas supply line **164**, and a raw material gas heater **165**.

[0190] The reactor **163** has a catalyst **167** that causes the reaction between CO.sub.2 and H.sub.2 to proceed, which is represented by the following formula (1).



[0191] The catalyst **167** is not particularly limited as long as it is a catalyst that can cause the reaction between CO.sub.2 and H.sub.2 to proceed and generate CH.sub.4. For example, a nickel (Ni)-based catalyst, a ruthenium (Ru)-based catalyst, and a platinum (Pt)-based catalyst can be used as the catalyst **167**.

[0192] The raw material gas supply line **164** supplies the raw material gas containing CO.sub.2 and H.sub.2 to the reactor **163**. In FIG. **21**, the raw material gas supply line **164** forms a line through which the raw material gas containing CO.sub.2 and H.sub.2 flows by merging a line through which CO.sub.2 circulates with a line through which H.sub.2 circulates, and the raw material gas line is connected to the reactor **163**.

[0193] The raw material gas supply line **164** includes an electrolysis device **168** that electrolyzes water (H.sub.2O) to generate hydrogen (H.sub.2) and oxygen (O.sub.2). The electrolysis device **168** performs electrolysis of H.sub.2O using, for example, electricity obtained by driving the power generator **39** (see FIG. **15**). O.sub.2 generated by the electrolysis device **168** is mixed with CO.sub.2 through the raw material gas supply line **164**. O.sub.2 generated by the electrolysis device **168** is supplied to, for example, the air supply line **96** (see FIG. **15**) according to the third embodiment, and mixed with the combustion air. The raw material gas supply line **164** may be connected to an H.sub.2 tank in which H.sub.2 is stored such that H.sub.2 is supplied from the H.sub.2 tank.

[0194] The raw material gas supply line **164** is connected to the carbon dioxide separation and collection device **143** (see FIGS. **19** and **20**) according to the third embodiment. Therefore, CO.sub.2 collected by the carbon dioxide separation and collection device **143** is mixed with H.sub.2 through the raw material gas supply line **164**. The raw material gas supply line **164** may be connected to a CO.sub.2 tank in which CO.sub.2 is stored such that CO.sub.2 is supplied from the CO.sub.2 tank.

[0195] The raw material gas heater **165** is provided in the raw material gas supply line **164** and

heats the raw material gas circulating through the raw material gas supply line **164**. The raw material gas heater **165** includes an accommodation container **165a** that accommodates the heat generating device **101**, and a heat medium circulation unit **165b** that circulates the heat medium between the inside and the outside of the accommodation container **165a**. The heat medium is heated by passing through a gap formed by an inner surface of the accommodation container **165a** and an outer surface of the sealed container **104** (see FIG. **16**) of the heat generating device **101**. The raw material gas is heated by heat exchange between the raw material gas and the heat medium. The raw material gas is heated to, for example, about 400° C.

[0196] The methane production device **162** has a catalyst **167** for producing CH.sub.4 from the raw material gas containing CO.sub.2 and H.sub.2, and heats the raw material gas by using, as a heat source, a heat medium heated by heat of the heat generating element **105** (see FIG. **16**), thereby causing CO.sub.2 and H.sub.2 to react. When the heated raw material gas comes into contact with the catalyst **167**, the reaction between CO.sub.2 and H.sub.2 proceeds, and CH.sub.4 is generated. CH.sub.4 generated by the methane production device **162** is supplied as a synthesized natural gas (SNG) to, for example, existing infrastructure equipment. In the methane production device **162**, H.sub.2O is also generated in the process of generating CH.sub.4 from the raw material gas in the reactor **163**. H.sub.2O generated in the reactor **163** is supplied to, for example, the electrolysis device **168**.

[0197] As described above, since the heat utilization system **160** includes the heat generating device **101** (see FIG. **16**) and the methane production device **162**, the heat generating element **105** is used as a heat source for generating CH.sub.4 from the raw material gas containing CO.sub.2 and H.sub.2, and thus the amount of CO.sub.2 discharging into the atmosphere can be reduced as compared with a case where a combustion device is used as a heat source.

[0198] Further, in the heat utilization system **160**, CO.sub.2 contained in the exhaust gas discharged from the combustion device is supplied to the methane production device **162**, and thus CO.sub.2 is converted to CH.sub.4, so that the discharging amount of CO.sub.2 is further reduced.

[0199] In the fourth embodiment, the heat generating element **105** is used as the heat source for generating CH.sub.4 from the raw material gas containing CO.sub.2 and H.sub.2. However, in an IS cycle in which hydrogen is produced from water using thermal energy or an ISN cycle in which ammonia (NH.sub.3) is produced from water and nitrogen (N.sub.2) using thermal energy, a heat medium heated to, for example, about 800° C. by the heat of the heat generating element **105** can be used as a heat source. In the IS cycle, water, iodine (I), and sulfur (S) are reacted to produce hydrogen iodide (HI), and the hydrogen iodide is thermally decomposed to produce hydrogen. As a heat source for thermally decomposing hydrogen iodide, a heat medium heated by the heat of the heat generating element **105** can be used as a heat source. In the ISN cycle, nitrogen is reacted with hydrogen iodide produced in the IS cycle to produce ammonium iodide (NH.sub.4I), and the ammonium iodide is thermally decomposed to produce ammonia. As a heat source for thermally decomposing the ammonium iodide, a heat medium heated by the heat of the heat generating element **105** can be used as a heat source.

5. Modification

[0200] The invention is not limited to the above-described embodiments, and can be appropriately modified within the scope of the gist of the invention.

[0201] A fin for improving heat exchange efficiency may be provided in a sealed container accommodating a heat generating structure. A sealed container including a fin will be described with reference to FIGS. **22** to **24**.

[0202] As shown in FIG. **22**, a sealed container **170** includes a container body **171** having a space therein, and a fin **172** provided on an outer surface of the container body **171**. The sealed container **170** accommodates a heat generating structure **173** having a plurality of heat generating elements **55** (see FIG. **23**). A configuration of the sealed container **170** described below is an example of a configuration required when an internal temperature of the sealed container **170** is maintained at

600° C. to 800° C., the heat generating structure **173** includes 48 heat generating elements **55**, and output of each heat generating element **55** is 20 W.

[0203] The container body **171** is formed in a tubular shape. Although the container body **171** has a cylindrical outer shape in FIG. **22**, the container body **171** may have various shapes such as an elliptic cylindrical shape and a square tubular shape. A length of the container body **171** is, for example, 250 mm. A diameter of the container body **171** is, for example, 80 mm. When the container body **171** has an elliptic cylindrical shape, the diameter of the container body **171** means a major axis thereof. When the container body **171** has a square tubular shape, the diameter of the container body **171** means a diameter of a circumscribed circle thereof.

[0204] The container body **171** is preferably made of a material having a melting point of 1000° C. or higher and a thermal conductivity of 50 W/m.K or more. As the material of the container body **171**, for example, copper, nickel, or tungsten is used. When the material of the container body **171** is copper, a thickness of the container body **171** is preferably 0.5 mm or more, and more preferably 1 mm or more. When the material of the container body **171** is nickel or tungsten, the thickness of the container body **171** is preferably 0.25 mm or more, and more preferably 0.5 mm or more. It is also possible to use gold and silver as the material of the container body **171**, whereas copper, nickel, and tungsten are preferred since copper, nickel, and tungsten are inexpensive. When a temperature inside the sealed container **170** is maintained at lower than 600° C., iron may be used as the material of container body **171**.

[0205] The fin **172** is spirally provided on an outer peripheral surface of the container body **171**. The number of turns of the fin **172** is, for example, 20. The fin **172** is formed in a belt shape. A width of the fin **172** is, for example, 20 mm. Therefore, the diameter of the sealed container **170** is 120 mm. An interval (pitch) between the fin **172** along a longitudinal direction of the container body **171** is preferably 100 mm or less, and more preferably 50 mm or less. A heat transfer area of the fin **172** is preferably 0.1 m²/kW or more. As the material of the fin **172**, for example, the same material as the material of the container body **171**, that is, copper, nickel, tungsten, or the like can be used. Aluminum may be used as the material of the fin **172**.

[0206] FIG. **23** is a cross-sectional view of the container body **171** taken in a radial direction. As shown in FIG. **23**, a plurality of heat generating elements **55** are arranged in contact with an inner surface of the container body **171**. The inner surface of the container body **171** is constituted by a plurality of flat surfaces. In FIG. **23**, the inner surface of the container body **171** is constituted by six flat surfaces. That is, a cross-sectional shape of a hollow portion of the container body **171** is hexagonal. The six heat generating elements **55** arranged on planes along the circumferential direction of the container body **171** face each other. A predetermined number of a plurality of heat generating elements **55** facing each other constitutes one set. In this example, six heat generating elements **55** constitute one set.

[0207] FIG. **24** is a cross-sectional view of the container body **171** taken in a direction orthogonal to the radial direction. As shown in FIG. **24**, the plurality of heat generating elements **55** are arranged along the longitudinal direction of the container body **171** on each plane constituting the inner surface of the container body **171**. In this example, eight heat generating elements **55** are arranged at equal intervals along the longitudinal direction of the container body **171** with respect to one plane. That is, eight sets of heat generating elements **55** are arranged along the longitudinal direction of the container body **171**.

[0208] The sealed container **170** and the heat generating structure **173** constitute a heat generating element unit **174**. The heat generating element unit **174** has a cylindrical shape as a whole. The heat generating element unit **174** is accommodated in an accommodation container **176** having a space therein. The accommodation container **176** has an inflow port **176a** through which the heat medium flows in, and an outflow port **176b** through which the heat medium flows out. In FIG. **24**, in the accommodation container **176**, the inflow port **176a** is provided at one end in the longitudinal direction of the container body **171** of the heat generating element unit **174**, and the outflow port

176b is provided at the other end in the longitudinal direction of the container body **171** of the heat generating element unit **174**. The heat medium flowing in through the inflow port **176a** moves spirally along the fin **172** of the sealed container **170** and flows out through the outflow port **176b**. The accommodation container **176** is covered with a heat insulating material **177**. As the heat medium, a gas having low reactivity and corrosiveness or a gas that does not aggregate or thermally decompose is used. The heat medium is preferably, for example, water vapor, air, a nitrogen gas, an argon gas, a helium gas, a xenon gas, a carbon dioxide gas, a chlorofluorocarbon gas, or a mixed gas thereof.

[0209] In FIG. **24**, the sealed container **170** is connected to a hydrogen-based gas supply and exhaust header **178**. The hydrogen-based gas supply and exhaust header **178** is connected to a hydrogen pipe **179**. Accordingly, the supply and the exhaust of the hydrogen-based gas are repeatedly performed. The heat generating element unit **174** may be replaceable by detachably attaching the sealed container **170** and the hydrogen-based gas supply and exhaust header **178**.

[0210] As described above, since the heat generating element unit **174** includes the fin **172**, it is possible to increase a contact area with the heat medium, and thus it is possible to improve the heat exchange efficiency between the heat generating structure **173** and the heat medium.

[0211] In the heat generating element unit **174**, since the fin **172** is provided in a spiral shape on the outer peripheral surface of the container body **171**, the heat medium can be moved in the spiral shape along the fin **172**, and thus a contact time with the heat medium is increased, and the heat of the heat generating structure **173** can be reliably transferred to the heat medium.

[0212] The inner surface of the container body **171** is constituted by six flat surfaces, whereas the number of flat surfaces constituting the inner surface can be appropriately changed. For example, the inner surface of the container body **171** may be formed of eight flat surfaces, and the cross-sectional shape of the hollow portion of the container body **171** may be octagonal.

[0213] The accommodation container **176** may be constituted to accommodate a plurality of heat generating element units **174**. For example, seven heat generating element units **174** can be accommodated inside the accommodation container **176**. For example, when a large number of heat generating element units **174**, which exceeds 20, are accommodated in the accommodation container **176**, it is preferable to change positions of the inflow port **176a** and the outflow port **176b** such that the heat medium flows in a direction orthogonal to the longitudinal direction of the container body **171** of the heat generating element unit **174**.

[0214] In the sealed container **170**, the plurality of heat generating elements **55** are brought into contact with the inner surface of the container body **171**, and the heat generated by the plurality of heat generating elements **55** is directly transferred to the container body **171**. However, a heat transfer support portion may be provided to support the plurality of heat generating elements **55** away from the inner surface of the container body **171** and to transfer the heat generated by the plurality of heat generating elements **55** to the container body **171**.

[0215] As shown in FIG. **25**, a sealed container **180** includes a container body **181**, a fin **182**, and a heat transfer support portion **183**. The sealed container **180** accommodates a heat generating structure **184** including a plurality of heat generating elements **55**. The container body **181** has the same configuration as the container body **171** except that the cross-sectional shape of the hollow portion is circular. That is, an inner surface of the container body **181** is made of a curved surface. The fin **182** has the same configuration as the fin **172**. Description of the container body **181** and the fin **182** will be omitted. The sealed container **180** and the heat generating structure **184** constitute a heat generating element unit **185**. The heat generating element unit **185** has a cylindrical shape as a whole. For example, instead of the heat generating element unit **174** (see FIG. **24**), the heat generating element unit **185** is accommodated in the accommodation container **176**. FIG. **25** is a cross-sectional view of the sealed container **180** taken in a direction orthogonal to the radial direction.

[0216] The heat transfer support portion **183** is provided inside the container body **181**, supports

the plurality of heat generating elements **55**, and transfers heat generated by the plurality of heat generating elements **55** to the container body **181**. The heat transfer support portion **183** includes a support pillar **183a** that supports the plurality of heat generating elements **55**, and a bridge **183b** that connects the support pillar **183a** and the container body **181**. In this example, the heat generating element **55** of 10 W is used.

[0217] The heat transfer support portion **183** includes at least one or more support pillars **183a** and at least one or more bridges **183b**. In this example, the heat transfer support portion **183** includes four support pillars **183a** and three bridges **183b**. The four support pillars **183a** are arranged at predetermined intervals from each other. Each support pillar **183a** extends along the longitudinal direction of the container body **181**, and both ends thereof are fixed to the container body **181** by a fixing member (not shown). The three bridges **183b** are arranged at predetermined intervals along the longitudinal direction of each support pillar **183a**. Each bridge **183b** is formed in, for example, a plate shape, and connects each support pillar **183a** and the container body **181** by a fixing member (not shown).

[0218] FIG. **26** is a cross-sectional view of the container body **181** taken in the radial direction. As shown in FIG. **26**, each support pillar **183a** is formed in a prism shape. In this example, the support pillar **183a** has a quadrangular prism shape having a rectangular cross section. The support pillars **183a** are arranged such that specific surfaces thereof face each other. That is, the four support pillars **183a** are arranged in a square tubular shape. The specific surface of each support pillar **183a** is referred to as a front surface. A surface opposite to the specific surface is referred to as a back surface. The back surface of each support pillar **183a** faces the inner surface of the container body **181**. Each support pillar **183a** supports the heat generating element **55** on at least one of the front surface and the back surface. In FIG. **26**, the heat generating element **55** is supported on both surfaces (the front surface and the back surface) of each support pillar **183a**. 12 heat generating elements **55** are supported by one support pillar **183a**. Each of the heat generating elements **55** is not in contact with the inner surface of the container body **181** and is separated from the inner surface of the container body **181**.

[0219] As the material of the heat transfer support portion **183**, that is, the material of the support pillar **183a** and the bridge **183b**, for example, the same material as that of the container body **181** can be used. A thickness of the support pillar **183a** and the bridge **183b** is preferably 1 mm or more when the support pillar **183a** and the bridge **183b** are made of copper, is preferably 4.4 mm or more when the support pillar **183a** and the bridge **183b** are made of nickel, and is preferably 2 mm or more when the support pillar **183a** and the bridge **183b** are made of tungsten. When the heat transfer support portion **183** is made of the above-described material and has various dimensions, heat generated by the heat generating element **55** can be transferred to the container body **181** and the fin **182** via the support pillar **183a** and the bridge **183b**. Even when the temperature of the heat generating element **55** instantaneously rises, the heat transfer support portion **183** is prevented from melting and being damaged. Instead of supporting the heat generating element **55** of 10 W on both surfaces of each support pillar **183a** as described above, for example, when the heat generating element **55** of 20 W is supported on both surfaces of each support pillar **183a** or when the heat generating element **55** of 40 W is supported on the front surface or the back surface of each support pillar **183a**, it is preferable to change various dimensions. For example, the thickness of the support pillar **183a** and the bridge **183b** is preferably 2 mm or more when the support pillar **183a** and the bridge **183b** are made of copper, is preferably 8.4 mm or more when the support pillar **183a** and the bridge **183b** are made of nickel, and is preferably 4 mm or more when the support pillar **183a** and the bridge **183b** are made of tungsten.

[0220] As described above, since the heat generating element unit **185** includes the heat transfer support portion **183**, the heat generated by the heat generating body **55** can be efficiently transferred to the container body **181** and the fin **182**, and thus the heat exchange efficiency between the heat generating structure **184** and the heat medium can be improved.

[0221] The heat transfer support portion **183** includes four support pillars **183a**, whereas the number of support pillars **183a** may be appropriately changed. For example, one support pillar **183a** may be arranged at a center of the container body **181**, or six support pillars **183a** may be arranged in a hexagonal tubular shape. The heat transfer support portion **183** includes three bridges **183b**, whereas the number of the bridges **183b** can be appropriately changed.

[0222] The heat transfer support portion **183** may be provided inside the container body **171** having a flat inner surface. Accordingly, the plurality of heat generating elements **55** are arranged on each plane constituting the inner surface of the container body **171**, and the plurality of heat generating elements **55** are supported by the heat transfer support portion **183**, so that the number of heat generating elements **55** can be increased.

[0223] The heat generating element units **174** and **185** are cylindrical, whereas the heat generating element units may have a flat plate shape.

[0224] As shown in FIG. **27**, a heat generating element unit **190** includes a sealed container **191** to which a hydrogen-based gas is supplied, and a heat generating structure **192** accommodated in the sealed container **191**. The heat generating element unit **190** has, for example, a flat plate shape having a vertical length of 800 mm, a horizontal length of 600 mm, and a thickness of 15 mm. FIG. **27** is a cross-sectional view of the flat-plate-shaped heat generating element unit **190** taken in a direction orthogonal to the thickness direction.

[0225] The sealed container **191** includes a container body **193** having a space therein. The container body **193** is formed in a flat plate shape. In this example, a cross-sectional shape of a hollow portion is quadrangular. The heat generating structure **192** includes a plurality of heat generating elements **55**, and is formed of 60 heat generating elements **55** in this example.

[0226] The container body **193** is connected to a hydrogen-based gas supply and exhaust header **194**. The hydrogen-based gas supply and exhaust header **194** is connected to a hydrogen pipe **195**. Accordingly, the supply and the exhaust of the hydrogen-based gas are repeatedly performed.

[0227] FIG. **28** is a cross-sectional view of the flat-plate-shaped heat generating element unit **190** taken in the thickness direction. As shown in FIG. **28**, the container body **193** has a first inner surface **193a** and a second inner surface **193b** facing the first inner surface **193a**. The plurality of heat generating elements **55** are arranged in contact with the first inner surface **193a** and the second inner surface **193b**. In this example, among 60 heat generating elements **55**, 30 heat generating elements **55** are arranged on the first inner surface **193a**, and 30 heat generating elements **55** are arranged on the second inner surface **193b**. The heat generating elements **55** arranged on the first inner surface **193a** and the heat generating elements **55** arranged on the second inner surface **193b** face each other.

[0228] As shown in FIG. **29**, the heat generating element unit **190** is accommodated in an accommodation container **196** having a space therein. An outer shape of the accommodation container **196** is, for example, similar to that of the container body **193**. Although a case where one heat generating element unit **190** is accommodated in one accommodation container **196** is described as an example, a plurality of heat generating element units **190** may be accommodated in one accommodation container **196**.

[0229] The accommodation container **196** is provided with a nozzle portion **196a** for injecting the heat medium and an outflow port **196b** through which the heat medium flows out. The nozzle portion **196a** sprays the heat medium onto the surface of the heat generating element unit **190** by spraying the heat medium from a tip end. The accommodation container **196** is provided with at least one nozzle portion **196a** and at least one outflow port **196b**. In FIG. **29**, the nozzle portion **196a** is provided in each of two wall portions facing the heat generating element unit **190**, and the outflow port **196b** is provided in each of two wall portions different from the wall portion in which each nozzle portion **196a** is provided.

[0230] The nozzle portion **196a** includes an injection portion **198** that injects the heat medium, and a piping portion **199** that is connected to the injection portion **198**. The injection portion **198** is

provided at the tip end of the nozzle portion **196a**. The piping portion **199** guides the heat medium to the injection portion **198**. The heat medium injected from the injection portion **198** and blown onto the heat generating element unit **190** flows out of the accommodation container **196** through the outflow port **196b**. In FIG. **29**, each of the nozzle portions **196a** has 11 injection portions **198**. [0231] As described above, the heat generating element unit **190** can be formed by forming the container body **193** of the sealed container **191** in a flat plate shape and arranging the plurality of heat generating elements **55** on the first inner surface **193a** and the second inner surface **193b** of the container body **193**. Therefore, the production is easy and the production cost can be reduced. [0232] The heat generating element unit **190** has a configuration in which the sealed container **191** includes the container body **193**, whereas a fin may be provided on the outer surface of the container body **193**.

[0233] As shown in FIG. **30**, a heat generating element unit **200** includes a sealed container **201** instead of the sealed container **191** of the heat generating element unit **190**. The sealed container **201** includes the container body **193** and a fin **202** provided on the outer surface of the container body **193**. The sealed container **201** includes at least one fin **202**. The fin **202** is formed by a plurality of ribs **203**. FIG. **30** is a plan view of the sealed container **201** formed by the plurality of ribs **203**. The heat generating structure **192** (see FIGS. **27** and **28**) is accommodated in the sealed container **201**. That is, the heat generating element unit **200** includes the sealed container **201** to which a hydrogen-based gas is supplied, and the heat generating structure **192** accommodated in the sealed container **201**.

[0234] FIG. **31** is a side view of the sealed container **201** including the fin **202** formed by the plurality of ribs **203**. As shown in FIG. **31**, the fin **202** is provided on two surfaces of the outer surface of the container body **193** facing each other. The plurality of ribs **203** protrude from the outer surface of the container body **193**. In this example, 16 ribs **203** are provided on each of two surfaces facing each other on the outer surface of the container body **193**.

[0235] The heat generating element unit **200** including the fin **202** is accommodated in, for example, the accommodation container **176** (see FIG. **24**), the accommodation container **196** (see FIG. **29**) provided with the nozzle portion **196a**, or the like. For example, when the heat generating element unit **200** including the fin **202** is accommodated in the accommodation container **196**, it is preferable to arrange the heat generating element unit **200** such that the longitudinal direction of the plurality of ribs **203** coincides with the circulation direction of the heat medium. Since the heat generating element unit **200** includes the fin **202**, it is possible to increase the contact area with the heat medium, and thus it is possible to improve the heat exchange efficiency between the heat generating structure **192** and the heat medium.

[0236] A plurality of accommodation containers **176** and a plurality of accommodation containers **196** may be prepared and connected in series. Since the number of the heat generating element units **190** and the number of the heat generating element units **200** are increased, the output can be improved.

[0237] The heat generating element unit **174** shown in FIG. **24**, the heat generating element unit **185** shown in FIG. **25**, the heat generating element unit **190** shown in FIG. **27**, and the heat generating element unit **200** shown in FIG. **30** can be used in the heat generating device **101** instead of the heat generating element unit **103** shown in FIG. **16**.

REFERENCE SIGN LIST

[0238] **10, 90, 140, 160** heat utilization system [0239] **11, 101** heat generating device [0240] **12, 102** heat utilization device [0241] **15, 104, 170, 180, 191, 201** sealed container [0242] **20, 106, 173, 184, 192** heat generating structure [0243] **21** heater [0244] **31, 147a, 165a, 176, 196** accommodation container [0245] **32, 147b, 165b** heat medium circulation unit [0246] **33** gas turbine [0247] **34** steam generator [0248] **35** steam turbine [0249] **36** Stirling engine [0250] **37** thermoelectric converter [0251] **38, 39, 40** power generator [0252] **55, 75, 80, 85, 86, 105** heat generating element [0253] **66** base [0254] **67** multilayer film [0255] **71** first layer [0256] **72** second

layer [0257] **77** third layer [0258] **82** fourth layer [0259] **125** combustion air circulation line [0260] **126** flow rate variable circulation fan [0261] **127** circulation flow rate control unit [0262] **142** boiler (combustion device) [0263] **143** carbon dioxide separation and collection device [0264] **162** methane production device [0265] **167** catalyst [0266] **171, 181, 193** container body [0267] **172, 182, 202** fin [0268] **183** heat transfer support portion [0269] **203** rib

Claims

1. A heat generating device comprising: a sealed container into which a hydrogen-based gas is supplied; and a heat generating structure that is accommodated in the sealed container and in which a plurality of heat generating elements that are configured to generate heat by occluding and discharging hydrogen contained in the hydrogen-based gas are radially arranged, wherein each of the plurality of heat generating elements 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, wherein the heat generating device includes a plurality of heat generating structures including the heat generating structure are arranged in a direction in which the hydrogen-based gas flows inside the sealed container.
3. The heat generating device according to claim 1, wherein the sealed container includes a container body that accommodates the heat generating structure, and a fin that is provided on an outer surface of the container body.
4. The heat generating device according to claim 3, wherein the container body is formed in a tubular shape, and the fin is provided in a spiral shape on an outer peripheral surface of the container body.
5. The heat generating device according to claim 3, wherein the sealed container further includes a heat transfer support portion that is provided inside the container body, supports the plurality of heat generating elements, and is configured to transfer the heat generated by the plurality of heat generating elements to the container body.
6. The heat generating device according to claim 3, wherein the container body is formed in a flat plate shape, and the fin is formed by a plurality of ribs protruding from the outer surface of the container body.
7. A heat utilization system comprising: the heat generating device according to claim 1; a combustion device that is configured to combust fuel and combustion air to generate heat; and a heat utilization device that is configured to preheat the combustion air by using the heat of the heat generating element.
8. The heat utilization system according to claim 7, further comprising: a combustion air circulation line in which the combustion air circulates; a flow rate variable circulation fan that is provided in the combustion air circulation line; and a circulation flow rate control unit that is configured to drive the flow rate variable circulation fan to control a circulation flow rate of the combustion air.
9. The heat utilization system according to claim 7, further comprising: a carbon dioxide separation and collection device that is configured to separate and collect carbon dioxide contained in an exhaust gas discharged from the combustion device using, as a heat source, a heat medium heated by the heat of the heat generating element.
10. The heat utilization system according to claim 7, further comprising: a methane production device that has a catalyst for producing methane from a raw material gas containing carbon oxide and hydrogen, and is configured to react the carbon dioxide with the hydrogen by heating the raw

material gas using, as the heat source, the heat medium heated by the heat of the heat generating element.
