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FUEL REFORMING SYSTEM

Abstract

A fuel reforming system for a vehicle on which a reciprocating engine is mounted is provided can comprise a decomposer to decompose hydrocarbon fuel into carbon and hydrogen gas by using heat and a pressure of combustion gas and a catalyst and to hold carbon. The decomposer can communicate with a combustion chamber via an openable/closable third port. A reforming space in which a reforming member including the catalyst is installed can be on the side of a connection portion of the decomposer with the third port. On an opposite side of interior of the connection portion of the decomposer with the third port, an additional space is provided to accommodate residual gas that remains in the third port and the decomposer when combustion gas is introduced into the decomposer through the third port.

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Background/Summary

CROSS-REFERENCE TO RELATED APPLICATION
[0001] This application claims priority to Japanese Patent Application No. 2024-021479 filed on Feb. 15, 2024, the entire disclosure of which is incorporated by reference herein.
TECHNICAL FIELD
[0002] The disclosed technique relates to a fuel reforming system for a vehicle on which a reciprocating engine is mounted.
BACKGROUND ART
[0003] A device (decomposition device) for directly decomposing a hydrocarbon into carbon and hydrogen is described in Patent Literature 1. This decomposition device includes a reactor in which a catalyst is accommodated. When raw material gas containing hydrocarbons is supplied to the reactor, carbon produced by the reaction of the catalyst adheres to the catalyst. Reaction gas containing hydrogen flows through the reactor.
CITATION LIST
Patent Literature
[0004] [Patent Literature 1] JP2022-104521A
SUMMARY
[0005] According to one or more aspects, a fuel reforming system for a vehicle, on which a reciprocating engine is mounted, and in the reciprocating engine, a combustion chamber where combustion occurs is partitioned in a cylinder in which a piston reciprocates, can be provided or implemented.
[0006] The fuel reforming system can include: a decomposer that decomposes hydrocarbon fuel into carbon and hydrogen gas by using heat and a pressure of combustion gas produced in the combustion chamber and a catalyst and holds the carbon; and a hydrocarbon fuel supply section that supplies the hydrocarbon fuel to the decomposer.
[0007] The decomposer can communicate with the combustion chamber via an openable/closable port. A reforming space in which a reforming member including the catalyst is installed can be provided on a side of a connection portion of the decomposer with the port. On an opposite side of interior of the connection portion of the decomposer with the port, an additional space can be provided adjacent to the reforming space, in the additional space, residual gas that remains in the port and the decomposer being accommodated when the combustion gas is introduced into the decomposer through the port.

Description

BRIEF DESCRIPTION OF DRAWINGS
[0008] FIG. **1** is a schematic view of a fuel reforming system according to one or more embodiments of the present disclosure.
[0009] FIG. **2** is a block diagram of a control system according to one or more embodiments of the present disclosure.
[0010] FIG. **3** is a view illustrating a six-stroke cycle according to one or more embodiments of the present disclosure.
[0011] FIG. **4** illustrates examples of operation of each valve, injection timing of fuel to be

reformed, and a change in an internal pressure of a decomposer, according to one or more embodiments of the present disclosure.
[0012] FIG. **5** is an example of a control map according to one or more embodiments of the present disclosure.
[0013] FIG. **6** is a schematic view illustrating a structure of a decomposer according to one or more embodiments of the present disclosure.
[0014] FIG. **7** is a schematic view illustrating a function of the decomposer according to one or more embodiments of the present disclosure.
[0015] FIG. **8**A is a view illustrating a structural problem of the decomposer (a comparative example).
[0016] FIG. **8**B is a view illustrating the structural problem of the decomposer (an example).
[0017] FIG. **9** is a schematic view illustrating a second fuel reforming system according to one or more embodiments of the present disclosure.
[0018] FIG. **10** is a schematic view illustrating a third fuel reforming system according to one or more embodiments of the present disclosure.
[0019] FIG. **11**A is a flowchart of control by the third fuel reforming system according to one or more embodiments of the present disclosure.
[0020] FIG. **11**B is a flowchart of control by the third fuel reforming system according to one or more embodiments of the present disclosure.
DETAILED DESCRIPTION OF EMBODIMENTS
[0021] In the technical field of vehicles (for example, four-wheeled vehicles), there is a demand for an approach to being carbon neutral. In order to make a vehicle, on which an engine using hydrocarbon (HC) fuel (including gasoline and/or light oil), carbon neutral, there may be a need or desire for a technique of collecting carbon (C) or carbon dioxide (CO2) from the hydrocarbon fuel, in addition to improvement in thermal efficiency of the engine and/or improvement in exhaust emission performance.
[0022] In the vehicle, on which the engine using the hydrocarbon fuel is mounted, in order to collect carbon or carbon dioxide, it may be considered to:
(1) collect carbon dioxide after combustion of the hydrocarbon fuel; or
(2) decompose the hydrocarbon fuel into carbon and hydrogen gas before combustion of the hydrocarbon fuel and collect carbon.
[0023] In consideration that collected carbon dioxide or carbon is stored in the vehicle, (2) may be viewed in terms of fuel economy performance of the vehicle due to a reason that carbon dioxide is heavier than carbon. In addition, in the case of (2), it may also be possible to use the hydrogen gas as the fuel for the engine. It is also noted that when the hydrogen gas is combusted, no carbon oxide may be produced due to the combustion.
[0024] Thus, it may be considered to mount the above-described decomposition device onto the vehicle. The decomposition device can include a heater for raising a temperature of the catalyst. Thus, when the decomposition device is mounted on the vehicle, heat of the combustion gas in the engine can be used to raise the temperature of the catalyst and raise a temperature of the hydrocarbon fuel.
[0025] However, in order to efficiently produce the hydrogen gas in the decomposition device, a reforming reaction can be promoted by bringing the heated hydrocarbon fuel into contact with the heated catalyst. Thus, it may be necessary or desirable to distribute the hydrocarbon fuel throughout the catalyst.
[0026] Meanwhile, when the decomposition device decomposes the hydrocarbon fuel into the hydrogen gas and carbon to take out the hydrogen gas from the decomposition device, gas containing impure gas such as nitrogen (residual gas) may remain in the decomposition device. This residual gas may prevent contact between the hydrocarbon fuel and the catalyst. Thus, the residual gas can disturb the reforming reaction.

[0027] The same can apply to carbon. When an amount of carbon inside the decomposition device is increased, carbon may disturb the reforming reaction. Thus, when the amount of carbon is increased, carbon may have to be removed from the decomposition device.
[0028] The technique disclosed herein can provide a fuel reforming system capable of efficiently producing hydrogen gas and suitable for mounting on a vehicle.
[0029] That is, in this fuel reforming system, the hydrocarbon fuel can be decomposed into carbon and the hydrogen gas by using a function of the reciprocating engine and using the heat and the pressure of the combustion gas produced in the combustion chamber and the catalyst. Thus, this fuel reforming system can facilitate the production of the hydrogen gas. This fuel reforming system can be suitable for mounting on the vehicle.
[0030] The produced hydrogen gas can be used as fuel for the reciprocating engine. Produced carbon can be held by the decomposer. Thus, the vehicle can become carbon neutral.
[0031] In the decomposer according to one or more embodiments of the present disclosure, the reforming space in which the reforming member including the catalyst is installed can be provided on an introduction side of the combustion gas. That is, a reforming reaction for producing the hydrogen gas can take place in the reforming space. In the interior of the decomposer on the opposite side, the additional space can be provided adjacent to the reforming space to accommodate the residual gas, which can remain in the port and the decomposer, when the combustion gas is introduced into the decomposer.
[0032] When the combustion gas is introduced into the decomposer through the port, the residual gas remaining therein can be pushed into the back of the decomposer. A mass of the residual gas can be formed in the back of the decomposer. The residual gas can have a lower temperature than the combustion gas and may not or does not contain the hydrocarbon fuel. Meanwhile, the residual gas can contain a relatively large amount of inert gas. That is, the reforming reaction may not occur in the portion where the mass of the residual gas is present.
[0033] Meanwhile, in this fuel reforming system, the mass of the residual gas can be accommodated in the additional space. As a result, the high-temperature, high-pressure combustion gas can be spread over the reforming space without excess or deficiency. The hydrogen gas can be efficiently produced without wasting the hydrocarbon fuel.
[0034] The fuel reforming system can further include a variable volume mechanism for varying a volume of the additional space. The volume of the additional space may be varied according to an operating state of the reciprocating engine.
[0035] In general, as the load of the reciprocating engine is increased, required combustion energy is increased. Thus, the pressure (temperature) of the combustion gas is increased as the load of the reciprocating engine is increased. Accordingly, a difference (differential pressure) between a pressure of the residual gas remaining in the port and the decomposer and the pressure of the combustion gas introduced from the combustion chamber into the decomposer can be relatively large when the load of the reciprocating engine is large, and can be relatively small when the load of the reciprocating engine is small.
[0036] When the differential pressure is relatively small, the mass of the residual gas can be increased. Meanwhile, when the differential pressure is relatively large, the residual gas can be further compressed. Thus, the mass of the residual gas can be reduced. Accordingly, when the load of the reciprocating engine is changed, an optimum volume of the additional space can also be changed.
[0037] Meanwhile, in this fuel reforming system according to one or more embodiments of the present disclosure, the volume of the additional space can be configured to be varied according to an operating state of the reciprocating engine. Thus, the volume of the additional space can be changed, and the volume of the additional space can be maintained in an optimum state.
[0038] The fuel reforming system may be configured such that the carbon can be held in a separable state in the decomposer and an openable/closable discharge passage can be connected to

the additional space and that the carbon separated from the decomposer can be discharged through the discharge passage.
[0039] Carbon produced in the reforming reaction can adhere to the catalyst. Thus, as the carbon deposition amount is increased, decomposition performance of the decomposer may deteriorate. At least for this reason, in order to maintain the decomposition performance of the decomposer, carbon may have to be removed from the decomposer when being deposited to some extent.
[0040] Meanwhile, in this fuel reforming system according to one or more embodiments of the present disclosure, the discharge passage can be connected to the additional space, and carbon separated from the decomposer can be configured to be discharged through the discharge passage. Thus, when necessary, carbon stored in the decomposer can be removed automatically. A yield of the hydrogen gas can be recovered, and decomposition capacity of the decomposer can be maintained.
[0041] In the fuel reforming system according to one or more embodiments of the present disclosure, the reciprocating engine may be configured to perform a six-stroke cycle including: an intake stroke in which at least intake air is introduced into the combustion chamber through an intake port by lowering the piston; a compression stroke in which air-fuel mixture containing the hydrogen gas supplied to the combustion chamber is compressed by raising the piston; an expansion stroke in which the piston is lowered by combustion of the air-fuel mixture; a recompression stroke in which the combustion gas is compressed by raising the piston; a re-expansion stroke in which the piston is lowered; and an exhaust stroke in which exhaust gas is discharged through an exhaust port by raising the piston. In the recompression stroke, the combustion gas may be introduced into the decomposer through the port, and the residual gas may be thereby pushed and accommodated in the additional space.
[0042] In the recompression stroke, the combustion gas in the combustion chamber can be pressurized by raising the piston. Since the gas can be introduced into the decomposer, an internal pressure of the decomposer can also be increased. Accordingly, the residual gas can be compressed, and a volume thereof can be reduced. Thus, an optimum volume of the additional space can be reduced. The decomposer can be compact in size, according to one or more embodiments of the present disclosure.
[0043] According to the disclosed technique, it can be possible to efficiently generate the hydrogen gas by using the functions of the reciprocating engine. Therefore, it can be possible to obtain the fuel reforming system suitable for mounting on the vehicle.
[0044] Hereinafter, the disclosed technique will be described. However, the following description is merely illustrative in nature.
(Configuration of Fuel Reforming System)
[0045] FIG. **1** illustrates a fuel reforming system **1** mounted on a vehicle. Hydrocarbon fuel is stored in a fuel tank that is mounted on the vehicle. The hydrocarbon fuel is gasoline, for example. The hydrocarbon fuel is not limited to gasoline. The fuel reforming system **1** decomposes the hydrocarbon fuel into carbon and hydrogen gas. Carbon is stored in a decomposer **6** described below. The hydrogen gas is used as fuel for a reciprocating engine **3**. The fuel reforming system **1** makes the vehicle, on which the hydrocarbon fuel is mounted, carbon neutral.
[0046] The fuel reforming system **1** includes the reciprocating engine **3** (hereinafter, also simply referred to as the engine **3**). The engine **3** includes a cylinder **31** and a piston **32** that reciprocates in the cylinder **31**. In an upper end portion of the cylinder **31**, a combustion chamber **3***a*, which is partitioned on a lower surface by the piston **32**, is formed. The engine **3** includes the plural cylinders **31**.
[0047] The plural cylinders **31** are arranged in a direction in which a crankshaft of the engine **3** extends, for example. The piston **32** in each of the cylinders **31** is connected to the crankshaft via a connecting rod. The connecting rod converts reciprocating motion of the piston **32** into rotation of the crankshaft. The crankshaft is connected to drive wheels via a transmission. The engine **3**

outputs a driving force for travel of the vehicle.

[0048] The engine **3** has an intake port **33**. The intake port **33** communicates with the upper portion of the cylinder **31**, that is, the combustion chamber **3***a*. Each of the cylinders **31** has the one or more intake ports **33**. Each of the cylinders **31** may have the two intake ports **33**, for example. The intake port **33** is connected to an intake pipe. As will be described below, intake air is introduced into each of the combustion chambers **3***a* through the respective intake port **33**. The intake air at least contains fresh air (outside air). The intake air may contain exhaust gas recirculation (EGR) gas.

[0049] The engine **3** includes an intake valve **34**. The intake valve **34** is a poppet valve that opens/closes the intake port **33**. When the intake valve **34** is opened, the intake air is introduced into the combustion chamber **3***a*. An intake valve train **41** illustrated in FIG. **2** opens/closes the intake valve **34**. The intake valve train **41** includes an intake camshaft that is mechanically connected to the intake valve **34**, for example.

[0050] The intake valve train **41** can continuously change valve timing of the intake valve **34** (so-called sequential-valve timing (S-VT)). The intake valve train **41** can also continuously change a valve lift of the intake valve **34** (so-called continuously variable valve lift (CVVL)). As the intake valve train **41**, a known hydraulic or electric mechanism can be employed. The intake valve train **41** changes the valve timing and/or the valve lift according to an operating state of the engine **3**.

[0051] The engine **3** has an exhaust port **35**. The exhaust port **35** communicates with the combustion chamber **3***a*. Each of the cylinders **31** has the one or more exhaust ports **35**. Each of the cylinders **31** may have the single exhaust port **35**, for example. The exhaust port **35** is connected to an exhaust pipe. As will be described below, exhaust gas is discharged from the combustion chamber **3***a* through the exhaust port **35**.

[0052] The engine **3** has an exhaust valve **36**. The exhaust valve **36** is a poppet valve that opens/closes the exhaust port **35**. When the exhaust valve **36** is opened, the exhaust gas is discharged to the outside of the cylinder **31**. An exhaust valve train **42** illustrated in FIG. **2** opens/closes the exhaust valve **36**. The exhaust valve train **42** has an exhaust camshaft that is mechanically connected to the exhaust valve **36**, for example.

[0053] The exhaust valve train **42** can continuously change valve timing of the exhaust valve **36** (so-called S-VT). The exhaust valve train **42** can also continuously change a valve lift of the exhaust valve **36** (so-called CVVL). As the exhaust valve train **42**, a known hydraulic or electric mechanism can be employed. The exhaust valve train **42** changes the valve timing and/or the valve lift according to the operating state of the engine **3**.

[0054] The engine **3** has a third port **37**. In this embodiment, the third port **37** corresponds to the “port” in the disclosed technique. The third port **37** communicates with the combustion chamber **3***a*. Each of the cylinders **31** has the at least one third port **37**. Each of the cylinders **31** may have the single third port **37**, for example.

[0055] The typical engine **3** has the two intake ports and the two exhaust ports for each of the cylinders **31**. The engine **3** in FIG. **1** has the two intake ports **33**, the single exhaust port **35**, and the single third port **37** per cylinder **31**. In order to facilitate understanding, in FIG. **1**, the exhaust port **35** and the third port **37** are illustrated in an offset manner.

[0056] The engine **3** has an on-off valve **38**. The on-off valve **38** is a poppet valve that opens/closes the third port **37**. A third valve train **43** illustrated in FIG. **2** opens/closes the on-off valve **38**. The third valve train **43** has a third camshaft that is mechanically connected to the on-off valve **38**, for example. The third valve train **43** opens the on-off valve **38** twice during one cycle.

[0057] The third valve train **43** can stop opening/closing of the on-off valve **38**. As a valve stopping mechanism for stopping opening/closing of the on-off valve **38**, a known hydraulic or electric mechanism can be employed. The valve stopping mechanism may be incorporated into a rocker arm that is interposed between the third camshaft and the on-off valve **38**, for example. Alternatively, the valve stopping mechanism may be incorporated into a lash adjuster that supports

the rocker arm. The on-off valve **38** may be mechanically connected to the intake camshaft or the exhaust camshaft.
[0058] An intake port injector **44** is attached to the engine **3**. An injection hole of the intake port injector **44** faces the inside of the intake port **33**. The intake port injector **44** injects the hydrocarbon fuel as fuel into the intake port **33**. A hydrocarbon fuel supply section **45** is connected to the intake port injector **44**. The hydrocarbon fuel supply section **45** includes a fuel tank for storing the hydrocarbon fuel and a fuel pump for pumping the hydrocarbon fuel.
[0059] A third port injector **46** is attached to the engine **3**. An injection hole of the third port injector **46** faces the inside of the third port **37**. The third port injector **46** injects the hydrocarbon fuel as fuel to be reformed into the third port **37**. The hydrocarbon fuel supply section **45** is also connected to the third port injector **46**.
[0060] Accordingly, the hydrocarbon fuel supply section **45** supplies the hydrocarbon fuel to the intake port injector **44** and the third port injector **46**.
[0061] A hydrogen injector **47** is attached to the engine **3**. An injection hole of the hydrogen injector **47** faces the combustion chamber **3***a*. The hydrogen injector **47** injects the hydrogen gas into the combustion chamber **3***a*.
[0062] An injector for injecting the hydrocarbon fuel may be attached to the engine **3** in a manner to face the combustion chamber **3***a*, and the hydrogen injector for injecting the hydrogen gas may be attached to the engine **3** in a manner to face the inside of the intake port **33**.
[0063] The decomposer **6** is connected to the third port **37**. The decomposer **6** communicates with the combustion chamber **3***a* via the third port **37**. The decomposer **6** decomposes the hydrocarbon fuel into carbon and the hydrogen gas. The decomposer **6** is attached to each of the cylinders **31**. The decomposer **6** may be shared by the plural cylinders **31**.
[0064] The decomposer **6** uses heat and a pressure of the combustion gas, which is produced in the combustion chamber **3***a*, and a catalyst to decompose the hydrocarbon fuel into carbon and the hydrogen gas. The decomposer **6** is a so-called membrane reactor that performs a reforming reaction. The decomposition of the hydrocarbon fuel such as isooctane is expressed by the following chemical reaction formula:

$$iC8H18(g)=8C(s)+9H2$$

[0065] Then, the produced hydrogen gas is taken out from the decomposer **6**. Produced carbon is held inside the decomposer **6**. Collection of carbon as a solid suppresses an increase in vehicle weight. The fuel reforming system **1** is suitable as an in-vehicle system. Details of the decomposer **6** will be described below.
[0066] The decomposer **6** is connected to a hydrogen gas supply section **5**. The hydrogen gas produced in the decomposer **6** is delivered to the hydrogen gas supply section **5**. The hydrogen gas supply section **5** includes: a gas tank that stores the hydrogen gas; an on-off valve that controls inflow and outflow of the hydrogen gas from the gas tank; and the like. The hydrogen gas supply section **5** is also connected to the hydrogen injector **47**.
[0067] The hydrogen gas supply section **5** supplies the hydrogen gas to the hydrogen injector **47**. This hydrogen gas is the hydrogen gas decomposed from the hydrocarbon fuel. That is, in this fuel reforming system **1**, the hydrogen gas obtained by removing carbon from the hydrocarbon fuel is reused as the fuel.
(Controller)
[0068] FIG. **2** is a block diagram of a control system **2** mounted on the vehicle. The fuel reforming system **1** cooperates with this control system **2**. The fuel reforming system **1** and the control system **2** share devices when necessary. The control system **2** includes a controller **21**. The controller **21** includes: hardware such as a processor, memory, and an interface; and software such as a database and a control program.
[0069] A rotational speed sensor **22** is electrically connected to the controller **21**. The rotational

speed sensor **22** is attached to the engine **3**. The rotational speed sensor **22** outputs a measurement signal corresponding to a rotational speed of the crankshaft to the controller **21**. The controller **21** obtains a speed of the engine **3** based on the measurement signal of the rotational speed sensor **22**.
[0070] An accelerator sensor **23** is electrically connected to the controller **21**. The accelerator sensor **23** is attached to an accelerator pedal. The accelerator sensor **23** outputs a signal corresponding to a depression amount of the accelerator pedal to the controller **21**. The controller **21** obtains a required load of the engine **3** based on the measurement signal from the accelerator sensor **23**.
[0071] A crank angle sensor **24** is electrically connected to the controller **21**. The crank angle sensor **24** is attached to the engine **3**. The crank angle sensor **24** outputs a signal corresponding to an angle of the crankshaft to the controller **21**. The controller **21** obtains a position of the piston **32** in each of the cylinders **31** based on the signal of the crank angle sensor **24**.
[0072] A hydrogen gas sensor **25** is attached to the decomposer **6**. The hydrogen gas sensor **25** measures an amount of the hydrogen gas produced in the decomposer **6**. The controller **21** outputs a control signal to the hydrogen gas sensor **25**. Based on the control signal from the controller **21**, the hydrogen gas sensor **25** outputs a signal corresponding to the amount of the hydrogen gas (concentration of the hydrogen gas) to the controller **21**. The controller **21** determines a degree of performance degradation of the decomposer **6** based on the signal from the hydrogen gas sensor **25**.
[0073] The intake valve train **41**, the exhaust valve train **42**, and the third valve train **43** are electrically connected to the controller **21**. The controller **21** outputs a control signal to each of the intake valve train **41**, the exhaust valve train **42**, and the third valve train **43** according to the operating state of the engine **3**. The intake valve train **41** changes the valve timing and/or the valve lift of the intake valve **34** based on the control signal from the controller **21**. The exhaust valve train **42** changes the valve timing and/or the valve lift of the exhaust valve **36** based on the control signal from the controller **21**. The third valve train **43** also switches between opening/closing and stopping of the on-off valve **38** based on the control signal from the controller **21**.
[0074] The above-described intake port injector **44**, third port injector **46**, and hydrogen injector **47** are each electrically connected to the controller **21**. The controller **21** outputs a control signal to each of the intake port injector **44**, the third port injector **46**, and the hydrogen injector **47**. The intake port injector **44** injects a predetermined amount of the hydrocarbon fuel into the intake port **33** at predetermined timing based on the control signal from the controller **21**. The third port injector **46** injects a predetermined amount of the hydrocarbon fuel into the third port **37** at predetermined timing based on the control signal from the controller **21**. The hydrogen injector **47** injects a predetermined amount of the hydrogen gas into the combustion chamber **3***a* at predetermined timing based on the control signal from the controller **21**.
[0075] The control system **2** has a spark plug **27**. The spark plug **27** is attached to the engine **3** in a manner to face the combustion chamber **3***a*. The spark plug **27** is electrically connected to the controller **21**. The controller **21** outputs a control signal to the spark plug **27**. The spark plug **27** ignites air-fuel mixture in the combustion chamber **3***a* at predetermined timing based on the control signal from the controller **21**.
[0076] The control system **2** may include an inverter **28**. In this case, the vehicle includes a drive motor (assist motor) that outputs the driving force for travel of the vehicle. The inverter **28** controls the drive motor thereof. The inverter **28** is electrically connected to the controller **21**. The controller **21** outputs a control signal to the inverter **28** when output of the engine **3** is insufficient. As a result, the drive motor is actuated to assist with the operation of the engine **3**.
[0077] The control system **2** may also include a slide device **70** (an example of a variable volume mechanism). In this case, the slide device **70** is electrically connected to the controller **21**. The controller **21** outputs a control signal to the slide device **70**. The slide device **70** moves a slider to be described below based on the control signal from the controller **21**.
[0078] The control system **2** may also include a carbon remover **80**. In this case, the carbon

remover **80** is electrically connected to the controller **21**. The controller **21** outputs a control signal to the carbon remover **80**. In this way, the carbon remover **80** is actuated or stopped. The inverter **28**, the slide device **70**, and the carbon remover **80** are related to another embodiment of the fuel reforming system **1** described below. Thus, these will be described separately below.

(Operation of Reciprocating Engine)

[0079] The engine **3** in this embodiment performs a six-stroke cycle in order for the decomposer **6** to decompose the hydrocarbon fuel. FIG. **3** illustrates each stroke thereof. FIG. **4** illustrates examples of the valve timing and the valve lift of each of the valves, the injection timing of the third port injector **46**, and a change in an internal pressure of the decomposer **6** in the six-stroke cycle.

[0080] S**1** is an intake stroke. In the intake stroke S**1**, the engine **3** introduces the intake air into the combustion chamber **3***a* by lowering the piston **32**. In the intake stroke S**1**, the intake valve **34** is opened. The intake air is introduced into the combustion chamber **3***a* through the intake port **33**. The intake air at least contains the fresh air.

[0081] The intake air may contain the EGR gas. The EGR gas is so-called external EGR gas that is recirculated into an intake pipe through an EGR passage. In the intake stroke S**1**, the exhaust valve **36** is opened. When the exhaust valve **36** is opened, the exhaust gas is introduced into the combustion chamber **3***a* through the exhaust port **35**. The exhaust gas that is introduced into the combustion chamber **3***a* is so-called internal EGR gas. The on-off valve **38** of the third port **37** is closed.

[0082] In FIG. **3**, the hydrogen injector **47** injects the hydrogen gas into the combustion chamber **3***a* during the intake stroke S**1**. The hydrogen injector **47** may inject the hydrogen gas in a compression stroke S**2** following the intake stroke S**1**. The hydrogen injector **47** may inject the hydrogen gas in a period from the intake stroke S**1** to the compression stroke S**2**.

[0083] When the hydrogen gas is insufficient, the intake port injector **44** may inject the hydrocarbon fuel into the intake port **33** so as to compensate for shortage in the intake stroke S**1**. When the hydrogen gas is unavailable, instead of the hydrogen injector **47**, the intake port injector **44** may inject the hydrocarbon fuel into the intake port **33** in the intake stroke S**1**.

[0084] When the hydrogen gas to be supplied to the combustion chamber **3***a* is insufficient, the intake port injector **44** injects the hydrocarbon fuel, thereby securing a required fuel amount for the engine **3**. The engine **3** can be operated by using the hydrocarbon fuel or using both of the hydrocarbon fuel and the hydrogen gas.

[0085] S**2** is the compression stroke. In the compression stroke S**2**, the engine **3** compresses the air-fuel mixture in the combustion chamber **3***a* by raising the piston **32**. The intake valve **34**, the exhaust valve **36**, and the on-off valve **38** are all closed.

[0086] The spark plug **27** ignites the air-fuel mixture in the combustion chamber **3***a* at timing near compression top dead center. The air-fuel mixture starts combustion. S**3** is an expansion stroke. In the expansion stroke S**3**, the piston **32** is lowered by the combustion of the air-fuel mixture. The intake valve **34**, the exhaust valve **36**, and the on-off valve **38** are all closed.

[0087] S**4** is a recompression stroke. In the recompression stroke S**4**, the engine **3** compresses combustion gas in the combustion chamber **3***a* by raising the piston **32**. In the recompression stroke S**4**, the on-off valve **38** is opened. The compressed combustion gas is introduced into the decomposer **6** through the third port **37**.

[0088] In addition, the third port injector **46** injects the hydrocarbon fuel into the third port **37** in the recompression stroke S**4**. In detail, as indicated by a reference sign F**1** in FIG. **4**, the third port injector **46** injects the fuel to be reformed in a latter half of the recompression stroke S**4**.

[0089] In the recompression stroke S**4**, a pressure of the combustion gas is increased over time. Thus, in the latter half of the recompression stroke S**4**, the internal pressure of the decomposer **6** is also kept high. Then, in the latter half of the recompression stroke S**4**, the high-pressure combustion gas flows into the decomposer **6**. In this state, since the hydrocarbon fuel is injected

toward the third port **37**, the hydrocarbon fuel can be effectively dispersed in the combustion gas even when the third port **37** is narrow.
[0090] In this way, the high-temperature, high-pressure combustion gas in the homogenized state of the hydrocarbon fuel is introduced into the decomposer **6**.
[0091] As described above, in the decomposer **6**, the hydrocarbon fuel is decomposed into carbon and the hydrogen gas by using the heat and the pressure of the combustion gas and the catalyst. Since the hydrocarbon fuel is homogenized, the hydrocarbon fuel can efficiently contact the catalyst. Doe to the high temperature and the high pressure, the reforming reaction can be promoted. Accordingly, the hydrogen gas can be effectively produced.
[0092] Since the high pressure of the combustion gas in the recompression stroke S**4** is applied to the inside of the decomposer **6**, the hydrogen gas produced inside the decomposer **6** is rapidly delivered to the hydrogen gas supply section **5**. Since the hydrogen gas inside the decomposer **6** is reduced, the decomposition reaction of the hydrocarbon fuel is promoted. The decomposer **6**, which uses the pressure in the recompression stroke S**4** of the engine **3**, can produce a relatively large amount of the hydrogen gas even in a small size. Produced carbon is stored in the decomposer **6**.
[0093] S**5** is a re-expansion stroke. In the re-expansion stroke S**5**, the piston **32** is lowered. The on-off valve **38** is opened in the re-expansion stroke S**5**. When the on-off valve **38** is opened, some of the residual gas in the decomposer **6** is discharged from the decomposer **6** to the combustion chamber **3***a*. Since the inside of the decomposer **6** can be scavenged, the high-temperature combustion gases can be guided into the third port **37** in the next cycle. Opening of the on-off valve **38** in the re-expansion stroke S**5** is advantageous in reducing pump loss of the engine **3**.
[0094] S**6** is an exhaust stroke. In the exhaust stroke S**6**, the engine **3** discharges the combustion gas in the combustion chamber **3***a* through the exhaust port **35** by raising the piston **32**. In the exhaust stroke S**6**, the exhaust valve **36** is opened. The combustion gas in the combustion chamber **3***a* is discharged to the exhaust port **35**. In the exhaust stroke S**6**, the intake valve **34** and the on-off valve **38** are closed.
[0095] After the exhaust stroke S**6**, the engine **3** returns to the intake stroke S**1**.
[0096] Instead of the on-off valve **38** being opened in the re-expansion stroke S**5**, or together with opening of the on-off valve **38**, the on-off valve **38** may be opened in the intake stroke S**1**. When the on-off valve **38** is opened in the intake stroke S**1**, the residual gas can be discharged from the decomposer **6** to the combustion chamber **3***a*. The combustion gas is the EGR gas.
[0097] When the on-off valve **38** is not opened in the re-expansion stroke S**5**, the hydrocarbon fuel, which has been introduced in the decomposer **6** in the recompression stroke S**4**, remains in the decomposer **6** for a long time. Thus, it is possible to obtain an advantage of promoting the decomposition reaction of the hydrocarbon fuel.
[0098] The fuel reforming system **1** stores carbon produced by the decomposition of the hydrocarbon fuel in the decomposer **6**. Then, the engine **3** combusts the hydrogen gas, which is produced by the decomposition of the hydrocarbon fuel. Thus, no carbon oxide is produced by the combustion. The fuel reforming system **1** can become carbon neutral.
[0099] The fuel reforming system **1** also decomposes the hydrocarbon fuel by using the heat and the pressure generated by the engine **3**. Accordingly, a separate dedicated device is not required. The fuel reforming system **1** is useful as the in-vehicle system.
[0100] FIG. **5** illustrates a control map of the engine **3**. The control map corresponds to an operating region of the engine **3** that is defined by the speed and the required load of the engine **3**. The controller **21** operates the engine **3** according to the control map.
[0101] The control map divides the operating region of the engine **3** into a first region **101** and a second region **102**. The first region **101** is a region where the speed is lower than a first speed N**1**. The second region **102** is a region where the speed is equal to or higher than the first speed N**1**. The first speed N**1** may be a speed that is included in a medium speed region in the case where the

operating region of the engine **3** is divided equally into three of a low speed region, the medium speed region, and a high speed region in a direction of the speed.
[0102] The controller **21** causes the engine **3** to perform the six-stroke cycle in the first region **101**. The hydrogen gas is used as the fuel while carbon is collected from the hydrocarbon fuel. Thus, the engine **3** can become carbon neutral.
[0103] Meanwhile, due to the large number of strokes, output is smaller in the six-stroke cycle than in a typical four-stroke cycle. Thus, in this vehicle, in the case where the six-stroke cycle is performed, and the required load of the engine **3** is equal to or greater than a predetermined load Pe**2**, the inverter **28** is controlled to drive the drive motor. In this way, the insufficient output of the engine **3** is compensated (motor assist).
[0104] The load Pe**2** may be a load included in a high-load region in the case where the operating region of the engine **3** is equally divided into three of low-load, medium-load, and high-load regions in a load direction.
[0105] In the second region **102**, the controller **21** operates the engine **3** in the normal four-stroke cycle including the intake stroke, the compression stroke, the expansion stroke, and the exhaust stroke.
[0106] More specifically, the controller **21** stops opening/closing of the on-off valve **38**. In a period from the intake stroke to the compression stroke, the hydrocarbon fuel is injected as the fuel from the intake port injector **44**. The hydrogen gas may be used as the fuel. The engine **3** has a mechanism that changes a speed ratio between the crankshaft and the camshaft when the stroke cycle is switched between the six-stroke cycle and the four-stroke cycle.
(Decomposer)
[0107] FIG. **6** illustrates an example of the decomposer **6** improved by application of the disclosed technique. The exemplified decomposer **6** has a sealed cylindrical case **61**. An opening **61***a* is formed at one end of the case **61**, and the third port **37** is connected to the opening **61***a*. The decomposer **6** communicates with the combustion chamber **3***a* via the third port **37**. The other end of the case **61** is sealed with an end wall **61***b*.
[0108] The inside of the case **61** is partitioned into two spaces. More specifically, the inside of the case **61** is partitioned into: a reforming space **62** that is located on a side of a connection portion with the third port **37**; and an additional space **63** that is located on an opposite side of the connection portion with the third port **37**. The reforming space **62** and the additional space **63** are adjacent to each other. The reforming space **62** is larger, and the reforming space **62** occupies a significant portion of the inside of the case **61**.
[0109] A collector pipe **64** is attached to the case **61**. The collector pipe **64** penetrates the end wall and extends along a center line A of the case **61**. A protruding end of the collector pipe **64** is located near the opening **61***a*. A significant portion of the collector pipe **64** in the case **61** is formed of a hydrogen permeable membrane **65** supported by a porous ceramic.
[0110] A reforming member **66** including a catalyst **66***b* is incorporated in the reforming space **62**. The reforming reaction occurs in the reforming member **66**. The exemplary reforming member **66** may be regarded as a reformer and can includes plural plate-shaped carriers **66***a*. These carriers **66***a* are radially attached to an inner wall of the case **61** and extend along the center line A of the case **61**. A protruding end of each of the carriers **66***a* is located around the collector pipe **64**.
[0111] A surface of each of the carriers **66***a* is covered with the catalyst **66***b*. An example of the catalyst **66***b* that can be used to decompose the hydrocarbon fuel is Ni—Al—Fe alloy. Any of various types of the catalysts can be used as the catalyst **66***b* as long as the catalyst **66***b* can be used to decompose the hydrocarbon fuel. The exemplary reforming member **66** can increase a surface area of the catalyst **66***b*. Since the combustion gas containing the hydrocarbon fuel and the catalyst **66***b* are easily brought into contact with each other, it is advantageous to decompose the hydrocarbon fuel.
[0112] FIG. **7** is a schematic view of the decomposer **6** for illustrating a function of the reforming

member **66**. As described above, in the recompression stroke S**4**, the hydrocarbon fuel is introduced into the decomposer **6** from the third port **37** together with the high temperature, high-pressure combustion gas (which may include the air). Then, in the reforming member **66**, the hydrocarbon fuel comes into contact with the catalyst **66***b*, whereby the reforming reaction (partial oxidation reaction when the air is contained in the combustion gas) occurs.

[0113] As a result, the hydrocarbon fuel is decomposed into carbon (denoted by the reference sign C) and the hydrogen gas. Carbon produced by the decomposition of the hydrocarbon fuel adheres, in a separable state, to the surface of the catalyst **66***b*. Then, carbon is deposited and covers the surface of the catalyst **66***b*. Thus, the decomposer **6** holds and stores the carbon.

[0114] When an adhering amount of carbon is increased, the combustion gas containing the hydrocarbon fuel hardly comes into contact with the catalyst **66***b*, and thus the production of the hydrogen gas is inhibited. The decomposition performance of the decomposer **6** deteriorates. To handle this, even when the adhering amount of carbon is increased, the state of the reforming member **66** can be reset by separating and eliminating carbon from the catalyst **66***b*. A yield of the hydrogen gas is recovered, and decomposition capacity of the decomposer **6** can be maintained.

[0115] Since the carrier **66***a* is formed in the plate shape that extends along the center line A of the case **61**, carbon, which has been separated from the catalyst **66***b*, can be easily eliminated. That is, with the combustion gas introduced into the decomposer **6**, carbon, which has been separated from the catalyst **66***b*, can be collected on the opposite side of the opening **61***a*. The form of the carrier **66***a* can be appropriately changed according to the specifications. For example, the carrier **66***a* may be a large number of balls.

[0116] The hydrogen permeable membrane **65** has pores in a molecular size and has a function to selectively allow the hydrogen gas to permeate. The hydrogen gas that is produced inside the reforming member **66** permeates the hydrogen permeable membrane **65** by the pressure of the combustion gas, and flows into the collector pipe **64**.

[0117] As illustrated in FIG. **1**, the hydrogen gas that has flowed into the collector pipe **64** is delivered to the hydrogen gas supply section **5**. Meanwhile, most of the other gases such as nitrogen gas and oxygen gas do not permeate the hydrogen permeable membrane **65**. For this reason, these gases remain inside the reforming member **66** (residual gas).

(Structural Problems of Decomposer)

[0118] The decomposer preferably has the high yield of the hydrogen gas. Accordingly, the reforming member **66** that causes the reforming reaction is usually provided in the entire interior of the case **61**. The decomposer prior to the application of the disclosed technique is also the same.

[0119] However, this type of the decomposer has a closed pipe structure, one end of which is open **61***a* and the other end of which is closed. Thus, such a problem has been acknowledged that, when the combustion gas is introduced, the entire reforming member **66** cannot be effectively used due to an influence of the residual gas.

[0120] FIG. **8**A illustrates, as a comparative example, a decomposer (pre-improvement decomposer **600**) prior to the application of the disclosed technique in a simplified manner. In the pre-improvement decomposer **600**, the reforming member **66** is provided in the entire interior of the case **61**. Before the recompression stroke S**4** in which the combustion gas is introduced into the pre-improvement decomposer **600**, the on-off valve **38** is closed. Residual gas Gr remains inside the third port **37** and the pre-improvement decomposer **600**.

[0121] Then, in the recompression stroke S**4**, the on-off valve **38** is opened, and the hydrocarbon fuel is injected from the third port injector **46**. As the piston **32** is raised, as illustrated in a top view of FIG. **8**A, combustion gas Gb, along with the hydrocarbon fuel, is introduced from the third port **37** side into the pre-improvement decomposer **600**. The combustion gas Gb has a higher pressure than the residual gas Gr.

[0122] Since the pre-improvement decomposer **600** has a closed pipe structure, the residual gas Gr has no place to flow. Since the reforming space **62** is occupied by the reforming member **66**, a flow

rate of the combustion gas Gb is reduced, and the combustion gas Gb is less likely to be mixed with the residual gas Gr.
[0123] Accordingly, the residual gas Gr is pushed into the back of the case **61** while being compressed by the combustion gas Gb. As a result, a mass of the residual gas Gr at the same pressure as the combustion gas Gb is formed in the back of the case **61**. The mass of the residual gas Gr has a lower temperature than the combustion gas Gb and does not contain the hydrocarbon fuel. The mass of the residual gas Gr also contains a large amount of inert gas.
[0124] Thus, in the portion occupied by the mass of the residual gas Gr, the reforming reaction does not occur even with the presence of the reforming member **66**. That is, the entire reforming member **66** cannot be effectively used. A boundary between the mass of the residual gas Gr and the combustion gas Gb is not necessarily clear unlike that illustrated in FIG. **8**A. There may be some width, shade, variation, or the like.
[0125] Meanwhile, in the decomposer according to one or more embodiments of the present disclosure, to which the disclosed technique is applied, that is, the decomposer **6** as described above, the inside of the case **61** is partitioned into the reforming space **62** located on the third port **37** side and the additional space **63** located on the opposite side. The reforming member **66** is installed in the reforming space **62**, and the additional space **63** is an empty space for a purpose of accommodating the mass of the residual gas Gr.
[0126] FIG. **8**B illustrates, as an example, the decomposer **6** in the simplified manner as in the comparative example. That is, the additional space **63** is a space in which the residual gas Gr is pushed and accommodated when the combustion gas Gb is introduced into the decomposer **6** in the recompression stroke S**4**. A pressure of the combustion gas Gb in the reforming space **62** is balanced with a pressure of the residual gas Gr in the additional space **63**.
[0127] A volume of the additional space **63** may be equal to or greater than a volume of the mass of the residual gas Gr. However, from a viewpoint of effective utilization of the reforming member **66**, and the like, the volume of the additional space **63** is preferably substantially the same as the volume of the mass of the residual gas Gr. Here, the volume of the additional space **63** is, for example, the volume when the internal pressure of the decomposer **6** is the highest.
[0128] When the inventors of the present disclosure studied by a CFD analysis, it was confirmed that a sufficient volume required for the additional space **63** can be calculated and identified from a volume of the combustion chamber **3***a*, a volume of the third port **37**, a volume of the decomposer **6**, a compression ratio of the engine **3**, and the like.
[0129] For the above reason, the decomposer **6** is provided with the additional space **63** having the sufficient volume. Accordingly, when the combustion gas Gb is introduced into the decomposer **6** in the recompression stroke S**4**, the residual gas Gr is pushed and accommodated in the additional space **63**. The reforming space **62** is filled with the combustion gas Gb. In the case of this fuel reforming system **1**, the entire reforming member **66** can be effectively used even in the decomposer **6** having the closed pipe structure.
[0130] Since the volume of the additional space **63** is substantially the same as that of the residual gas Gr, the combustion gas Gb hardly flows into the additional space **63**. The almost all amount of the hydrocarbon fuel injected as the reformed fuel can be brought into contact with the catalyst **66***b*. Since the internal pressure of the decomposer **6** can be maintained high, it is advantageous for the reforming reaction. In addition, since the hydrogen gas can rapidly permeate, the production of the hydrogen gas can be promoted.
[0131] The yield of the hydrogen gas can be effectively improved by the very simple improvement. Since a large-scale change is unnecessary, the disclosed technique can be easily implemented. Therefore, the disclosed technique has excellent practicality.
[0132] Since the volume of the additional space **63** is set according to the residual gas Gr that is compressed in the recompression stroke S**4**, the volume thereof can also be reduced. Thus, the decomposer **6** can be made compact in size.

<Modifications of Fuel Reforming System>
[0133] FIG. **9** illustrates a modification of the fuel reforming system **1** (second fuel reforming system **1**B) in a simplified manner. As described above, the second fuel reforming system **1**B further includes the slide device **70** (an example of the variable volume mechanism) that varies the volume of the additional space **63**. Then, the volume of the additional space **63** is varied by the slide device **70** according to the operating state of the engine **3**.
[0134] More specifically, the slide device **70** has a disk-shaped slider **70***a* in a portion on an opposite side of the connection portion of the case **61** with the third port **37**. An outer peripheral edge of the slider **70***a* is in close contact with an inner peripheral surface of the case **61**. Then, the collector pipe **64** penetrates the central portion thereof. The slider **70***a* has a seal and is configured to prevent gas leakage from a clearance therebetween.
[0135] The slider **70***a* is driven by an attached drive unit **70***b*. Accordingly, the slider **70***a* slides along the center line A of the case **61**. A space between the reforming space **62** and the slider **70***a* corresponds to the additional space **63**. Due to movement of the slider **70***a*, the volume of the additional space **63** is changed to be increased or reduced. As a structure of the slide device **70**, various forms are considered. The optimum form may be selected according to the specification.
[0136] For example, the slider **70***a* may be connected to a predetermined crank, and rotational motion of the crank may be converted into reciprocating motion of the slider **70***a*. Alternatively, the slider **70***a* may reciprocate by attaching a rack to the slider **70***a* and rotating a predetermined pinion that meshes with the rack. Further alternatively, the slider **70***a* may be coupled to a predetermined hydraulic piston, and the slider **70***a* may reciprocate by hydraulic control.
[0137] In order to position the slider **70***a*, for example, in the case of using the crank, a rotation angle thereof may be controlled by using a variable valve timing mechanism such as the above-described intake valve train. When the rack and a pinion are used, the pinion may be driven by a servo motor to control a rotation angle thereof. In the case of using the hydraulic piston, the position of the slider **70***a* may be detected by a sensor, and the hydraulic pressure may be controlled based on the position.
[0138] In general, as the load of the engine **3** is increased, required combustion energy is increased. Thus, the pressure (temperature) of the combustion gas Gb is increased as the load of the engine **3** is increased. Accordingly, in the recompression stroke S**4**, a difference (differential pressure) between the pressure of the residual gas Gr remaining in the decomposer **6** and the pressure of the combustion gas Gb introduced from the combustion chamber **3***a* into the decomposer **6** is large when the load of the engine **3** is large, and is small when the load of the engine **3** is small.
[0139] When the differential pressure is small, the mass of the residual gas Gr is increased. Meanwhile, when the differential pressure is large, the residual gas Gr is further compressed. Thus, the mass of the residual gas Gr is reduced. Accordingly, when the load of the engine **3** is changed, the optimum volume of the additional space **63** is also changed.
[0140] Meanwhile, in the second fuel reforming system **1**B, the volume of the additional space **63** is configured to be varied. Thus, the volume of the additional space **63** can be changed and optimized. That is, the controller **21** outputs a control signal to the drive unit **70***b* according to the load of the engine **3**. Then, the slider **70***a* moves to a position where the volume of the additional space **63** becomes optimum with the load.
[0141] For example, when the required load for the engine **3** is increased, the controller **21** moves the slider **70***a* in a manner to reduce the volume of the additional space **63** according to the required load. In this way, it is possible to introduce the large amount of the high-temperature, high-pressure combustion gas Gb into the reforming space **62** without flowing into the additional space **63**. Thus, the reforming member **66** can be effectively used, and the large amount of the hydrogen gas can be produced.
<Application Example of Fuel Reforming System>
[0142] FIG. **10** illustrates an application example of the fuel reforming system **1** (third fuel

reforming system **1**C). The third fuel reforming system **1**C is obtained by further improving the second fuel reforming system **1**B.

[0143] As illustrated in FIG. **2**, similar to the second fuel reforming system **1**B, the third fuel reforming system **1**C includes the slide device **70** that varies the volume of the additional space **63**. The third fuel reforming system **1**C also includes the carbon remover **80**. The carbon remover **80** separates the carbon adhering to the catalyst **66***b* from the catalyst **66***b* by processing to apply a physical impact onto the carrier **66***a*, scrape the surface of the carrier **66***a* with a scraper, or the like, for example.

[0144] The third fuel reforming system **1**C is devised such that carbon can be automatically discharged from the decomposer **6** and collected.

[0145] In the case of the exemplified decomposer **6**, the opposite side of the opening **61***a* in the case **61** is expanded. One end of a discharge passage **81** is connected to the expanded portion. The other end of the discharge passage **81** is connected to a collection box **82**. The collection box **82** collects and temporarily stores carbon to be discharged until carbon is collected.

[0146] As illustrated in a top view of FIG. **10**, at a position (control position **83**) in a range where the slider **70***a* moves according to the required load of the engine **3**, a space between the discharge passage **81** and the additional space **63** is blocked by the slider **70***a*. Thus, the discharge passage **81** does not communicate with the additional space **63**. Meanwhile, as illustrated in a bottom view of FIG. **10**, when the slider **70***a* moves to a predetermined position (discharge position **84**) provided in the expanded portion, the discharge passage **81** communicates with the additional space **63**.

[0147] As described above, when the combustion gas Gb is introduced from the third port **37**, carbon, which has been separated from the catalyst **66***b*, is collected on the opposite side of the opening **61***a*, that is, in the additional space **63**. Accordingly, when the combustion gas Gb is introduced from the third port **37** in a state where the discharge passage **81** communicates with the additional space **63**, carbon can be discharged to the collection box **82** through the discharge passage **81**.

[0148] Since carbon stored inside the decomposer **6** can be automatically removed, the state of the reforming member **66** can be reset as necessary. The yield of the hydrogen gas is recovered, and the decomposition capacity of the decomposer **6** can be maintained in the appropriate state.

[0149] Switching of the communication state between the discharge passage **81** and the additional space **63** is not limited to the exemplary form. For example, a lid body may be provided in a connection portion of the case **61** with the discharge passage **81**, and the lid body may be opened/closed. In short, the discharge passage **81** may be configured to be openable/closable.

(Specific Example of Control of Third Fuel Reforming System)

[0150] FIG. **11**A and FIG. **11**B illustrate an example of the control of the third fuel reforming system **1**C.

[0151] The controller **21** reads the various signals input from the accelerator sensor **23** and the like (step S**1**). During the operation of the engine **3**, the controller **21** identifies the output required for the engine **3** based on the read signals, and executes the operation (Yes in step S**2**). Then, with termination of the operation of the engine **3**, the control by the controller **21** is also terminated (No in step S**2**).

[0152] The controller **21** refers to the control map and determines whether the engine **3** is operated in the first region **101** (step S**3**).

[0153] As a result, if the engine **3** is operated in the first region **101**, the controller **21** executes the operation in the six-stroke cycle, that is, the operation using the hydrogen gas as the main fuel (step S**4**). On the other hand, if the engine **3** is not operated in the first region **101**, that is, operates in the second region **102**, the controller **21** executes the operation in the four-stroke cycle, that is, the operation using the hydrocarbon fuel as the main fuel (step S**5**).

[0154] When the engine **3** is operated in the six-stroke cycle, the controller **21** estimates the carbon deposition amount in the catalyst **66***b* based on the signals from the hydrogen gas sensor **25** and the

like. When the carbon deposition amount is excessive, the function of the catalyst **66***b* is impaired. As a result, the produced amount of the hydrogen gas is reduced.
[0155] The controller **21** compares an upper limit value Ds of the carbon deposition amount, which is set in advance based on an experiment or the like, with an estimated value Dc of the carbon deposition amount (step S**6**). As a result, if it is determined that the estimated value Dc of the carbon deposition amount is equal to or greater than the upper limit value Ds of the carbon deposition amount, the controller **21** executes a carbon removal mode (step S**7**).
[0156] FIG. **11**B illustrates an example of control in the carbon removal mode. In the carbon removal mode, the controller **21** outputs the control signal to the slide device **70**, and moves the slider **70***a* to the discharge position **84** illustrated in the bottom view of FIG. **10** (step S**10**). Then, the controller **21** outputs the control signal to the carbon remover **80** to activate the carbon remover **80** (step S**11**). In this way, the carbon that has adhered to the catalyst **66***b* is separated from the catalyst **66***b*.
[0157] The controller **21** determines whether a predetermined carbon removal time ts, which is set in advance based on an experiment or the like, has elapsed (step S**12**). The carbon removal time ts is a sufficient time to reset the catalyst **66***b* and is set according to performance of the carbon remover **80**.
[0158] If the carbon removal time ts has elapsed, the controller **21** stops the carbon remover **80** (step S**13**). During this time, since the engine **3** is operated in the six-stroke cycle, the combustion gas Gb is repeatedly introduced into the decomposer **6**. The hydrocarbon fuel may not be injected from the third port injector **46**. That is, only the combustion gas Gb may be introduced.
[0159] At this time, since the inside of the decomposer **6** communicates with the collection box **82** via the discharge passage **81**, the combustion gas Gb easily flows. In this way, separated carbon is discharged from the decomposer **6** to the collection box **82** through the additional space **63** and the discharge passage **81**.
[0160] Next, the controller **21** moves the slider **70***a* to the control position **83** in order to execute the normal operation in the six-stroke cycle (step S**14**). Then, the processing returns to that in FIG. **11**A.
[0161] On the other hand, if it is determined that the estimated value Dc of the carbon deposition amount is less than the upper limit value Ds of the carbon deposition amount (No in step S**6**), the controller **21** moves the slider **70***a* according to the operating state of the engine **3** (step S**8**). That is, the volume of the additional space **63** is optimized according to the required load of the engine **3**.
[0162] During the operation of the engine **3**, the controller **21** repeats such processing.
[0163] Note that the disclosed technique is not limited to the above-described embodiments, and includes various other configurations. For example, the individual configurations of the first to third fuel reforming systems may be appropriately combined as necessary. The vehicle to which the disclosed technique can be applied is not limited to a hybrid vehicle. The drive source may be the reciprocating engine only.
[0164] Embodiments of the disclosed subject matter can also be as set forth according to the following brackets/parentheticals.
[0165] [1]A fuel reforming system for a vehicle, on which a reciprocating engine is mounted, wherein in the reciprocating engine, a combustion chamber where combustion occurs is partitioned inside a cylinder in which a piston reciprocates, the fuel reforming system comprising: [0166] a decomposer that decomposes hydrocarbon fuel into carbon and hydrogen gas using heat and a pressure of combustion gas produced in the combustion chamber and a catalyst and holds the carbon; and [0167] a hydrocarbon fuel supply that supplies the hydrocarbon fuel to the decomposer, wherein [0168] the decomposer communicates with the combustion chamber via an openable/closable port, [0169] a reforming space in which a reformer including the catalyst is on a side of a connection portion of the decomposer with the openable/closable port, and [0170] on an

opposite side of an interior of the connection portion of the decomposer with the port, an additional space is adjacent to the reforming space, wherein in the additional space, residual gas that remains in the port and the decomposer is accommodated under a condition where the combustion gas is introduced into the decomposer through the openable/closable port.

[2]

[0171] The fuel reforming system according to [1], further comprising: [0172] a variable volume mechanism to vary a volume of the additional space, wherein [0173] the volume of the additional space is varied according to an operating state of the reciprocating engine.

[3]

[0174] The fuel reforming system according to [1] or [2], wherein [0175] the carbon is held in a separable state in the decomposer, and [0176] an openable/closable discharge passage is connected to the additional space and is configured to discharge the carbon separated from the decomposer.

[4]

[0177] The fuel reforming system according to any one of [1] to [3], wherein [0178] the reciprocating engine is configured to perform a six-stroke cycle including: [0179] an intake stroke in which at least intake air is introduced into the combustion chamber through an intake port by lowering the piston; [0180] a compression stroke in which air-fuel mixture containing the hydrogen gas supplied to the combustion chamber is compressed by raising the piston; [0181] an expansion stroke in which the piston is lowered by combustion of the air-fuel mixture; [0182] a recompression stroke in which the combustion gas is compressed by raising the piston; [0183] a re-expansion stroke in which the piston is lowered; and [0184] an exhaust stroke in which exhaust gas is discharged through an exhaust port by raising the piston, and [0185] in the recompression stroke, the combustion gas is introduced into the decomposer through the port, and the residual gas is thereby pushed and accommodated in the additional space.

[5]

[0186] The fuel reforming system according to any one of [1] to [4], wherein [0187] the decomposer is adjacent to an exhaust port of the reciprocating engine.

[6]

[0188] The fuel reforming system according to any one of [1] to [5], wherein [0189] the openable/closable port is adjacent to an exhaust port of the reciprocating engine.

[7]

[0190] The fuel reforming system according to any one of [1] to [6], wherein [0191] a total internal volume of the additional space is less than a total internal volume of the reforming space, and [0192] no portion of the additional space is adjacent to the connection portion of the decomposer with the openable/closable port.

[8]

[0193] The fuel reforming system according to any one of [1] to [7], wherein [0194] the reforming space and the additional space each circumscribe a collector pipe extending into the decomposer from the opposite side opposite the connection portion.

[9]

[0195] The fuel reforming system according to any one of [1] to [8], wherein [0196] the additional space circumscribes a portion of a hydrogen permeable membrane.

[10]

[0197] A method regarding a fuel reforming system for a vehicle, on which a reciprocating engine is mounted, wherein in the reciprocating engine, a combustion chamber where combustion occurs is partitioned inside a cylinder in which a piston reciprocates, the method comprising: [0198] providing a decomposer that decomposes hydrocarbon fuel into carbon and hydrogen gas using heat and a pressure of combustion gas produced in the combustion chamber and a catalyst and holds the carbon; and [0199] providing a hydrocarbon fuel supply that supplies the hydrocarbon fuel to the decomposer, wherein [0200] the decomposer communicates with the combustion chamber via an openable/closable port, [0201] a reforming space in which a reformer including the catalyst is on a side of a connection portion of the decomposer with the openable/closable port, and [0202] on an opposite side of an interior of the connection portion of the decomposer with the port, an additional space is adjacent to the reforming space, wherein in the additional space, residual gas that remains in the decomposer is accommodated under a condition where the combustion gas is introduced into the decomposer through the openable/closable port.

[11]

[0203] The method according to [10], further comprising: [0204] decomposing, using the decomposer, the hydrocarbon fuel into the carbon and the hydrogen gas using the heat and the pressure of combustion gas produced in the combustion chamber and the catalyst; and [0205] holding the carbon.

[12]

[0206] The method according to [10] or [11], further comprising performing a six-stroke cycle including: [0207] an intake stroke in which at least intake air is introduced into the combustion chamber through an intake port by lowering the piston; [0208] a compression stroke in which air-fuel mixture containing the hydrogen gas supplied to the combustion chamber is compressed by raising the piston; [0209] an expansion stroke in which the piston is lowered by combustion of the air-fuel mixture; [0210] a recompression stroke in which the combustion gas is compressed by raising the piston; [0211] a re-expansion stroke in which the piston is lowered; and [0212] an exhaust stroke in which exhaust gas is discharged through an exhaust port by raising the piston, and [0213] in the recompression stroke, the combustion gas is introduced into the decomposer through the port, and the residual gas is thereby pushed and accommodated in the additional space.

[13]

[0214] The method according to any one of [10] to [12], further comprising varying an internal volume of the additional space using a slider and according to an operating state of the reciprocating engine.

[14]

[0215] The method according to any one of [10] to [14], further comprising discharging the carbon from the additional space via a discharge passage.

[15]

[0216] The method according to any one of [10] to [14], wherein [0217] the decomposer is adjacent to an exhaust port of the reciprocating engine, [0218] the openable/closable port is adjacent to an exhaust port of the reciprocating engine, [0219] a total internal volume of the additional space is less than a total internal volume of the reforming space, and [0220] no portion of the additional space is adjacent to the connection portion of the decomposer with the openable/closable port.

[16]

[0221] The method according to any one of [10] to [16], wherein [0222] the additional space circumscribes a portion of a hydrogen permeable membrane forming part of a collector pipe extending into the decomposer from the opposite side opposite the connection portion.

[17]

[0223] A decomposer for a fuel reforming system for decomposing hydrocarbon fuel into carbon and hydrogen gas using heat and a pressure of combustion gas produced in a combustion chamber and a catalyst, the decomposer being in communication with the combustion chamber via an openable/closable port and comprising: [0224] a case including: [0225] an opening to receive an output from the openable/closable port, [0226] a reforming space adjacent to the opening and in which a reformer including the catalyst is on a side of a connection portion of the decomposer with the openable/closable port, [0227] an additional space on a side of the case opposite the opening to store residual gas that remains in the reforming space, [0228] wherein the additional space is adjacent to the reforming space such that no portion of the additional space is adjacent to the

connection portion of the decomposer with the openable/closable port, and [0229] wherein a total internal volume of the additional space is less than a total internal volume of the reforming space.
[18]
[0230] The decomposer according to [17], further comprising a discharge passage coupled directly to the additional space to discharge the carbon separated from the decomposer.
[19]
[0231] The decomposer according to [17] or [18], further comprising: [0232] a variable volume mechanism to vary a volume of the additional space, wherein [0233] the volume of the additional space is varied according to an operating state.
[20]
[0234] The decomposer according to any one of [17] to [19], wherein [0235] the reforming space and the additional space each circumscribe a collector pipe extending into the decomposer from the opposite side opposite the connection portion.
REFERENCE SIGNS LIST
[0236] **1**: fuel reforming system [0237] **2**: control system [0238] **3**: reciprocating engine [0239] **3***a*: combustion chamber [0240] **5**: hydrogen gas supply section [0241] **6**: decomposer [0242] **21**: controller [0243] **22**: rotational speed sensor [0244] **23**: accelerator sensor [0245] **24**: crank angle sensor [0246] **25**: H**2** sensor [0247] **27**: spark plug [0248] **28**: inverter [0249] **31**: cylinder [0250] **32**: piston [0251] **33**: intake port [0252] **34**: intake valve [0253] **35**: exhaust port [0254] **36**: exhaust valve [0255] **37**: third port [0256] **38**: on-off valve [0257] **41**: intake valve train [0258] **42**: exhaust valve train [0259] **43**: third valve train [0260] **44**: intake port injector [0261] **45**: hydrocarbon fuel supply section [0262] **46**: third port injector [0263] **47**: hydrogen injector [0264] **61**: case of the decomposer [0265] **61***a*: opening [0266] **62**: reforming space [0267] **63**: additional space [0268] **64**: collector pipe [0269] **65**: hydrogen permeable membrane [0270] **66**: reforming member/reformer [0271] **66***a*: carrier [0272] **66***b*: catalyst [0273] **70**: slide device (variable volume mechanism) [0274] **70***a*: slider [0275] **70***b*: drive device [0276] **80**: carbon remover [0277] **81**: discharge passage [0278] **82**: collection box [0279] **83**: control position [0280] **84**: discharge position [0281] Gr: residual gas [0282] Gb: combustion gas

Claims

1. A fuel reforming system for a vehicle, on which a reciprocating engine is mounted, wherein in the reciprocating engine, a combustion chamber where combustion occurs is partitioned inside a cylinder in which a piston reciprocates, the fuel reforming system comprising: a decomposer that decomposes hydrocarbon fuel into carbon and hydrogen gas using heat and a pressure of combustion gas produced in the combustion chamber and a catalyst and holds the carbon; and a hydrocarbon fuel supply that supplies the hydrocarbon fuel to the decomposer, wherein the decomposer communicates with the combustion chamber via an openable/closable port, a reforming space in which a reformer including the catalyst is on a side of a connection portion of the decomposer with the openable/closable port, and on an opposite side of an interior of the connection portion of the decomposer with the port, an additional space is adjacent to the reforming space, wherein in the additional space, residual gas that remains in the port and the decomposer is accommodated under a condition where the combustion gas is introduced into the decomposer through the openable/closable port.
2. The fuel reforming system according to claim 1, further comprising: a variable volume mechanism to vary a volume of the additional space, wherein the volume of the additional space is varied according to an operating state of the reciprocating engine.
3. The fuel reforming system according to claim 1, wherein the carbon is held in a separable state in the decomposer, and an openable/closable discharge passage is connected to the additional space and is configured to discharge the carbon separated from the decomposer.

4. The fuel reforming system according to claim 1, wherein the reciprocating engine is configured to perform a six-stroke cycle including: an intake stroke in which at least intake air is introduced into the combustion chamber through an intake port by lowering the piston; a compression stroke in which air-fuel mixture containing the hydrogen gas supplied to the combustion chamber is compressed by raising the piston; an expansion stroke in which the piston is lowered by combustion of the air-fuel mixture; a recompression stroke in which the combustion gas is compressed by raising the piston; a re-expansion stroke in which the piston is lowered; and an exhaust stroke in which exhaust gas is discharged through an exhaust port by raising the piston, and in the recompression stroke, the combustion gas is introduced into the decomposer through the port, and the residual gas is thereby pushed and accommodated in the additional space.
5. The fuel reforming system according to claim 1, wherein the decomposer is adjacent to an exhaust port of the reciprocating engine.
6. The fuel reforming system according to claim 1, wherein the openable/closable port is adjacent to an exhaust port of the reciprocating engine.
7. The fuel reforming system according to claim 1, wherein a total internal volume of the additional space is less than a total internal volume of the reforming space, and no portion of the additional space is adjacent to the connection portion of the decomposer with the openable/closable port.
8. The fuel reforming system according to claim 1, wherein the reforming space and the additional space each circumscribe a collector pipe extending into the decomposer from the opposite side opposite the connection portion.
9. The fuel reforming system according to claim 1, wherein the additional space circumscribes a portion of a hydrogen permeable membrane.
10. A method regarding a fuel reforming system for a vehicle, on which a reciprocating engine is mounted, wherein in the reciprocating engine, a combustion chamber where combustion occurs is partitioned inside a cylinder in which a piston reciprocates, the method comprising: providing a decomposer that decomposes hydrocarbon fuel into carbon and hydrogen gas using heat and a pressure of combustion gas produced in the combustion chamber and a catalyst and holds the carbon; and providing a hydrocarbon fuel supply that supplies the hydrocarbon fuel to the decomposer, wherein the decomposer communicates with the combustion chamber via an openable/closable port, a reforming space in which a reformer including the catalyst is on a side of a connection portion of the decomposer with the openable/closable port, and on an opposite side of an interior of the connection portion of the decomposer with the port, an additional space is adjacent to the reforming space, wherein in the additional space, residual gas that remains in the decomposer is accommodated under a condition where the combustion gas is introduced into the decomposer through the openable/closable port.
11. The method according to claim 10, further comprising: decomposing, using the decomposer, the hydrocarbon fuel into the carbon and the hydrogen gas using the heat and the pressure of combustion gas produced in the combustion chamber and the catalyst; and holding the carbon.
12. The method according to claim 10, further comprising performing a six-stroke cycle including: an intake stroke in which at least intake air is introduced into the combustion chamber through an intake port by lowering the piston; a compression stroke in which air-fuel mixture containing the hydrogen gas supplied to the combustion chamber is compressed by raising the piston; an expansion stroke in which the piston is lowered by combustion of the air-fuel mixture; a recompression stroke in which the combustion gas is compressed by raising the piston; a re-expansion stroke in which the piston is lowered; and an exhaust stroke in which exhaust gas is discharged through an exhaust port by raising the piston, and in the recompression stroke, the combustion gas is introduced into the decomposer through the port, and the residual gas is thereby pushed and accommodated in the additional space.
13. The method according to claim 10, further comprising varying an internal volume of the additional space using a slider and according to an operating state of the reciprocating engine.

14. The method according to claim 10, further comprising discharging the carbon from the additional space via a discharge passage.
15. The method according to claim 10, wherein the decomposer is adjacent to an exhaust port of the reciprocating engine, the openable/closable port is adjacent to an exhaust port of the reciprocating engine, a total internal volume of the additional space is less than a total internal volume of the reforming space, and no portion of the additional space is adjacent to the connection portion of the decomposer with the openable/closable port.
16. The method according to claim 10, wherein the additional space circumscribes a portion of a hydrogen permeable membrane forming part of a collector pipe extending into the decomposer from the opposite side opposite the connection portion.
17. A decomposer for a fuel reforming system for decomposing hydrocarbon fuel into carbon and hydrogen gas using heat and a pressure of combustion gas produced in a combustion chamber and a catalyst, the decomposer being in communication with the combustion chamber via an openable/closable port and comprising: a case including: an opening to receive an output from the openable/closable port, a reforming space adjacent to the opening and in which a reformer including the catalyst is on a side of a connection portion of the decomposer with the openable/closable port, an additional space on a side of the case opposite the opening to store residual gas that remains in the reforming space, wherein the additional space is adjacent to the reforming space such that no portion of the additional space is adjacent to the connection portion of the decomposer with the openable/closable port, and wherein a total internal volume of the additional space is less than a total internal volume of the reforming space.
18. The decomposer according to claim 17, further comprising a discharge passage coupled directly to the additional space to discharge the carbon separated from the decomposer.
19. The decomposer according to claim 17, further comprising: a variable volume mechanism to vary a volume of the additional space, wherein the volume of the additional space is varied according to an operating state.
20. The decomposer according to claim 17, wherein the reforming space and the additional space each circumscribe a collector pipe extending into the decomposer from the opposite side opposite the connection portion.