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FUEL TREATMENT DEVICE

Abstract

The fuel processing device including a reforming unit and a combustion unit. The reforming unit includes a first tubular wall and a second tubular wall. The fuel processing device further includes: a merging portion; an exhaust gas flow path; an oxidizing agent flow path; an oxidizing agent branching portion; a combustion supporting gas flow path that connects between the oxidizing agent branching portion and the combustion unit and is configured to allow a part of the oxidizing agent to flow through the combustion supporting gas flow path as the combustion supporting gas; and an outer peripheral gas introducing flow path that connects between the oxidizing agent branching portion and an outer peripheral flow path and is configured to allow the other part of the oxidizing agent to flow through the outer peripheral gas introducing flow path as the outer peripheral gas.

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Background/Summary

TECHNICAL FIELD
[0001] This disclosure relates to a fuel processing device.
BACKGROUND ART
[0002] A fuel processing device is used in a fuel cell system, a hydrogen station, or the like. The fuel processing device generates s a reformed gas containing hydrogen by a reforming reaction of a hydrocarbon-based raw material such as a natural gas, alcohols, or ammonia. The reforming reaction is an endothermic reaction, and hence thermal energy is required for the reforming reaction. Thus, the fuel processing device includes a combustor configured to generate thermal energy.
[0003] In Patent Literature 1, a hydrogen generating device is described. This hydrogen generating device includes a reformer, a combustor, and an exhaust gas path. A reforming catalyst is filled inside the reformer. The reformer reforms a fuel to generate a reformed gas containing hydrogen. The combustor heats the reformer. The exhaust gas path covers a periphery of an outer wall of the reformer. A combustion exhaust gas from the combustor flows through the exhaust gas path.
CITATION LIST
Patent Literature
[0004] [PTL 1] JP 2017-105695 A
SUMMARY OF INVENTION
Technical Problem
[0005] In the above-mentioned hydrogen generating device, the reformer is mainly heated from an outer peripheral side by the combustion exhaust gas, and hence there is a limitation in the heat transfer area between the reformer and the combustion exhaust gas. Thus, in the above-mentioned hydrogen generating device, there is a problem in that thermal efficiency is degraded.
[0006] This disclosure has been made in order to solve the problems as described above, and has an object to provide a fuel processing device that can obtain a higher thermal efficiency.
Solution to Problem
[0007] According to this disclosure, there is provided a fuel processing device including: a reforming unit configured to generate a reformed gas from a raw material; and a combustion unit configured to combust a fuel and a combustion supporting gas in a combustion space to generate a combustion gas. The reforming unit includes: a first tubular wall; and a second tubular wall arranged on an outer peripheral side with respect to the first tubular wall. A reforming reaction flow path is formed between the first tubular wall and the second tubular wall, the reforming reaction flow path being configured to be filled with a reforming catalyst and to allow the raw material and the reformed gas to flow through the reforming reaction flow path. A combustion gas flow path configured to allow the combustion gas to flow through the combustion gas flow path is formed on an inner peripheral side with respect to the first tubular wall. The combustion gas flow path is adjacent to the reforming reaction flow path across the first tubular wall. A n outer peripheral flow path configured to allow an outer peripheral gas to flow through the outer peripheral flow path is formed on an outer peripheral side with respect to the second tubular wall. The outer peripheral flow path is adjacent to the reforming reaction flow path across the second tubular wall. The fuel processing device further includes: a merging portion configured to allow the combustion gas having flowed through the combustion gas flow path and the outer peripheral gas having flowed

through the outer peripheral flow path to merge with each other; an exhaust gas flow path configured to allow the combustion gas and the outer peripheral gas that have merged at the merging portion to flow through the exhaust gas flow path as an exhaust gas; an oxidizing agent flow path configured to allow an oxidizing agent supplied from a heating source to pass through the oxidizing agent flow path; an oxidizing agent branching portion provided in the oxidizing agent flow path; a combustion supporting gas flow path that connects between the oxidizing agent branching portion and the combustion unit and is configured to allow a part of the oxidizing agent to flow through the combustion supporting gas flow path as the combustion supporting gas; and an outer peripheral gas introducing flow path that connects between the oxidizing agent branching portion and the outer peripheral flow path and is configured to allow the other part of the oxidizing agent to flow through the outer peripheral gas introducing flow path as the outer peripheral gas.
Advantageous Effects of Invention
[0008] According to this disclosure, in the fuel processing device, a higher thermal efficiency can be obtained.

Description

BRIEF DESCRIPTION OF DRAWINGS
[0009] FIG. **1** is a schematic cross-sectional view of a fuel processing device according to a first embodiment.
[0010] FIG. **2** is a graph for showing a temperature distribution of the fuel processing device according to the first embodiment.
[0011] FIG. **3** is a schematic cross-sectional view of a fuel processing device according to a second embodiment.
[0012] FIG. **4** is a graph for showing a temperature distribution of the fuel processing device according to the second embodiment.
[0013] FIG. **5** is a schematic cross-sectional view of a fuel processing device according to a third embodiment.
[0014] FIG. **6** is a graph for showing a temperature distribution of the fuel processing device according to the third embodiment.
[0015] FIG. **7** is a schematic cross-sectional view of a fuel processing device according to a fourth embodiment.
[0016] FIG. **8** is a schematic cross-sectional view of a fuel processing device according to a modification example of the fourth embodiment.
[0017] FIG. **9** is a schematic cross-sectional view of a fuel processing device according to a fifth embodiment.
[0018] FIG. **10** is a schematic cross-sectional view of a fuel processing device according to a sixth embodiment.
DESCRIPTION OF EMBODIMENTS
First Embodiment
[0019] A fuel processing device according to a first embodiment is described. FIG. **1** is a schematic cross-sectional view of the fuel processing device according to this embodiment. The up-and-down direction of FIG. **1** represents a vertical direction.
[0020] As illustrated in FIG. **1**, a fuel processing device **100** has a cylindrical shape about a center axis **100***a*. The center axis **100***a* extends in the up-and-down direction. The fuel processing device **100** includes a reforming unit **110** and a combustion unit **120**. The combustion unit **120** is provided below the reforming unit **110**. The combustion unit **120** generates a combustion gas F**51** for heating the reforming unit **110**.
[0021] The reforming unit **110** has a multiple tube structure including a flame tube wall **503**, an

inner wall **501**, a middle wall **502**, and an outer wall **504**. Each of the flame tube wall **503**, the inner wall **501**, the middle wall **502**, and the outer wall **504** has a cylindrical shape about the center axis **100***a*. The inner wall **501** is arranged on the outer peripheral side with respect to the flame tube wall **503** so as to surround the flame tube wall **503**. The middle wall **502** is arranged on the outer peripheral side with respect to the inner wall **501** so as to surround the inner wall **501**. The outer wall **504** is arranged on the outer peripheral side with respect to the middle wall **502** so as to surround the middle wall **502**. The inner wall **501** is an example of a first tubular wall. The middle wall **502** is an example of a second tubular wall.

[0022] A combustion gas flow path **401** is formed in a space between the flame tube wall **503** and the inner wall **501**. The combustion gas flow path **401** is formed in an annular shape in horizontal cross section. The combustion gas flow path **401** extends in the up-and-down direction. The combustion gas F**51** flows upward through the combustion gas flow path **401**.

[0023] An upper end portion of the space between the inner wall **501** and the middle wall **502** is closed by a closing wall **505**. The closing wall **505** is provided between the inner wall **501** and the middle wall **502**.

[0024] A reforming reaction flow path **402** is formed in a space between the inner wall **501** and the middle wall **502**. The reforming reaction flow path **402** is formed in an annular shape in horizontal cross section. The reforming reaction flow path **402** extends in the up-and-down direction. The reforming reaction flow path **402** is adjacent to the combustion gas flow path **401** across the inner wall **501**. A raw material F**52** and a reformed gas F**53** flow downward through the reforming reaction flow path **402**.

[0025] A reforming catalyst **5** is filled in the reforming reaction flow path **402**. A catalyst layer is formed in the reforming reaction flow path **402** by the reforming catalyst **5**. An upper end portion of the reforming catalyst **5** serves as an inlet portion of the reforming reaction flow path **402**. A lower end portion of the reforming catalyst **5** serves as an outlet of the reforming reaction flow path **402**.

[0026] The raw material F**52** is supplied to the reforming reaction flow path **402** from the outside of the fuel processing device **100**. In the reforming reaction flow path **402**, the reformed gas F**53** is generated from the raw material F**52** due to a catalytic action of the reforming catalyst **5**.

[0027] On the upstream side with respect to the inlet of the reforming reaction flow path **402** in the flow of the raw material F**52**, a first raw material preheating unit **203** and a second raw material preheating unit **203***a* are provided. The second raw material preheating unit **203***a* is provided on the downstream side with respect to the first raw material preheating unit **203** in the flow of the raw material F**52**. The second raw material preheating unit **203***a* is formed in the space between the inner wall **501** and the middle wall **502**. The first raw material preheating unit **203** is formed of a pipe. The first raw material preheating unit **203** passes through an upper surface wall **506** and the closing wall **505**, and is connected to the second raw material preheating unit **203***a*.

[0028] The raw material F**52** passes through the first raw material preheating unit **203** and the second raw material preheating unit **203***a* in this order to flow into the reforming reaction flow path **402**. The reformed gas F**53** generated in the reforming reaction flow path **402** flows out to the outside of the fuel processing device **100**.

[0029] A reformed gas temperature sensor **9** is provided at the outlet of the reforming reaction flow path **402**. The reformed gas temperature sensor **9** detects a temperature of the reformed gas F**53** flowing out from the reforming reaction flow path **402**, and outputs a detection signal to a controller **8**.

[0030] A catalyst layer outer peripheral flow path **403** is formed in a space between the middle wall **502** and the outer wall **504**. The catalyst layer outer peripheral flow path **403** is formed in an annular shape in horizontal cross section. The catalyst layer outer peripheral flow path **403** extends in the up-and-down direction. The catalyst layer outer peripheral flow path **403** is adjacent to the reforming reaction flow path **402** across the middle wall **502**. A catalyst layer outer peripheral gas

F**54** flows upward through the catalyst layer outer peripheral flow path **403**.

[0031] An upper end portion of a space on the inner peripheral side with respect to the outer wall **504** is closed by the upper surface wall **506**. The upper surface wall **506** is formed in a disk shape about the center axis **100***a*. The upper surface wall **506** faces the closing wall **505** with a gap. The gap between the upper surface wall **506** and the closing wall **505** serves as a communication portion **510**. The space between the flame tube wall **503** and the inner wall **501** and the space between the middle wall **502** and the outer wall **504** are in communication with each other through the communication portion **510**. The first raw material preheating unit **203** passes through the communication portion **510**.

[0032] An exhaust gas flow path **404** is connected to the upper surface wall **506**. The exhaust gas flow path **404** is provided on the center axis **100***a* of the fuel processing device **100**. An exhaust gas F**58** flows through the exhaust gas flow path **404**.

[0033] In a radial direction of the reforming unit **110**, the reforming reaction flow path **402** is sandwiched by the combustion gas flow path **401** and the catalyst layer outer peripheral flow path **403** from both sides. A direction in which the raw material F**52** and the reformed gas F**53** flow in the reforming reaction flow path **402** is opposite to the direction in which the combustion gas F**51** flows in the combustion gas flow path **401** and the direction in which the catalyst layer outer peripheral gas F**54** flows in the catalyst layer outer peripheral flow path **403**. That is, the flows of the raw material F**52** and the reformed gas F**53** in the reforming reaction flow path **402** are opposite to the flow of the combustion gas F**51** in the combustion gas flow path **401** and the flow of the catalyst layer outer peripheral gas F**54** in the catalyst layer outer peripheral flow path **403**.

[0034] Heat exchange is performed through the inner wall **501** between the combustion gas F**51** in the combustion gas flow path **401** and the raw material F**52** and the reformed gas F**53** in the reforming reaction flow path **402**. Heat exchange is performed through the middle wall **502** between the catalyst layer outer peripheral gas F**54** in the catalyst layer outer peripheral flow path **403** and the raw material F**52** and the reformed gas F**53** in the reforming reaction flow path **402**.

[0035] Further, similarly to the reforming reaction flow path **402**, the second raw material preheating unit **203***a* is sandwiched by the combustion gas flow path **401** and the catalyst layer outer peripheral flow path **403** from both sides. Heat exchange is performed through the inner wall **501** between the combustion gas F**51** in the combustion gas flow path **401** and the raw material F**52** in the second raw material preheating unit **203***a*. Heat exchange is performed through the middle wall **502** between the catalyst layer outer peripheral gas F**54** in the catalyst layer outer peripheral flow path **403** and the raw material F**52** in the second raw material preheating unit **203***a*.

[0036] The catalyst layer outer peripheral gas F**54** flows through the communication portion **510** around the first raw material preheating unit **203**. In the first raw material preheating unit **203**, heat exchange is performed between the catalyst layer outer peripheral gas F**54** and the raw material F**52**. The first raw material preheating unit **203** may meander along the circumferential direction of the fuel processing device **100** so as to secure a larger heat transfer area between the first raw material preheating unit **203** and the catalyst layer outer peripheral gas F**54**.

[0037] An upper end portion of the internal space of the flame tube wall **503** is closed by a closing wall **507**. The closing wall **507** faces the upper surface wall **506** with a gap.

[0038] The combustion unit **120** includes a combustor **1**. The combustor **1** is arranged on the center axis **100***a*. The combustor **1** is arranged below the flame tube wall **503**. A combustion fuel F**55**, a combustion raw material F**59**, and a combustion supporting gas F**56** are supplied to the combustor **1**. The combustor **1** combusts the combustion fuel F**55** or the combustion raw material F**59** and the combustion supporting gas F**56**. With this, flame is formed in a combustion space **202**, and the combustion gas F**51** is generated.

[0039] A flame partition plate **3** is provided inside the flame tube wall **503**. The internal space of the flame tube wall **503** is partitioned into an upper part and a lower part by the flame partition plate **3**. A heat shield material **6** is provided in a space above the flame partition plate **3** and below the closing wall **507** inside the flame tube wall **503**. A space below the flame partition plate **3** inside the flame tube wall **503** serves as a radiation heat transfer space **201**. A lower end of the flame tube wall **503** is opened. The flame partition plate **3** faces the combustor **1** across the radiation heat transfer space **201**. The radiation heat transfer space **201** is surrounded by the flame tube wall **503**, the flame partition plate **3**, and the combustor **1**.

[0040] The combustion space **202** is formed at a lower portion of the radiation heat transfer space **201**. The radiation heat transfer space **201** is connected to a lower end portion of the combustion gas flow path **401**. The combustion gas F**51** generated by the combustor **1** passes through the combustion space **202** and the radiation heat transfer space **201** to flow into the combustion gas flow path **401**. The flame partition plate **3** is heated by radiation heat from the combustion space **202** through the radiation heat transfer space **201**.

[0041] The periphery of the combustion space **202** is surrounded by a heat shield wall **4**. The heat shield wall **4** has a cylindrical shape about the center axis of the fuel processing device **100**. The height of the heat shield wall **4** is approximately the same as the height of the combustion space **202**, that is, the height of flame formed by the combustor **1**.

[0042] An air flow path **405** is formed on the outer peripheral side of the heat shield wall **4**. The air flow path **405** is formed in an annular shape so as to surround the periphery of the heat shield wall **4**. Air F**57** for temperature adjustment flows through the air flow path **405**. On the upstream side with respect to the air flow path **405** in the flow of the air F**57**, a flow rate adjustment valve **406** configured to adjust the flow rate of the air F**57** is provided. The flow rate adjustment valve **406** is an example of a configuration for adjusting the flow rate of the air F**57**.

[0043] The air F**57** is supplied from the air flow path **405** to the combustion gas F**51** on the downstream side with respect to the combustion space **202** and on the upstream side with respect to the combustion gas flow path **401**. With this, the temperature of the combustion gas F**51** flowing into the combustion gas flow path **401** is adjusted.

[0044] An oxidizing agent F**50** is supplied to the fuel processing device **100** from a heating source (not shown). The oxidizing agent F**50** in a state of being heated by the heating source is supplied to the fuel processing device **100**. The oxidizing agent F**50** to be supplied to the fuel processing device **100** has a temperature higher than the temperature of the raw material F**52** to be supplied to the fuel processing device **100**. The heating source in this embodiment is a high-temperature fuel cell. Further, the oxidizing agent F**50** in this embodiment is a cathode off-gas supplied from the high-temperature fuel cell.

[0045] An oxidizing agent inflow pipe **300** is provided in the fuel processing device **100**. An oxidizing agent flow path **600** is formed inside the oxidizing agent inflow pipe **300**. The oxidizing agent F**50** flows through the oxidizing agent flow path **600**.

[0046] The oxidizing agent inflow pipe **300** branches into a combustion supporting gas conduit **302** and a catalyst layer outer peripheral gas introducing pipe **301** at an oxidizing agent branching portion **2**. A combustion supporting gas flow path **602** is formed inside the combustion supporting gas conduit **302**. The combustion supporting gas F**56** flows through the combustion supporting gas flow path **602**. The combustion supporting gas F**56** is a part of the oxidizing agent F**50**.

[0047] A catalyst layer outer peripheral gas introducing flow path **601** is formed inside the catalyst layer outer peripheral gas introducing pipe **301**. The catalyst layer outer peripheral gas F**54** flows through the catalyst layer outer peripheral gas introducing flow path **601**. The catalyst layer outer peripheral gas F**54** is the other part of the oxidizing agent F**50**. That is, the oxidizing agent F**50** flowing through the oxidizing agent flow path **600** splits into the combustion supporting gas F**56** and the catalyst layer outer peripheral gas F**54** at the oxidizing agent branching portion **2**.

[0048] The ratio between the flow rate of the catalyst layer outer peripheral gas F**54** and the flow rate of the combustion supporting gas F**56** in the oxidizing agent branching portion **2** is set in advance in accordance with the operating condition of the fuel processing device **100** and the combustion condition of the combustor **1**. For example, when the oxidizing agent F**50** is a cathode off-gas of a solid oxide fuel cell, the ratio between the flow rate of the catalyst layer outer peripheral gas F**54** and the flow rate of the combustion supporting gas F**56** is set to from about 3:1 to about 11:1.

[0049] The combustion supporting gas conduit **302** is connected to the combustor **1**. With this, a part of the oxidizing agent F**50** is supplied to the combustor **1** as the combustion supporting gas F**56**. The catalyst layer outer peripheral gas introducing pipe **301** is connected to a lower portion of the catalyst layer outer peripheral flow path **403**. With this, the other part of the oxidizing agent F**50** is supplied to the catalyst layer outer peripheral flow path **403** as the catalyst layer outer peripheral gas F**54**.

[0050] The combustion gas F**51** having flowed through the combustion gas flow path **401** and the catalyst layer outer peripheral gas F**54** having flowed through the catalyst layer outer peripheral flow path **403** merge with each other at a merging portion **200**. The merging portion **200** is formed in a ring shape about the center axis **100***a*. The merging portion **200** in this embodiment is located at the upper end portion of the space between the flame tube wall **503** and the inner wall **501**. The combustion gas F**51** and the catalyst layer outer peripheral gas F**54** that have merged at the merging portion **200** turn into the exhaust gas F**58**. The exhaust gas F**58** passes through the exhaust gas flow path **404** to flow out to the outside of the fuel processing device **100**.

[0051] Although not illustrated, the fuel processing device **100** is surrounded by an appropriate heat insulating material. With this, heat loss due to heat radiation from the fuel processing device **100** is suppressed.

[0052] The controller **8** is configured to control the entire fuel processing device **100**. The controller **8** includes a microcomputer including, for example, a central processing unit (CPU), a read only memory (ROM), and a random access memory (RAM).

[0053] Next, the operation of the fuel processing device according to this embodiment is described. The raw material F**52** supplied to the fuel processing device **100** is preheated by the catalyst layer outer peripheral gas F**54** in the first raw material preheating unit **203**. The raw material F**52** is further preheated by the combustion gas F**51** and the catalyst layer outer peripheral gas F**54** in the second raw material preheating unit **203***a*. The raw material F**52** is preheated in the first raw material preheating unit **203** and the second raw material preheating unit **203***a* to be heated to from about 350° C. to about 400° C.

[0054] The heated raw material F**52** flows into the reforming reaction flow path **402**. The raw material F**52** of the reforming reaction flow path **402** is heated from the inner peripheral side by the combustion gas F**51** flowing through the combustion gas flow path **401**. Further, the raw material F**52** of the reforming reaction flow path **402** is heated also from the outer peripheral side by the catalyst layer outer peripheral gas F**54** flowing through the catalyst layer outer peripheral flow path **403**. With this, the raw material F**52** passing through the reforming catalyst **5** is heated to from about 550° C. to about 650° C. Further, the raw material F**52** passing through the reforming catalyst **5** is reformed to the reformed gas F**53** by a reforming reaction which is an endothermic reaction.

[0055] For example, when the raw material F**52** is methane and water vapor, a general reforming reaction is expressed by the following formula (1) and formula (2). In the reforming reaction flow path **402**, an endothermic reaction of methane and water vapor occurs due to the catalytic action of the reforming catalyst **5**. With this reaction, hydrogen is generated.

CH.sub.4+H.sub.2O.Math.CO+3H.sub.2 (1)

CO+H.sub.2O.Math.CO.sub.2+H.sub.2 (2)

[0056] The flow rate of methane and water vapor is generally represented by the S/C ratio. The S/C ratio is a molar fraction of water vapor(S) with respect to carbon (C) contained in the raw material. In general, the flow rate of the water vapor to be supplied to the reforming reaction flow path **402** is set such that the S/C ratio becomes a constant value within a range of from about 2.5 to about 3.5. As the reforming catalyst **5**, for example, Ni-based, Pt-based, or Ru-based reforming catalyst is used. The reforming catalyst **5** is carried on a carrier, such as Al.sub.2O.sub.3 or MgO.

[0057] The reformed gas F**53** is supplied to the high-temperature fuel cell or the like while maintaining the temperature after the reforming reaction. Examples of the high-temperature fuel cell include a solid oxide fuel cell and a molten carbonate fuel cell.

[0058] In the combustor **1**, due to a combustion reaction between the combustion supporting gas F**56** and the combustion fuel F**55** or the combustion raw material F**59**, the combustion gas F**51** having a temperature of from about 700° C. to about 1,200° C. is generated. For example, an ignition plug (not shown) is used for ignition at the combustor **1**.

[0059] The combustion gas F**51** passes through the combustion space **202** and the radiation heat transfer space **201** to flow into the combustion gas flow path **401**. The combustion gas F**51** flows upward through the combustion gas flow path **401**. The heat of the combustion gas F**51** is transfer to the reforming reaction flow path **402** through the inner wall **501**. With this, the temperature of the combustion gas F**51** decreases to about 400° C. The heat transferred to the reforming reaction flow path **402** is a part of the thermal energy required for the reforming reaction.

[0060] Heat transfer from the combustion gas flow path **401** to the reforming reaction flow path **402** is performed by convection of the combustion gas F**51**. Further, the heat transfer from the combustion gas flow path **401** to the reforming reaction flow path **402** is performed also by radiation from the flame tube wall **503** and radiation from the combustion gas F**51**. The radiation heat transfer space **201** is formed at the periphery of the combustor **1**, and hence a particularly large amount of heat is given to the reforming reaction flow path **402** due to radiation from the radiation heat transfer space **201**.

[0061] The downstream portion of the combustion space **202** in the flow of the combustion gas F**51** is connected to the air flow path **405**. With this, the air F**57** for temperature adjustment is mixed with the combustion gas F**51** on the downstream side with respect to the position at which combustion is completed in the combustion space **202**. Thus, the temperature of the combustion gas F**51** can be adjusted without affecting the combustion reaction.

[0062] In the reformed gas temperature sensor **9**, the temperature of the reformed gas F**53** at the outlet of the reforming reaction flow path **402** is detected. The controller **8** controls the flow rate of the air F**57** based on the temperature detected by the reformed gas temperature sensor **9**. For example, the controller **8** controls the flow rate adjustment valve **406** such that the flow rate of the air F**57** increases as the temperature of the reformed gas F**53** increases. With this, the reaction temperature of the reforming reaction expressed by the formula (1) and the formula (2) can be adjusted.

[0063] For example, the oxidizing agent F**50** having a temperature of from 650° C. to 700° C. is supplied to the oxidizing agent flow path **600** from the heating source. The oxidizing agent F**50** splits into the combustion supporting gas flow path **602** and the catalyst layer outer peripheral gas introducing flow path **601** at the oxidizing agent branching portion **2**. A part of the oxidizing agent F**50** flows through the combustion supporting gas flow path **602** as the combustion supporting gas F**56**. The combustion supporting gas F**56** flows through the combustion supporting gas flow path **602** to be supplied to the combustor **1**.

[0064] The other part of the oxidizing agent F**50** flows through the catalyst layer outer peripheral gas introducing flow path **601** as the catalyst layer outer peripheral gas F**54**. The catalyst layer outer peripheral gas F**54** flows through the catalyst layer outer peripheral gas introducing flow path **601** to be supplied to the catalyst layer outer peripheral flow path **403**. The catalyst layer outer peripheral gas F**54** gives heat to the reforming reaction flow path **402** via the middle wall **502** while flowing through the catalyst layer outer peripheral flow path **403**. The heat is the remaining thermal energy of the thermal energy required for the reforming reaction. The heat is given to the reforming reaction flow path **402** so that the temperature of the catalyst layer outer peripheral gas F**54**

decreases to about 400° C.
[0065] The catalyst layer outer peripheral gas F**54** passes through the communication portion **510** to merge with the combustion gas F**51** at the merging portion **200**. The merged gas flows out to the outside from the exhaust gas flow path **404** as the exhaust gas F**58**.
[0066] FIG. **2** is a diagram for illustrating a temperature distribution of the fuel processing device according to this embodiment. The horizontal axis of FIG. **2** represents the position "x" in the center axis **100***a* direction. The position x is non-dimensional with the inlet of the reforming reaction flow path **402** being set as 0, the outlet of the reforming reaction flow path **402** being set as 1, and the length of the reforming reaction flow path **402** in the center axis **100***a* direction being set as L. The range in which the position "x" is a negative value indicates the second raw material preheating unit **203***a* or the first raw material preheating unit **203**. The merging portion **200** in this embodiment is provided at a position smaller than 0 in the center axis **100***a* direction. The vertical axis of FIG. **2** represents the temperature (C). The solid line in FIG. **2** represents the temperature of the combustion gas F**51**. The long-dashed broken line in FIG. **2** represents the temperature of the catalyst layer outer peripheral gas F**54**. The short-dashed broken line in FIG. **2** represents the temperature of the raw material F**52** and the reformed gas F**53**.
[0067] When the filled amount of the reforming catalyst **5** or the like is appropriately set, the reforming reaction expressed by the formula (1) and the formula (2) is affected by the temperature distribution of the raw material F**52** and the reformed gas F**53** flowing through the reforming reaction flow path **402**.
[0068] The combustion supporting gas F**56** is supplied to the combustor **1**. The combustion supporting gas F**56** is a part of the oxidizing agent F**50** that has split at the oxidizing agent branching portion **2**. The flow rate of the combustion supporting gas F**56** defines the flame temperature at the time of combustion and affects the combustion state. That is, when it is assumed that the flow rate of the combustion fuel F**55** is constant, the heat insulating flame temperature is theoretically determined.
[0069] When the flame temperature is excessively high, there is a fear in that the heat resistance of the member forming the fuel processing device **100** cannot be secured. In contrast, when the flame temperature is excessively low, heat transfer from the combustion gas F**51** to the raw material F**52** and the reformed gas F**53** is difficult. That is, there is an appropriate range for the flame temperature. Further, there is a range of an appropriate oxygen ratio for completely combusting the combustion fuel F**55** in the combustion space **202**. Thus, the flow rate of the combustion supporting gas F**56**, that is, a distribution ratio at the oxidizing agent branching portion **2** is substantially determined.
[0070] In the fuel processing device of this embodiment, when the flow rate of the combustion supporting gas F**56** and the flow rate of the catalyst layer outer peripheral gas F**54** are appropriately balanced with respect to the reforming reaction, a temperature distribution generally as illustrated in FIG. **2** is formed. That is, each of the flame temperature and the oxygen ratio falls within an appropriate range in accordance with the flow rate of the combustion fuel F**55**, and, when the thermal energy of the catalyst layer outer peripheral gas F**54** and the combustion supporting gas F**56** falls within an appropriate range, the temperature of the combustion gas F**51** and the temperature of the catalyst layer outer peripheral gas F**54** decrease similarly from the right side to the left side of FIG. **2**. With this, at the merging portion **200**, the temperature of the combustion gas F**51** and the temperature of the catalyst layer outer peripheral gas F**54** are approximately the same.
[0071] Here, the oxidizing agent F**50** is not limited to the cathode off-gas supplied from the high-temperature fuel cell. It is only required that the oxidizing agent F**50** have a gas temperature of about 600° C. or more and contain a required amount of a composition that is a combustion-supporting gas of a combustion reaction. As the oxidizing agent F**50**, a high-temperature oxygen-containing exhaust gas in a plant, or the like, can be used.
[0072] Fuel to be supplied to the combustor **1** may be the same as the raw material F**52** or may be

different from the raw material F**52**. In the fuel to be supplied to the combustor **1**, a material which is the same as the raw material F**52** and a material different from the raw material F**52** may be mixed with each other.

[0073] When, for example, the fuel processing device **100** is incorporated in the fuel cell system, the combustion fuel F**55** may be a part or an entirety of an anode off-gas. From about 70% to about 90% of the hydrogen contained in the reformed gas F**53** is consumed for power generation in a fuel cell stack. The remaining hydrogen is contained in the anode off-gas. Thus, a part or an entirety of the anode off-gas can be supplied to the combustor **1** as the combustion fuel F**55**.

[0074] The combustion raw material F**59** is the same as the raw material F**52**. The combustion raw material F**59** is supplied to the combustor **1**, for example, in a temperature rise process at the time of activation of the fuel processing device **100**. As the fuel of the combustor **1**, a material in which a part or an entirety of the anode off-gas and the raw material F**52** are mixed with each other may be used.

[0075] In this embodiment, a part of the oxidizing agent F**50** supplied from the heating source is used as the combustion supporting gas F**56**, and the other part of the oxidizing agent F**50** is used as the catalyst layer outer peripheral gas F**54**. The combustion supporting gas F**56** is supplied to the combustor **1** to be combusted together with the combustion fuel F**55** or the combustion raw material F**59**. The catalyst layer outer peripheral gas F**54** passes through the catalyst layer outer peripheral flow path **403** to give heat to the second raw material preheating unit **203***a* and the reforming reaction flow path **402** from the outer peripheral side. The combustion gas F**51** generated by combustion passes through the combustion gas flow path **401** to give heat to the second raw material preheating unit **203***a* and the reforming reaction flow path **402** from the inner peripheral side.

[0076] As described above, heat is given to the second raw material preheating unit **203***a* and the reforming reaction flow path **402** from both sides of the outer peripheral side and the inner peripheral side. With this, the heat transfer area with respect to the second raw material preheating unit **203***a* and the reforming reaction flow path **402** can be increased, thereby being capable of decreasing the loss of the thermal energy. Thus, the fuel processing device with a high thermal efficiency is achieved. Further, the heat transfer property is improved, thereby being capable of attaining a reduction in size of the fuel processing device **100**.

[0077] Further, heat is given to the reforming reaction flow path **402** from both sides of the outer peripheral side and the inner peripheral side so that the temperature of the reforming reaction flow path **402** can be made uniform in the radial direction of the fuel processing device **100**. Thus, the reformed gas F**53** with a small composition variation due to the reaction can be obtained.

[0078] A temperature difference may be caused in the combustion gas F**51** in the circumferential direction due to the combustion state of the combustor **1**. In this case, through heat transfer from the combustion gas F**51**, a temperature difference may be caused also in the flame tube wall **503** in the circumferential direction. However, in this embodiment, the radiation heat transfer space **201** is provided on the inner side of the flame tube wall **503**. Thus, when a temperature difference is caused in the circumferential direction of the flame tube wall **503**, due to radiation from the radiation heat transfer space **201**, heat transfer from a high-temperature portion to a low-temperature portion of the flame tube wall **503** occurs. Thus, the temperature difference in the circumferential direction of the flame tube wall **503** can be reduced. As a result, the temperature of the reformed gas F**53** flowing through the reforming reaction flow path **402** can be made uniform in the circumferential direction.

[0079] In this embodiment, on the inner peripheral side of the downstream-side portion of the combustion gas flow path **401**, the flame partition plate **3** and the heat shield material **6** are provided. Thus, in the downstream-side portion of the combustion gas flow path **401**, heat transfer from the radiation heat transfer space **201** is suppressed. With this, the reforming reaction flow path **402** can be prevented from being overheated. As a result, carbon is prevented from precipitating

due to heat decomposition of the raw material F**52**.
[0080] As described above, the fuel processing device **100** according to this embodiment includes the reforming unit **110** and the combustion unit **120**. The reforming unit **110** is configured to generate the reformed gas F**53** from the raw material F**52**. The combustion unit **120** is configured to combust the combustion fuel F**55** or the combustion raw material F**59** and the combustion supporting gas F**56** in the combustion space **202** to generate the combustion gas F**51**.
[0081] The reforming unit **110** includes the inner wall **501**, and the middle wall **502** arranged on the outer peripheral side with respect to the inner wall **501**. The reforming reaction flow path **402** is formed between the inner wall **501** and the middle wall **502**. The reforming catalyst **5** is filled in the reforming reaction flow path **402**. The raw material F**52** and the reformed gas F**53** flow through the reforming reaction flow path **402**.
[0082] The combustion gas flow path **401** is formed on the inner peripheral side with respect to the inner wall **501**. The combustion gas F**51** flows through the combustion gas flow path **401**. The combustion gas flow path **401** is adjacent to the reforming reaction flow path **402** across the inner wall **501**. The catalyst layer outer peripheral flow path **403** is formed on the outer peripheral side with respect to the middle wall **502**. The catalyst layer outer peripheral gas F**54** flows through the catalyst layer outer peripheral flow path **403**. The catalyst layer outer peripheral flow path **403** is adjacent to the reforming reaction flow path **402** across the middle wall **502**.
[0083] The fuel processing device **100** further includes the merging portion **200**, the exhaust gas flow path **404**, the oxidizing agent flow path **600**, the oxidizing agent branching portion **2**, the combustion supporting gas flow path **602**, and the catalyst layer outer peripheral gas introducing flow path **601**.
[0084] At the merging portion **200**, the combustion gas F**51** having flowed through the combustion gas flow path **401** and the catalyst layer outer peripheral gas F**54** having flowed through the catalyst layer outer peripheral flow path **403** merge with each other. The combustion gas F**51** and the catalyst layer outer peripheral gas F**54** that have merged at the merging portion **200** flow through the exhaust gas flow path **404** as the exhaust gas F**58**. The oxidizing agent F**50** supplied from the heating source flows through the oxidizing agent flow path **600**. The oxidizing agent branching portion **2** is provided in the oxidizing agent flow path **600**. The combustion supporting gas flow path **602** connects between the oxidizing agent branching portion **2** and the combustion unit **120**. The combustion supporting gas flow path **602** allows a part of the oxidizing agent F**50** to flow therethrough as the combustion supporting gas F**56**. The catalyst layer outer peripheral gas introducing flow path **601** connects between the oxidizing agent branching portion **2** and the catalyst layer outer peripheral flow path **403**. The catalyst layer outer peripheral gas introducing flow path **601** allows the other part of the oxidizing agent F**50** to flow therethrough.
[0085] Here, the combustion fuel F**55** and the combustion raw material F**59** are examples of fuel. The inner wall **501** is an example of the first tubular wall. The middle wall **502** is an example of the second tubular wall. The catalyst layer outer peripheral flow path **403** is an example of an outer peripheral flow path. The catalyst layer outer peripheral gas F**54** is an example of an outer peripheral gas. The catalyst layer outer peripheral gas introducing flow path **601** is an example of an outer peripheral gas introducing flow path.
[0086] According to this configuration, the raw material F**52** and the reformed gas F**53** in the reforming reaction flow path **402** are heated by the combustion gas F**51** in the combustion gas flow path **401** from the inner peripheral side, and is heated from the outer peripheral side by the catalyst layer outer peripheral gas F**54** in the catalyst layer outer peripheral flow path **403**. With this, the heat transfer area with respect to the reforming reaction flow path **402** can be increased, thereby being capable of obtaining a higher thermal efficiency in the fuel processing device **100**. Further, the temperature distribution of the reforming reaction flow path **402** can be made uniform in the radial direction, thereby being capable of obtaining the reformed gas F**53** with a small composition variation due to a reaction. Further, heat radiation from the reforming reaction flow path **402** can be

suppressed, thereby being capable of reducing the loss of the thermal energy.

[0087] The fuel processing device **100** according to this embodiment further includes the flame tube wall **503**, the flame partition plate **3**, and the radiation heat transfer space **201**. The flame tube wall **503** is arranged on the inner peripheral side with respect to the inner wall **501**. The flame partition plate **3** is arranged inside the flame tube wall **503** so as to correspond to the combustion unit **120**. The radiation heat transfer space **201** is surrounded by the flame tube wall **503**, the flame partition plate **3**, and the combustion unit **120**.

[0088] According to this configuration, the temperature difference of the flame tube wall **503** in the circumferential direction can be reduced by radiation in the radiation heat transfer space **201**. Thus, the temperature of the reformed gas F**53** flowing through the reforming reaction flow path **402** can be made uniform in the circumferential direction.

[0089] The fuel processing device **100** according to this embodiment further includes the first raw material preheating unit **203**. The first raw material preheating unit **203** preheats the raw material F**52** flowing into the reforming reaction flow path **402**, by heat transfer from the catalyst layer outer peripheral gas F**54** or the combustion gas F**51**. Here, the first raw material preheating unit **203** is an example of a raw material preheating unit. According to this configuration, the raw material F**52** is preheated before flowing into the reforming reaction flow path **402**, thereby being capable of promoting the reforming reaction in the reforming reaction flow path **402**.

[0090] The fuel processing device **100** according to this embodiment further includes the air flow path **405**. The air flow path **405** supplies the air F**57** for temperature adjustment to the combustion gas F**51** on the downstream side with respect to the combustion space **202**. According to this configuration, the temperature of the combustion gas F**51** can be adjusted without affecting the combustion reaction.

[0091] The fuel processing device **100** according to this embodiment further includes the reformed gas temperature sensor **9** and the controller **8**. The reformed gas temperature sensor **9** detects the temperature of the reformed gas F**53** at the outlet of the reforming reaction flow path **402**. The controller **8** controls the flow rate of the air F**57** to be supplied to the combustion gas F**51** based on the temperature detected by the reformed gas temperature sensor **9**. According to this configuration, the reaction temperature of the reforming reaction can be adjusted.

[0092] In the fuel processing device **100** according to this embodiment, the heating source is the fuel cell. The oxidizing agent F**50** is the cathode off-gas supplied from the fuel cell. According to this configuration, heat can be effectively utilized in the fuel cell system.

Second Embodiment

[0093] A fuel processing device according to a second embodiment is described. FIG. **3** is a schematic cross-sectional view of the fuel processing device according to this embodiment. The up-and-down direction of FIG. **3** represents a vertical direction.

[0094] As illustrated in FIG. **3**, the merging portion **200** in this embodiment is formed between the flame tube wall **503** and the inner wall **501**. The combustion gas flow path **401** is formed below the merging portion **200** in the space between the flame tube wall **503** and the inner wall **501**. A downstream portion **403***b* of the catalyst layer outer peripheral flow path **403** is formed above the merging portion **200** in the space between the flame tube wall **503** and the inner wall **501**. An upstream portion **403***a* of the catalyst layer outer peripheral flow path **403** is formed in the space between the middle wall **502** and the outer wall **504**. The downstream portion **403***b* is continuous with the upstream portion **403***a* through the communication portion **510**. The downstream portion **403***b* faces the upstream portion **403***a* across the second raw material preheating unit **203***a* and the reforming reaction flow path **402**.

[0095] Further, in this embodiment, an oxidizing agent distribution regulator **303** is provided in the catalyst layer outer peripheral gas introducing flow path **601**. The oxidizing agent distribution regulator **303** adjusts the ratio between the flow rate of the combustion supporting gas F**56** and the flow rate of the catalyst layer outer peripheral gas F**54**. As the oxidizing agent distribution regulator

303, for example, an orifice plate is used. The orifice plate is provided so that the pressure loss of the catalyst layer outer peripheral gas F**54** in the catalyst layer outer peripheral gas introducing flow path **601** changes. An appropriate orifice plate is provided so that the combustion supporting gas F**56** and the catalyst layer outer peripheral gas F**54** are distributed at a desired ratio between the respective flow rates at the oxidizing agent branching portion **2**. The other configurations are similar to those of the first embodiment.

[0096] The operation of the fuel processing device according to this embodiment is described. The catalyst layer outer peripheral gas F**54** flows upward through the upstream portion **403***a* of the catalyst layer outer peripheral flow path **403**. The flow of the catalyst layer outer peripheral gas F**54** in the upstream portion **403***a* is opposite to the flows of the raw material F**52** and the reformed gas F**53** in the reforming reaction flow path **402** and the flow of the raw material F**52** in the second raw material preheating unit **203***a*. The catalyst layer outer peripheral gas F**54** flowing through the upstream portion **403***a* gives thermal energy to the raw material F**52** and the reformed gas F**53** flowing through the reforming reaction flow path **402** from the outer peripheral side, and gives thermal energy to the raw material F**52** flowing through the second raw material preheating unit **203***a* from the outer peripheral side.

[0097] The catalyst layer outer peripheral gas F**54** flows upward through the upstream portion **403***a*, and then passes through the communication portion **510** to flow around on the inner peripheral side with respect to the second raw material preheating unit **203***a* and the reforming reaction flow path **402** and flow into the downstream portion **403***b*. At the downstream portion **403***b*, the catalyst layer outer peripheral gas F**54** flows downward. The flow of the catalyst layer outer peripheral gas F**54** in the downstream portion **403***b* is parallel to the flows of the raw material F**52** and the reformed gas F**53** in the reforming reaction flow path **402** and the flow of the raw material F**52** in the second raw material preheating unit **203***a*. The catalyst layer outer peripheral gas F**54** flowing through the downstream portion **403***b* gives thermal energy to the raw material F**52** flowing through the second raw material preheating unit **203***a* from the inner peripheral side, and gives thermal energy to the raw material F**52** and the reformed gas F**53** flowing through the reforming reaction flow path **402** from the inner peripheral side.

[0098] The catalyst layer outer peripheral gas F**54** flowing through the downstream portion **403***b* merges with the combustion gas F**51** at the merging portion **200**. The merged gas flows out to the outside from the exhaust gas flow path **404** as the exhaust gas F**58**.

[0099] FIG. **4** is a graph for showing the temperature distribution of the fuel processing device according to this embodiment. The horizontal axis and the vertical axis in FIG. **4** are similar to the horizontal axis and the vertical axis in FIG. **2**. Here, the merging portion **200** in this embodiment is provided at a position larger than 0 and smaller than 1 in the center axis **100***a* direction, and is provided on the inner peripheral side with respect to the reforming reaction flow path **402**. The communication portion **510** is provided at a position smaller than 0 in the center axis **100***a* direction. The solid line in FIG. **4** represents the temperature of the combustion gas F**51**. The long-dashed broken line in FIG. **4** represents the temperature of the catalyst layer outer peripheral gas F**54**. The short-dashed broken line in FIG. **4** represents the temperature of the raw material F**52** and the reformed gas F**53**.

[0100] Even when the combustion condition as described above is appropriately held, when the distribution ratio of the combustion supporting gas F**56** from the oxidizing agent F**50** is small in thermal energy, the temperature decrease of the combustion gas F**51** accompanying heat transfer to the reforming reaction flow path **402** is larger than the temperature decrease of the catalyst layer outer peripheral gas F**54** accompanying heat transfer to the reforming reaction flow path **402**. With this, heat transfer performance is degraded.

[0101] For example, when the distribution ratio of the combustion supporting gas F**56** from the oxidizing agent F**50** is small in thermal energy, even when the combustion temperature is the same, the thermal energy of the combustion gas F**51** becomes smaller. In contrast, the thermal energy of the catalyst layer outer peripheral gas F**54** becomes larger. Thus, as the position in the center axis **100***a* direction is closer to the inlet of the reforming reaction flow path **402**, the temperature of the combustion gas F**51** becomes significantly smaller than the temperature of the catalyst layer outer peripheral gas F**54**. With this, in the vicinity of the inlet of the reforming reaction flow path **402**, the temperature difference between the combustion gas F**51** and the raw material F**52** and the reformed gas F**53** decreases, with the result that the heat transfer property is degraded.

[0102] In contrast, the temperature of the catalyst layer outer peripheral gas F**54** does not decrease as in the temperature of the combustion gas F**51**, even when the position in the center axis **100***a* direction approaches the inlet of the reforming reaction flow path **402**. With this, the temperature difference between the catalyst layer outer peripheral gas F**54** and the raw material F**52** and the reformed gas F**53** is larger than the temperature difference between the combustion gas F**51** and the raw material F**52** and the reformed gas F**53**. Thus, particularly in the vicinity of the inlet of the reforming reaction flow path **402**, the temperature of the reforming reaction flow path **402** is non-uniform in the radial direction of the fuel processing device **100**.

[0103] In this embodiment, the catalyst layer outer peripheral gas F**54** first flows through the upstream portion **403***a* of the catalyst layer outer peripheral flow path **403**. The flow of the catalyst layer outer peripheral gas F**54** at the upstream portion **403***a* is opposite to the flows of the raw material F**52** and the reformed gas F**53**. The catalyst layer outer peripheral gas F**54** at the upstream portion **403***a* gives thermal energy to the raw material F**52** and the reformed gas s F**53** from the outer peripheral side. The section from the point A to the point B in FIG. **4** represents the temperature distribution of the catalyst layer outer peripheral gas F**54** at the upstream portion **403***a*.

[0104] After that, the catalyst layer outer peripheral gas F**54** is reversed at the communication portion **510** to flow around on the inner peripheral side with respect to the reforming reaction flow path **402** and flow into the downstream portion **403***b* of the catalyst layer outer peripheral flow path **403**. The flow of the catalyst layer outer peripheral gas F**54** at the downstream portion **403***b* is parallel to the flows of the raw material F**52** and the reformed gas F**53**. The catalyst layer outer peripheral gas F**54** at the downstream portion **403***b* gives thermal energy to the raw material F**52** and the reformed gas F**53** from the inner peripheral side. The section from the point B to the point C in FIG. **4** represents the temperature distribution of the catalyst layer outer peripheral gas F**54** at the downstream portion **403***b*.

[0105] That is, heat is given to the downstream-side portion of the reforming reaction flow path **402** in the flows of the raw material F**52** and the reformed gas F**53** by the catalyst layer outer peripheral gas F**54** from the outer peripheral side, and heat is given thereto by the combustion gas F**51** from the inner peripheral side. Heat is given to the upstream-side portion of the reforming reaction flow path **402** by the catalyst layer outer peripheral gas F**54** flowing through the upstream portion **403***a* from the outer peripheral side, and heat is given thereto by the catalyst layer outer peripheral gas F**54** flowing through the downstream portion **403***b* from the inner peripheral side.

[0106] As illustrated in FIG. **4**, in this embodiment, also on the inner peripheral side in the vicinity of the inlet of the reforming reaction flow path **402**, the temperature difference between the catalyst layer outer peripheral gas F**54** at the downstream portion **403***b* and the raw material F**52** and the reformed gas F**53** can be secured. Thus, the heat transfer property of the fuel processing device **100** can be improved. Thus, also when the distribution ratio of the combustion supporting gas F**56** is small in thermal energy, the thermal efficiency of the fuel processing device **100** can be improved.

[0107] Further, in this embodiment, the temperature of the reforming reaction flow path **402** can be made uniform in the radial direction of the fuel processing device **100**. Thus, also when the distribution ratio of the combustion supporting gas F**56** is small in thermal energy, the reformed gas F**53** with a small composition variation due to a reaction can be obtained.

[0108] Further, in this embodiment, the temperature of the combustion gas F**51** at the merging portion **200** and the temperature of the catalyst layer outer peripheral gas F**54** at the merging portion **200** can be brought closer to each other. Thus, the loss of the thermal energy can be reduced. Accordingly, even when the distribution ratio of the combustion supporting gas F**56** is small in thermal energy, the thermal efficiency of the fuel processing device **100** can be improved.

[0109] Further, in this embodiment, the combustion reaction can be performed in a range of an appropriate oxygen ratio, thereby being capable of attaining stable complete combustion. Further, the heat transfer property is improved in this embodiment, thereby being capable of attaining a reduction in size of the fuel processing device **100**.

[0110] In this embodiment, the oxidizing agent distribution regulator **303** is provided in the catalyst layer outer peripheral gas introducing flow path **601**, but the configuration is not limited thereto. The distribution ratio between the combustion supporting gas F**56** and the catalyst layer outer peripheral gas F**54** is determined based on the ratio between the pressure loss of the flow path of the combustion supporting gas F**56** and the pressure loss of the flow path of the catalyst layer outer peripheral gas F**54**. Thus, the oxidizing agent distribution regulator **303** may be provided in the combustion supporting gas flow path **602**, and or may be provided in each of the combustion supporting gas flow path **602** and the catalyst layer outer peripheral gas introducing flow path **601**.

[0111] As described above, in the fuel processing device **100** according to this embodiment, in at least one of the combustion supporting gas flow path **602** and the catalyst layer outer peripheral gas introducing flow path **601**, the oxidizing agent distribution regulator **303** configured to determine the distribution ratio between the combustion supporting gas F**56** and the catalyst layer outer peripheral gas F**54** is provided. According to this configuration, the temperature of the reforming reaction flow path **402** can be made uniform in the radial direction, thereby being capable of obtaining the reformed gas F**53** with a small composition variation due to a reaction.

[0112] In the fuel processing device **100** according to this embodiment, the catalyst layer outer peripheral flow path **403** includes the upstream portion **403***a* and the downstream portion **403***b*. The upstream portion **403***a* is formed on the outer peripheral side with respect to the middle wall **502**. The downstream portion **403***b* is formed on the inner peripheral side with respect to the inner wall **501**. The merging portion **200** is located on the inner peripheral side with respect to the inner wall **501**. The upstream portion **403***a* and the downstream portion **403***b* face each other across the reforming reaction flow path **402**. According to this configuration, even when the distribution ratio of the combustion supporting gas F**56** is small in thermal energy, the reformed gas F**53** with a small composition variation due to a reaction can be obtained, and the thermal efficiency of the fuel processing device **100** can be improved.

Third Embodiment

[0113] A fuel processing device according to a third embodiment is described. FIG. **5** is a schematic cross-sectional view of the fuel processing device according to this embodiment. The up-and-down direction of FIG. **5** represents a vertical direction.

[0114] As illustrated in FIG. **5**, the merging portion **200** in this embodiment is formed between the middle wall **502** and the outer wall **504**. The catalyst layer outer peripheral flow path **403** is formed below the merging portion **200** in the space between the middle wall **502** and the outer wall **504**. A downstream portion **401***b* of the combustion gas flow path **401** is formed above the merging portion **200** in the space between the middle wall **502** and the outer wall **504**. An upstream portion **401***a* of the combustion gas flow path **401** is formed in the space between the flame tube wall **503** and the inner wall **501**. The downstream portion **401***b* is continuous with the upstream portion **401***a* through the communication portion **510**. The downstream portion **401***b* faces the upstream portion **401***a* across the second raw material preheating unit **203***a* and the reforming reaction flow path **402**. The other configurations are similar to those of the first embodiment.

[0115] The operation of the fuel processing device according to this embodiment is described. The combustion gas F**51** flows upward through the upstream portion **401***a* of the combustion gas flow path **401**. The flow of the combustion gas F**51** in the upstream portion **401***a* is opposite to the flows of the raw material F**52** and the reformed gas F**53** in the reforming reaction flow path **402** and the flow of the raw material F**52** in the second raw material preheating unit **203***a*. The combustion gas

F**51** flowing through the upstream portion **401***a* gives thermal energy to the raw material F**52** and the reformed gas F**53** flowing through the reforming reaction flow path **402** from the inner peripheral side, and gives thermal energy to the raw material F**52** flowing through the second raw material preheating unit **203***a* from the inner peripheral side.

[0116] The combustion gas F**51** flows upward through the upstream portion **401***a*, and then passes through the communication portion **510** to flow around on the outer peripheral side with respect to the second raw material preheating unit **203***a* and the reforming reaction flow path **402** and flow into the downstream portion **401***b*. At the downstream portion **401***b*, the combustion gas F**51** flows downward. The flow of the combustion gas F**51** in the downstream portion **401***b* is parallel to the flows of the raw material F**52** and the reformed gas F**53** in the reforming reaction flow path **402** and the flow of the raw material F**52** in the second raw material preheating unit **203***a*. The combustion gas F**51** flowing through the downstream portion **401***b* gives thermal energy to the raw material F**52** flowing through the second raw material preheating unit **203***a* from the outer peripheral side, and gives thermal energy to the raw material F**52** and the reformed gas F**53** flowing through the reforming reaction flow path **402** from the outer peripheral side.

[0117] The combustion gas F**51** flowing through the downstream portion **401***b* merges with the catalyst layer outer peripheral gas F**54** at the merging portion **200**. The merged gas flows out to the outside from the exhaust gas flow path **404** as the exhaust gas F**58**.

[0118] FIG. **6** is a graph for showing the temperature distribution of the fuel processing device according to this embodiment. The horizontal axis and the vertical axis in FIG. **6** are similar to the horizontal axis and the vertical axis in FIG. **2**. Here, the merging portion **200** in this embodiment is provided at a position larger than 0 and smaller than 1 in the center axis **100***a* direction, and is provided on the outer peripheral side with respect to the reforming reaction flow path **402**. The solid line in FIG. **6** represents the temperature of the combustion gas F**51**. The long-dashed broken line in FIG. **6** represents the temperature of the catalyst layer outer peripheral gas F**54**. The short-dashed broken line in FIG. **6** represents the temperature of the raw material F**52** and the reformed gas F**53**.

[0119] Even when the combustion condition is appropriately held, when the distribution ratio of the catalyst layer outer peripheral gas F**54** from the oxidizing agent F**50** is small in thermal energy, the temperature decrease of the catalyst layer outer peripheral gas F**54** accompanying heat transfer to the reforming reaction flow path **402** is larger than the temperature decrease of the combustion gas F**51** accompanying heat transfer to the reforming reaction flow path **402**. With this, heat transfer performance is degraded.

[0120] For example, when the distribution ratio of the catalyst layer outer peripheral gas F**54** from the oxidizing agent F**50** is small in thermal energy, the thermal energy of the catalyst layer outer peripheral gas F**54** becomes smaller. In contrast, the thermal energy of the combustion gas F**51** becomes larger. Thus, as the position in the center axis **100***a* direction is closer to the inlet of the reforming reaction flow path **402**, the temperature of the catalyst layer outer peripheral gas F**54** becomes significantly smaller than the temperature of the combustion gas F**51**. With this, in the vicinity of the inlet of the reforming reaction flow path **402**, the temperature difference between the catalyst layer outer peripheral gas F**54** and the raw material F**52** and the reformed gas F**53** decreases, with the result that the heat transfer property is degraded.

[0121] In contrast, the temperature of the combustion gas F**51** does not decrease as in the temperature of the catalyst layer outer peripheral gas F**54**, even when the position in the center axis **100***a* direction approaches the inlet of the reforming reaction flow path **402**. With this, the temperature difference between the combustion gas F**51** and the raw material F**52** and the reformed gas F**53** is larger than the temperature difference between the catalyst layer outer peripheral gas F**54** and the raw material F**52** and the reformed gas F**53**. Thus, particularly in the vicinity of the inlet of the reforming reaction flow path **402**, the temperature of the reforming reaction flow path **402** is non-uniform in the radial direction of the fuel processing device **100**.

[0122] In this embodiment, the combustion gas F**51** first flows through the upstream portion **401***a* of the combustion gas flow path **401**. The flow of the combustion gas F**51** at the upstream portion **401***a* is opposite to the flows of the raw material F**52** and the reformed gas F**53**. The combustion gas F**51** at the upstream portion **401***a* gives thermal energy to the raw material F**52** and the reformed gas F**53** from the inner peripheral side. The section from the point D to the point E in FIG. **6** represents the temperature distribution of the combustion gas F**51** at the upstream portion **401***a*.
[0123] After that, the combustion gas F**51** is reversed at the communication portion **510** to flow around on the outer peripheral side with respect to the reforming reaction flow path **402** and flow into the downstream portion **401***b* of the combustion gas flow path **401**. The flow of the combustion gas F**51** at the downstream portion **401***b* is parallel to the flows of the raw material F**52** and the reformed gas F**53**. The combustion gas F**51** at the downstream portion **401***b* gives thermal energy to the raw material F**52** and the reformed gas F**53** from the outer peripheral side. The section from the point E to the point F in FIG. **6** represents the temperature distribution of the combustion gas F**51** at the downstream portion **401***b*.
[0124] That is, heat is given to the downstream-side portion of the reforming reaction flow path **402** in the flows of the raw material F**52** and the reformed gas F**53** by the combustion gas F**51** from the inner peripheral side, and heat is given thereto by the catalyst layer outer peripheral gas F**54** from the outer peripheral side. Heat is given to the upstream-side portion of the reforming reaction flow path **402** by the combustion gas F**51** flowing through the upstream portion **401***a* from the inner peripheral side, and heat is given thereto by the combustion gas F**51** flowing through the downstream portion **401***b* from the outer peripheral side.
[0125] As illustrated in FIG. **6**, in this embodiment, also on the outer peripheral side in the vicinity of the inlet of the reforming reaction flow path **402**, the temperature difference between the combustion gas F**51** at the downstream portion **401***b* and the raw material F**52** and the reformed gas F**53** can be secured. Thus, the heat transfer property of the fuel processing device **100** can be improved. Thus, also when the distribution ratio of the catalyst layer outer peripheral gas F**54** is small in thermal energy, the thermal efficiency of the fuel processing device **100** can be improved.
[0126] Further, in this embodiment, the temperature of the reforming reaction flow path **402** can be made uniform in the radial direction of the fuel processing device **100**. Thus, also when the distribution ratio of the catalyst layer outer peripheral gas F**54** is small in thermal energy, the reformed gas F**53** with a small composition variation due to a reaction can be obtained. Moreover,
[0127] Further, in this embodiment, the temperature of the combustion gas F**51** at the merging portion **200** and the temperature of the catalyst layer outer peripheral gas F**54** at the merging portion **200** can be brought closer to each other. Thus, the loss of the thermal energy can be reduced. Accordingly, even when the distribution ratio of the catalyst layer outer peripheral gas F**54** is small in thermal energy, the thermal efficiency of the fuel processing device **100** can be improved.
[0128] Further, in this embodiment, the combustion reaction can be performed in a range of an appropriate oxygen ratio, thereby being capable of attaining stable complete combustion. Further, the heat transfer property is improved, thereby being capable of attaining a reduction in size of the fuel processing device **100**.
[0129] As described above, in the fuel processing device **100** according to this embodiment, the combustion gas flow path **401** includes the upstream portion **401***a* and the downstream portion **401***b*. The upstream portion **401***a* is formed on the inner peripheral side with respect to the inner wall **501**. The downstream portion **401***b* is formed on the outer peripheral side with respect to the middle wall **502**. The merging portion **200** is located on the outer peripheral side with respect to the middle wall **502**. The upstream portion **401***a* of the combustion gas flow path **401** and the downstream portion **401***b* of the combustion gas flow path **401** face each other across the reforming reaction flow path **402**. According to this configuration, even when the distribution ratio of the

catalyst layer outer peripheral gas F**54** is small in thermal energy, the reformed gas F**53** with a small composition variation due to a reaction can be obtained, and the thermal efficiency of the fuel processing device **100** can be improved.

Fourth Embodiment

[0130] A fuel processing device according to a fourth embodiment is described. FIG. **7** is a schematic cross-sectional view of the fuel processing device according to this embodiment. The up-and-down direction of FIG. **7** represents a vertical direction.

[0131] As illustrated in FIG. **7**, the first raw material preheating unit **203** penetrates the upper surface wall **506** and the closing wall **505**, and passes through the communication portion **510** to be connected to the second raw material preheating unit **203***a*. The first raw material preheating unit **203** is bent in a helical shape about the center axis **100***a* in the communication portion **510**. The first raw material preheating unit **203** is formed of a circular pipe. The first raw material preheating unit **203** is configured to absorb a change in distance between the upper surface wall **506** and the closing wall **505** when the helical portion extends and contracts in the center axis **100***a* direction. The other configurations are similar to those of the second embodiment.

[0132] The operation of the fuel processing device according to this embodiment is described. The raw material F**52** passes through the first raw material preheating unit **203** and the second raw material preheating unit **203***a* before being introduced into the reforming reaction flow path **402**. In the first raw material preheating unit **203**, the raw material F**52** receives thermal energy from the catalyst layer outer peripheral gas F**54** flowing through the communication portion **510**. With this, the raw material F**52** is preheated. In the second raw material preheating unit **203***a*, the raw material F**52** receives thermal energy from the catalyst layer outer peripheral gas F**54** flowing through the upstream portion **403***a* of the catalyst layer outer peripheral flow path **403**, and receives thermal energy from the catalyst layer outer peripheral gas F**54** flowing through the downstream portion **403***b* of the catalyst layer outer peripheral flow path **403**. With this, the raw material F**52** is further preheated. The preheated raw material F**52** flows into the reforming reaction flow path **402**.

[0133] The fuel processing device **100** includes the combustor **1** at a lower portion on the center axis **100***a*. Thus, in the fuel processing device **100**, such a distribution temperature is formed that, in the up-and-down direction, the temperature is higher on the lower portion side, and in the radial direction, the temperature is higher on the inner peripheral side. In the reforming reaction flow path **402**, such a generally one-dimensional temperature distribution that the temperature is higher on the lower portion side is formed.

[0134] Meanwhile, a flammable gas flows through the reforming reaction flow path **402**, and hence the strength of the structure member for forming the reforming reaction flow path **402** is required to be secured. Thus, it is effective that thermal stress is prevented from being generated also under the high-temperature operation state in the inner wall **501** and the middle wall **502**. In this embodiment, the first raw material preheating unit **203** is formed in a helical shape so that thermal expansion of the inner wall **501** and the middle wall **502** can be absorbed by the first raw material preheating unit **203**.

[0135] According to this embodiment, the following effects are obtained in addition to the effects of the second embodiment. The first raw material preheating unit **203** is formed in a helical shape in the communication portion **510**, thereby being capable of increasing the heat transfer area of the first raw material preheating unit **203**. With this, the heat transfer performance can be improved as compared to a case in which the raw material F**52** is preheated only by the second raw material preheating unit **203***a*.

[0136] Further, the first raw material preheating unit **203** is formed in a helical shape so that thermal expansion of the inner wall **501** and the middle wall **502** can be absorbed by the first raw material preheating unit **203**. With this, the reliability of the structure member of the fuel processing device **100** can be improved.

[0137] Next, a modification example of this embodiment is described. FIG. **8** is a schematic cross-sectional view of a fuel processing device according to the modification example of this embodiment. As illustrated in FIG. **8**, the first raw material preheating unit **203** has a structure that is extendable and contractable in the center axis **100***a* direction at least between the upper surface wall **506** and the closing wall **505**. For example, a bellows tube having stretchability is used as the first raw material preheating unit **203** between the upper surface wall **506** and the closing wall **505**. The other configurations are similar to those of the second embodiment.

[0138] According to this modification example, the same effects as those of the configuration illustrated in FIG. **7** are obtained. Further, according to this modification example, the length of the first raw material preheating unit **203** in the center axis **100***a* direction can be made shorter than that of the configuration illustrated in FIG. **7**, thereby being capable of reducing the size of the fuel processing device **100**. The first raw material preheating unit **203** may meander along the circumferential direction of the fuel processing device **100** so as to secure a large heat transfer area between the first raw material preheating unit **203** and the catalyst layer outer peripheral gas F**54**.

[0139] As described above, in the fuel processing device **100** according to this embodiment, the first raw material preheating unit **203** has a structure that is extendable and contractable. According to this configuration, thermal expansion of the inner wall **501** and the middle wall **502** can be absorbed by the first raw material preheating unit **203**, thereby being capable of improving the reliability of the structure member of the fuel processing device **100**.

Fifth Embodiment

[0140] A fuel processing device according to a fifth embodiment is described. FIG. **9** is a schematic cross-sectional view of the fuel processing device according to this embodiment. The up-and-down direction of FIG. **9** represents a vertical direction.

[0141] As illustrated in FIG. **9**, the fuel processing device **100** includes a cathode gas preheating unit **204**. A cathode gas F**60** flows into the cathode gas preheating unit **204** from the outside of the fuel processing device **100**. In the cathode gas preheating unit **204**, the cathode gas F**60** is preheated by radiation heat from the combustion space **202** and heat transfer from the exhaust gas F**58**. The preheated cathode gas F**60** is supplied to the heating source outside the fuel processing device **100** as the preheated cathode gas F**61**. As the heating source, the high-temperature fuel cell (not shown) is used.

[0142] The cathode gas preheating unit **204** includes the exhaust gas flow path **404**, a preheating flow path **204***a*, and an exhaust flow path **204***b*. The exhaust gas flow path **404** is formed above the merging portion **200**. The exhaust gas flow path **404** is formed in an annular shape having the same diameter as that of the combustion gas flow path **401** in horizontal cross section. The exhaust gas flow path **404** extends in the up-and-down direction. The exhaust gas F**58** in which the combustion gas F**51** and the catalyst layer outer peripheral gas F**54** have merged with each other flows upward through the exhaust gas flow path **404**.

[0143] The preheating flow path **204***a* is arranged on the inner peripheral side with respect to the combustion gas flow path **401** and the exhaust gas flow path **404**. The preheating flow path **204***a* is formed in an annular shape in horizontal cross section. The preheating flow path **204***a* extends in the up-and-down direction. The preheating flow path **204***a* is arranged on a side opposite to the radiation heat transfer space **201** across the flame partition plate **3**, that is, is arranged above the flame partition plate **3**.

[0144] The preheating flow path **204***a* is adjacent to the combustion gas flow path **401** and the exhaust gas flow path **404** across the flame tube wall **503**. The cathode gas F**60** supplied from the outside of the fuel processing device **100** flows downward through the preheating flow path **204***a*. The flow of the cathode gas F**60** in the preheating flow path **204***a* is opposite to the flow of the combustion gas F**51** in the combustion gas flow path **401** and the flow of the exhaust gas F**58** in the exhaust gas flow path **404**. The cathode gas F**60** in the preheating flow path **204***a* is preheated through heat exchange between the exhaust gas F**58** in the exhaust gas flow path **404** and the combustion gas F**51** in the combustion gas flow path **401**.

[0145] The exhaust flow path **204***b* is arranged on the inner peripheral side with respect to the preheating flow path **204***a*. The exhaust flow path **204***b* extends in the up-and-down direction. A lower end portion of the exhaust flow path **204***b* is connected to a lower end portion of the preheating flow path **204***a*. The preheated cathode gas F**61** preheated in the preheating flow path **204***a* flows upward through the exhaust flow path **204***b*. The preheated cathode gas F**61** having flowed out from the exhaust flow path **204***b* is supplied to the heating source outside the fuel processing device **100**.
[0146] The first raw material preheating unit **203** has a structure that is extendable and contractable in the center axis **100***a* direction between the upper surface wall **506** and the closing wall **505**. The other configurations are similar to those of the first embodiment.
[0147] Next, the operation of the fuel processing device according to this embodiment is described. The raw material F**52** passes through the first raw material preheating unit **203** and the second raw material preheating unit **203***a* to be introduced into the reforming reaction flow path **402**. The raw material F**52** of the reforming reaction flow path **402** is heated from the inner peripheral side by the combustion gas F**51** in the combustion gas flow path **401**. Further, the raw material F**52** of the reforming reaction flow path **402** is heated also from the outer peripheral side by the catalyst layer outer peripheral gas F**54** in the catalyst layer outer peripheral flow path **403**. In the reforming reaction flow path **402**, the reformed gas F**53** is generated from the raw material F**52** due to a catalytic action of the reforming catalyst **5**.
[0148] Meanwhile, in the combustor **1**, due to a combustion reaction between the combustion supporting gas F**56** and the combustion fuel F**55** or the combustion raw material F**59**, the combustion gas F**51** of about 700° C. to 1, 200° C. is generated. In the radiation heat transfer space **201**, heat transfer is promoted by radiation heat from flame of the combustor **1**, convection heat transfer by the combustion gas F**51**, or the like to heat the flame partition plate **3**.
[0149] The combustion gas F**51** flows into the combustion gas flow path **401**. The combustion gas F**51** in the combustion gas flow path **401** merges with the catalyst layer outer peripheral gas F**54** at the merging portion **200** to turn into the exhaust gas F**58**. The exhaust gas F**58** flows through the exhaust gas flow path **404**.
[0150] The cathode gas F**60** is supplied to the cathode gas preheating unit **204** from the outside of the fuel processing device **100**. The cathode gas F**60** flows into the preheating flow path **204***a*. The cathode gas F**60** in the preheating flow path **204***a* is preheated through heat exchange between the exhaust gas F**58** in the exhaust gas flow path **404** and the combustion gas F**51** in the combustion gas flow path **401**. The cathode gas F**60** receives thermal energy from the flame partition plate **3** to be further preheated and increased in temperature to about 550° C. With this, the cathode gas F**60** turns into the preheated cathode gas F**61**. The preheated cathode gas F**61** passes through the exhaust flow path **204***b* to flow out from the fuel processing device **100**, and is supplied to the heating source.
[0151] Heat is given to the cathode gas F**60** from the exhaust gas F**58** so that the temperature of the exhaust gas F**58** decreases to, for example, about 65° C. The exhaust gas F**58** decreased in temperature is exhausted to the outside of the fuel processing device **100**.
[0152] In this embodiment, the thermal energy of the exhaust gas F**58** is collected in the cathode gas preheating unit **204** so that an operation with thermal efficiency higher than that of the fuel processing device **100** of each of the first embodiment to the fourth embodiment can be enabled.
[0153] The thermal energy collected in the cathode gas preheating unit **204** is used for preheating the cathode gas F**60**. The preheated cathode gas F**60** is supplied to the fuel cell or the like. The exhaust gas of the fuel cell is used as the oxidizing agent F**50**. With this, heat can be effectively utilized in the fuel cell system. Further, the fuel processing device **100** has a temperature increase function of the cathode gas, thereby being capable of attaining a reduction in size and higher efficiency of the fuel cell system.
[0154] In this embodiment, the cathode gas F**60** is preheated through heat exchange between the

combustion gas F**51** in the combustion gas flow path **401** and the exhaust gas F**58** in the exhaust gas flow path **404**, but the configuration is not limited thereto. The cathode gas F**60** may be preheated only through heat exchange with the exhaust gas F**58** in the exhaust gas flow path **404**. In this case, a heat insulating material or the like may be provided so as to block heat transfer from the combustion gas flow path **401** to the cathode gas preheating unit **204**.

[0155] Further, in this embodiment, the heat shield material **6** is not provided, but a heat shield material having an appropriate thickness may be provided in accordance with a temperature required for the preheated cathode gas F**61**.

[0156] As described above, the fuel processing device **100** according to this embodiment further includes the cathode gas preheating unit **204**. The cathode gas preheating unit **204** is configured to preheat the cathode gas F**60** to be supplied to the fuel cell through heat transfer from the exhaust gas F**58**. According to this configuration, heat can be effectively utilized in the fuel cell system.

[0157] In the fuel processing device **100** according to this embodiment, the cathode gas preheating unit **204** is further configured to preheat the cathode gas F**60** by radiation heat from the combustion space **202**.

Sixth Embodiment

[0158] A fuel processing device according to a sixth embodiment is described. FIG. **10** is a schematic cross-sectional view of the fuel processing device according to this embodiment. The up-and-down direction of FIG. **10** represents a vertical direction.

[0159] As illustrated in FIG. **10**, the cathode gas preheating unit **204** includes a main body portion **204***c* and a box body heat exchange unit **205**. The main body portion **204***c* has the same configuration as that of the cathode gas preheating unit **204** in the fifth embodiment.

[0160] The box body heat exchange unit **205** is formed in a box body shape. The reforming unit **110**, the combustion unit **120**, and the main body portion **204***c* of the cathode gas preheating unit **204** are accommodated in the internal space of the box body heat exchange unit **205**. That is, the reforming unit **110**, the combustion unit **120**, and the main body portion **204***c* of the cathode gas preheating unit **204** are surrounded by the box body heat exchange unit **205**.

[0161] The box body heat exchange unit **205** includes a preheating flow path **205***a* and an exhaust gas flow path **205***b*. The exhaust gas flow path **205***b* is provided on the internal space side of the box body heat exchange unit **205** with respect to the preheating flow path **205***a*.

[0162] The preheating flow path **205***a* is connected to the upstream side of the preheating flow path **204***a*. The cathode gas F**60** before flowing into the preheating flow path **204***a* flows through the preheating flow path **205***a*. The exhaust gas flow path **205***b* is connected to the downstream side of the exhaust gas flow path **404**. The exhaust gas F**58** having flowed out from the exhaust gas flow path **404** flows through the exhaust gas flow path **205***b*. In the box body heat exchange unit **205**, heat exchange between the cathode gas F**60** in the preheating flow path **205***a* and the exhaust gas F**58** in the exhaust gas flow path **205***b* is performed.

[0163] In the internal space of the box body heat exchange unit **205**, a fuel cell **10** is arranged. That is, the fuel cell **10** is surrounded by the box body heat exchange unit **205**. The fuel cell **10** includes an anode **11** and a cathode **12**. The anode **11** and the cathode **12** are partitioned from each other by an electrolyte.

[0164] The inlet of the anode **11** is connected to the reforming reaction flow path **402**. The outlet of the anode **11** is connected to the combustor **1**. The inlet of the cathode **12** is connected to the exhaust flow path **204***b* of the cathode gas preheating unit **204**. The outlet of the cathode **12** is connected to the oxidizing agent flow path **600**.

[0165] Although not illustrated, a heat insulating material that suppresses a heat interference between devices and heat radiation is arranged inside and outside the box body heat exchange unit **205** as required.

[0166] Next, the operation of the fuel processing device according to this embodiment is described. The exhaust gas F**58** having flowed out from the exhaust gas flow path **404** flows into the exhaust gas flow path **205***b* of the box body heat exchange unit **205**. The exhaust gas F**58** in the exhaust gas flow path **205***b* gives thermal energy to the cathode gas F**60** in the preheating flow path **205***a*. With this, the temperature of the exhaust gas F**58** decreases. The exhaust gas F**58** having flowed through the exhaust gas flow path **205***b* is exhausted to the outside from the box body heat exchange unit **205**.

[0167] Meanwhile, the cathode gas F**60** flows into the preheating flow path **205***a* of the box body heat exchange unit **205** from the outside. The cathode gas F**60** in the preheating flow path **205***a* receives thermal energy from the exhaust gas F**58** of the exhaust gas flow path **205***b*. The cathode gas F**60** having flowed out from the preheating flow path **205***a* of the box body heat exchange unit **205** flows into the preheating flow path **204***a* of the main body portion **204***c*.

[0168] The cathode gas F**60** in the preheating flow path **204***a* receives thermal energy from the exhaust gas F**58** and the combustion gas F**51** and the flame partition plate **3** to turn into the preheated cathode gas F**61**. The preheated cathode gas F**61** passes through the exhaust flow path **204***b* to flow out from the main body portion **204***c*, and is supplied to the cathode **12** of the fuel cell **10**.

[0169] In the cathode **12**, oxygen required for a battery reaction of the fuel cell **10** is consumed. With this, the preheated cathode gas F**61** turns into a cathode off-gas. The cathode off-gas flows out from the cathode **12**, and flows into the oxidizing agent flow path **600** as the oxidizing agent F**50**.

[0170] The reformed gas F**53** having flowed out from the reforming reaction flow path **402** is supplied to the anode **11** of the fuel cell **10**. In the anode **11**, hydrogen required for a battery reaction of the fuel cell **10** is consumed. With this, the reformed gas F**53** turns into an anode off-gas. The anode off-gas flows out from the anode **11**. At least a part of the anode off-gas having flowed out from the anode **11** is supplied to the combustor **1** as the combustion fuel F**55**.

[0171] In this embodiment, heat exchange between the cathode gas F**60** and the exhaust gas F**58** is performed in the box body heat exchange unit **205**. Although the temperature difference between the cathode gas F**60** and the exhaust gas F**58** is relatively small, the heat transfer area between the cathode gas F**60** and the exhaust gas F**58** can be largely secured, thereby being capable of effectively performing heat recovery.

[0172] Further, the fuel cell **10**, the reforming unit **110** of the fuel processing device **100**, the combustion unit **120**, and the main body portion **204***c* are surrounded by the box body heat exchange unit **205**. With this, heat radiation from the fuel cell **10** and the fuel processing device **100** can be suppressed.

[0173] Further, the heat transfer area between the cathode gas F**60** and the exhaust gas F**58** can be largely secured in the box body heat exchange unit **205**, thereby being capable of reducing the size of the main body portion **204***c* of the cathode gas preheating unit **204**. Thus, according to this embodiment, higher efficiency and a reduction in size of the fuel processing device for a fuel cell can be attained.

[0174] The configuration of the fuel cell system is not limited to the configuration illustrated in FIG. **10**. For example, a part of the anode off-gas may be used as the combustion fuel F**55**, and the remaining anode off-gas may be recycled as a part of the raw material F**52**. In this case, the flow path of the anode off-gas is configured to condense a part of the contained water vapor of the anode off-gas, and then, branch the anode off-gas. Further, the thermal energy of the anode off-gas may be collected, for example, to use for vaporization heat for generating water vapor.

[0175] As described above, in the fuel processing device **100** according to this embodiment, the cathode gas preheating unit **204** includes the box body heat exchange unit **205**. The box body heat exchange unit **205** surrounds the combustion unit **120** and the reforming unit **110**, and the fuel cell **10**. In the box body heat exchange unit **205**, heat exchange between the exhaust gas F**58** and the cathode gas F**60** is performed. According to this configuration, the heat transfer area between the cathode gas F**60** and the exhaust gas F**58** can be largely secured, thereby being capable of effectively performing heat recovery. Further, heat radiation from the fuel cell **10** and the fuel

processing device **100** can be suppressed.
[0176] In the above-mentioned embodiments, the flow paths, such as the catalyst layer outer peripheral flow path **403**, the combustion gas flow path **401**, the exhaust gas flow path **404**, the preheating flow path **205***a*, the exhaust gas flow path **205***b*, and the preheating flow path **204***a*, are described as being like spaces, but those flow paths may be replaced with heat transfer promoting structures, such as a fin structure and particle filling. With this, the heat transfer performance can be further improved, thereby being capable of attaining higher efficiency and a reduction in size of the fuel processing device **100**. Further, at least a part of the second raw material preheating unit **203***a* located on the upstream side of the reforming reaction flow path **402** may be formed as a heat transfer promoting structure. With this, heat transfer performance to the raw material F**52** is improved, thereby being capable of attaining the fuel processing device **100** which has high efficiency and is small in size.
[0177] Further, in the above-mentioned embodiments, although not particularly described, it is desired to provide a unit for reducing a dynamic pressure of a flow, for example, a baffle plate, to the second raw material preheating unit **203***a* into which the raw material F**52** flows from the first raw material preheating unit **203** in order to attain uniform gas distribution in the circumferential direction in the second raw material preheating unit **203***a*. Further, this description is not limited only to the second raw material preheating unit **203***a*, and, for example, also applies to a portion at which the catalyst layer outer peripheral gas F**54** flows into the catalyst layer outer peripheral flow path **403**.
[0178] The above-mentioned embodiments and modification example can be implemented in combination.
REFERENCE SIGNS LIST
[0179] **1** combustor, **2** oxidizing agent branching portion, **3** flame partition plate, **4** heat shield wall, **5** reforming catalyst, **6** heat shield material, **8** controller, **9** reformed gas temperature sensor, **10** fuel cell, **11** anode, **12** cathode, **100** fuel processing device, **100***a* center axis, **110** reforming unit, **120** combustion unit, **200** merging portion, **201** radiation heat transfer space, **202** combustion space, **203** first raw material preheating unit, **203***a* second raw material preheating unit, **204** cathode gas preheating unit, **204***a* preheating flow path, **204***b* exhaust flow path, **204***c* main body portion, **205** box body heat exchange unit, **205***a* preheating flow path, **205***b* exhaust gas flow path, **300** oxidizing agent inflow pipe, **301** catalyst layer outer peripheral gas introducing pipe, **302** combustion supporting gas conduit, **303** oxidizing agent distribution regulator, **401** combustion gas flow path, **401***a* upstream portion, **401***b* downstream portion, **402** reforming reaction flow path, **403** catalyst layer outer peripheral flow path, **403***a* upstream portion, **403***b* downstream portion, **404** exhaust gas flow path, **405** air flow path, **406** flow rate adjustment valve, **501** inner wall, **502** middle wall, **503** flame tube wall, **504** outer wall, **505** closing wall, **506** upper surface wall, **507** closing wall, **510** communication portion, **600** oxidizing agent flow path, **601** catalyst layer outer peripheral gas introducing flow path, **602** combustion supporting gas flow path, F**50** oxidizing agent, F**51** combustion gas, F**52** raw material, F**53** reformed gas, F**54** catalyst layer outer peripheral gas, F**55** combustion fuel, F**56** combustion supporting gas, F**57** air, F**58** exhaust gas, F**59** combustion raw material, F**60** cathode gas, F**61** preheated cathode gas.

Claims

1. A fuel processing device, comprising: a reforming unit configured to generate a reformed gas from a raw material; and a combustion unit configured to combust a fuel and a combustion supporting gas in a combustion space to generate a combustion gas, wherein the reforming unit includes: a first tubular wall; and a second tubular wall arranged on an outer peripheral side with respect to the first tubular wall, wherein a reforming reaction flow path is formed between the first tubular wall and the second tubular wall, the reforming reaction flow path being configured to be filled with a reforming catalyst and to allow the raw material and the reformed gas to flow through the reforming reaction flow path, wherein a combustion gas flow path configured to allow the combustion gas to flow through the combustion gas flow path is formed on an inner peripheral side with respect to the first tubular wall, wherein the combustion gas flow path is adjacent to the reforming reaction flow path across the first tubular wall, wherein an outer peripheral flow path configured to allow an outer peripheral gas to flow through the outer peripheral flow path is formed on an outer peripheral side with respect to the second tubular wall, wherein the outer peripheral flow path is adjacent to the reforming reaction flow path across the second tubular wall, and wherein the fuel processing device further comprises: a merging portion configured to allow the combustion gas having flowed through the combustion gas flow path and the outer peripheral gas having flowed through the outer peripheral flow path to merge with each other; an exhaust gas flow path configured to allow the combustion gas and the outer peripheral gas that have merged at the merging portion to flow through the exhaust gas flow path as an exhaust gas; an oxidizing agent flow path configured to allow an oxidizing agent supplied from a heating source to pass through the oxidizing agent flow path; an oxidizing agent branching portion provided in the oxidizing agent flow path; a combustion supporting gas flow path that connects between the oxidizing agent branching portion and the combustion unit and is configured to allow a part of the oxidizing agent to flow through the combustion supporting gas flow path as the combustion supporting gas; and an outer peripheral gas introducing flow path that connects between the oxidizing agent branching portion and the outer peripheral flow path and is configured to allow the other part of the oxidizing agent to flow through the outer peripheral gas introducing flow path as the outer peripheral gas.

2. The fuel processing device according to claim 1, wherein an oxidizing agent distribution regulator configured to determine a distribution ratio between the combustion supporting gas and the outer peripheral gas is provided in at least one of the combustion supporting gas flow path or the outer peripheral gas introducing flow path.

3. The fuel processing device according to claim 1, wherein the outer peripheral flow path includes: an upstream portion formed on an outer peripheral side with respect to the second tubular wall; and a downstream portion formed on an inner peripheral side with respect to the first tubular wall, wherein the merging portion is located on an inner peripheral side with respect to the first tubular wall, and wherein the upstream portion of the outer peripheral flow path and the downstream portion of the outer peripheral flow path face each other across the reforming reaction flow path.

4. The fuel processing device according to claim 1, wherein the combustion gas flow path includes: an upstream portion formed on an inner peripheral side with respect to the first tubular wall; and a downstream portion formed on an outer peripheral side with respect to the second tubular wall, wherein the merging portion is located on an outer peripheral side with respect to the second tubular wall, and wherein the upstream portion of the combustion gas flow path and the downstream portion of the combustion gas flow path face each other across the reforming reaction flow path.

5. The fuel processing device according to claim 1, further comprising: a flame tube wall arranged on an inner peripheral side with respect to the first tubular wall; a flame partition plate arranged inside the flame tube wall so as to be opposed to the combustion unit; and a radiation heat transfer space surrounded by the flame tube wall, the flame partition plate, and the combustion unit.

6. The fuel processing device according to claim 1, further comprising a raw material preheating unit configured to preheat the raw material flowing into the reforming reaction flow path by heat transfer from the outer peripheral gas or the combustion gas.

7. The fuel processing device according to claim 6, wherein the raw material preheating unit has a structure that is extendable and contractable.

8. The fuel processing device according to claim 1, wherein the heating source is a fuel cell, and wherein the oxidizing agent is a cathode off-gas supplied from the fuel cell.

9. The fuel processing device according to claim 8, further comprising a cathode gas preheating unit configured to preheat a cathode gas supplied to the fuel cell through heat transfer from the exhaust gas.

10. The fuel processing device according to claim 9, wherein the cathode gas preheating unit is further configured to preheat the cathode gas by radiation heat from the combustion space.

11. The fuel processing device according to claim 9, wherein the cathode gas preheating unit includes a box body heat exchange unit surrounding the combustion unit and the reforming unit, and the fuel cell, and wherein the box body heat exchange unit is configured to allow heat exchange between the exhaust gas and the cathode gas to be performed in the box body heat exchange unit.

12. The fuel processing device according to claim 1, further comprising an air flow path configured to supply air for temperature adjustment to the combustion gas on a downstream side with respect to the combustion space.

13. The fuel processing device according to claim 12, further comprising: a reformed gas temperature sensor configured to detect a temperature of the reformed gas at an outlet of the reforming reaction flow path; and a controller, wherein the controller is configured to control a flow rate of the air supplied to the combustion gas based on the temperature detected by the reformed gas temperature sensor.