



(12) **United States Patent**
Chen et al.

(10) **Patent No.:** **US 9,595,726 B2**
(45) **Date of Patent:** **Mar. 14, 2017**

(54) **FUEL REFORMING SYSTEM AND PROCESS**

(56) **References Cited**

(71) Applicant: **ADVANCED COOLING TECHNOLOGIES, INC.**, Lancaster, PA (US)

U.S. PATENT DOCUMENTS

(72) Inventors: **Chien-Hua Chen**, Lititz, PA (US);
Howard Pearlman, Haddon Township, NJ (US)

3,302,683 A 2/1967 Kemp
3,351,563 A * 11/1967 Negra C01B 3/38
252/373
3,397,028 A 8/1968 Brauer
(Continued)

(73) Assignee: **Advanced Cooling Technologies, Inc.**, Lancaster, PA (US)

FOREIGN PATENT DOCUMENTS

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 511 days.

CA 2436997 7/2010
CN 101589275 A 11/2009
(Continued)

(21) Appl. No.: **14/148,971**

Primary Examiner — Melvin C Mayes
Assistant Examiner — Kenneth Vaden
(74) *Attorney, Agent, or Firm* — McNeese Wallace & Nurick LLC

(22) Filed: **Jan. 7, 2014**

(65) **Prior Publication Data**

(57) **ABSTRACT**

US 2015/0191352 A1 Jul. 9, 2015

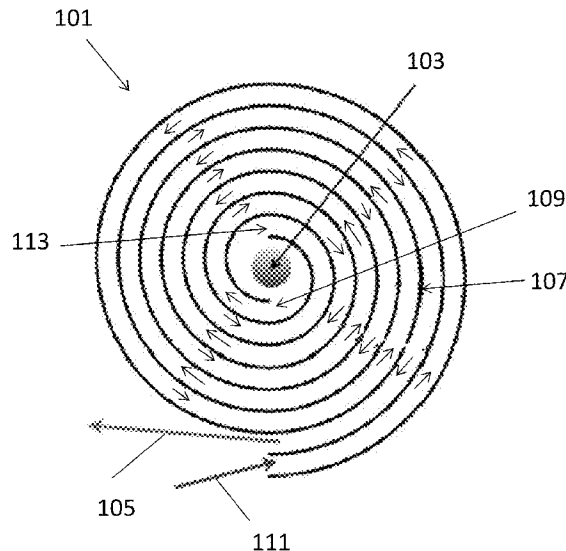
Fuel reforming processes and systems are disclosed. The fuel reforming process includes providing a fuel reformer, the fuel reformer comprising a reaction zone configured for exothermic partial oxidation to generate reformates and a heat exchanger extending from the reaction zone, the heat exchanger configured to expel the reformates through a reformate path and receive fuel-rich reactants through a fuel path, generating the reformates by the exothermic partial oxidation of the fuel-rich reactants within the reaction zone, heating the fuel-rich reactants in reaction zone with the heat exchanger by heat from the reformates in the reformate path. The process is energetically self-sustained and operates without a catalyst. The fuel reforming system includes the fuel reformer with a spiral heat exchanger and a component capable of operation with the reformates and incompatible with combustion products, such as a fuel cell.

(51) **Int. Cl.**
C01B 3/38 (2006.01)
H01M 8/06 (2016.01)
C01B 3/36 (2006.01)

(52) **U.S. Cl.**
CPC **H01M 8/0618** (2013.01); **C01B 3/36** (2013.01); **C01B 2203/0255** (2013.01); **C01B 2203/0283** (2013.01); **C01B 2203/062** (2013.01); **C01B 2203/066** (2013.01); **C01B 2203/0883** (2013.01); **C01B 2203/1235** (2013.01); **C01B 2203/1241** (2013.01); **C01B 2203/1247** (2013.01)

(58) **Field of Classification Search**
USPC 252/373
See application file for complete search history.

17 Claims, 3 Drawing Sheets



(56)

References Cited

U.S. PATENT DOCUMENTS

4,227,021 A * 10/1980 Grosskinsky C07C 51/487
562/513

4,369,029 A 1/1983 Forster et al.

5,188,740 A * 2/1993 Khan C02F 1/025
210/609

5,520,864 A * 5/1996 Frei F02M 69/06
261/88

5,529,484 A 6/1996 Moard et al.

6,613,972 B2 9/2003 Cohen et al.

6,840,762 B2 1/2005 Maruta et al.

6,936,238 B2 8/2005 Sennoun et al.

6,951,456 B2 10/2005 Cohen et al.

7,135,154 B2 11/2006 Deshpande

7,247,402 B2 7/2007 Haile et al.

7,316,563 B2 1/2008 Marshall

7,625,414 B2 12/2009 Nougier et al.

8,323,363 B2 12/2012 Bingue et al.

2002/0020113 A1 2/2002 Kennedy et al.

2004/0123523 A1 7/2004 Rong et al.

2007/0131909 A1 * 6/2007 Rojey C10J 3/00
252/373

2008/0249196 A1 * 10/2008 Wentink C01B 3/16
518/702

2009/0087801 A1 4/2009 Schoegl et al.

2009/0119991 A1 * 5/2009 Johnson C10J 3/66
48/78

2010/0175639 A1 7/2010 Al-Dawood et al.

2011/0120012 A1 * 5/2011 Balmas C10J 3/00
48/197 R

2011/0168360 A1 * 7/2011 Chang F28F 3/048
165/104.31

2012/0095118 A1 * 4/2012 Bracht C01B 3/36
518/703

2013/0015405 A1 1/2013 Quintero et al.

2013/0105739 A1 5/2013 Bingue et al.

FOREIGN PATENT DOCUMENTS

DE 19903168 A1 8/2000

DE 10345902 B4 5/2005

DE 102007025785 B4 2/2009

EP 1345679 B1 3/2013

JP 2007507686 11/2007

JP 2010513834 4/2010

WO 0247186 A2 6/2002

WO 2007121004 A2 10/2007

WO 2013008020 A1 1/2013

* cited by examiner

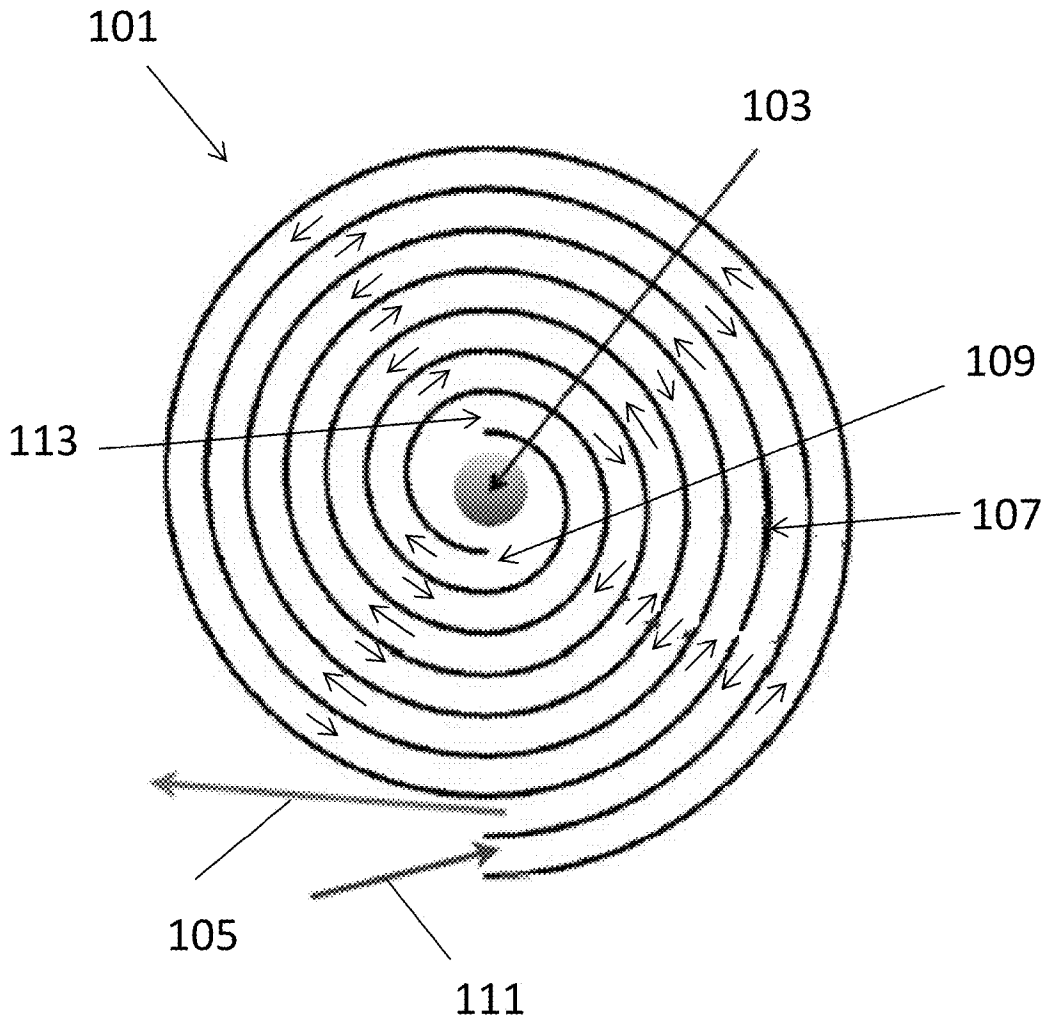


FIG - 1

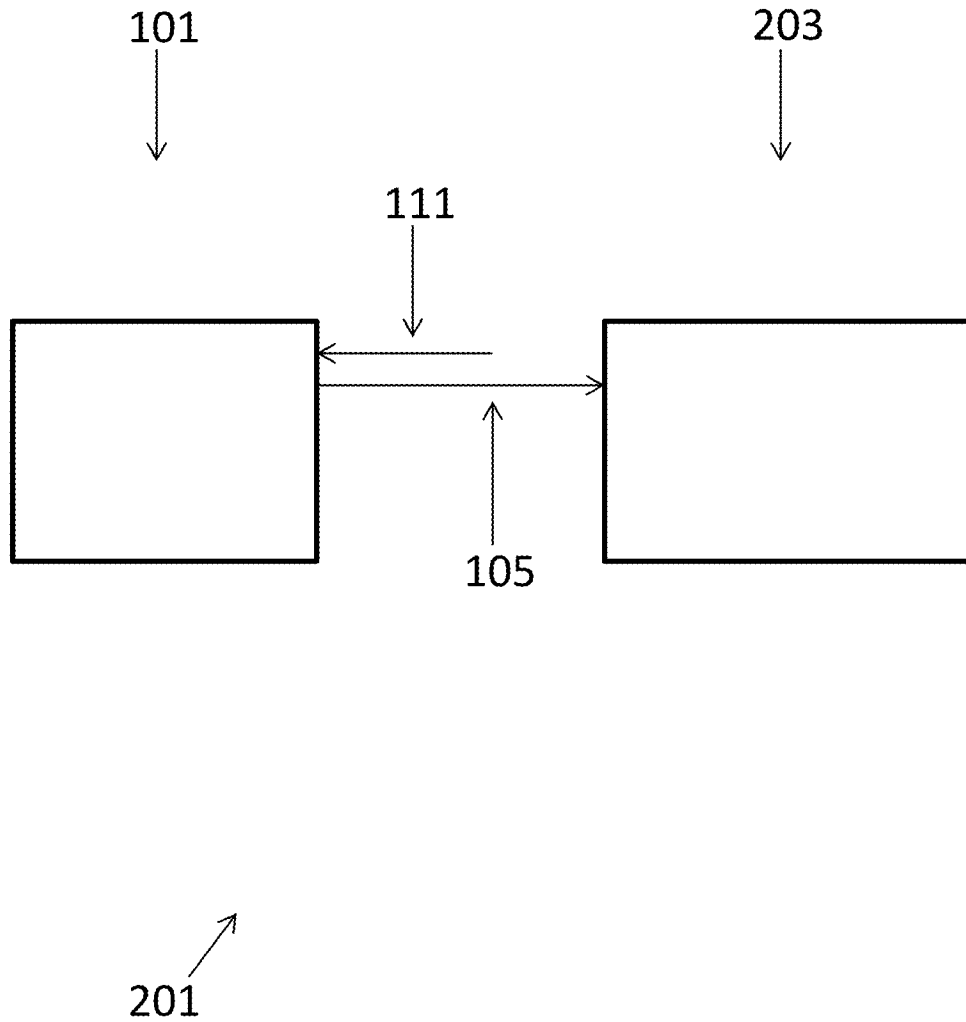


FIG - 2

FIG - 3

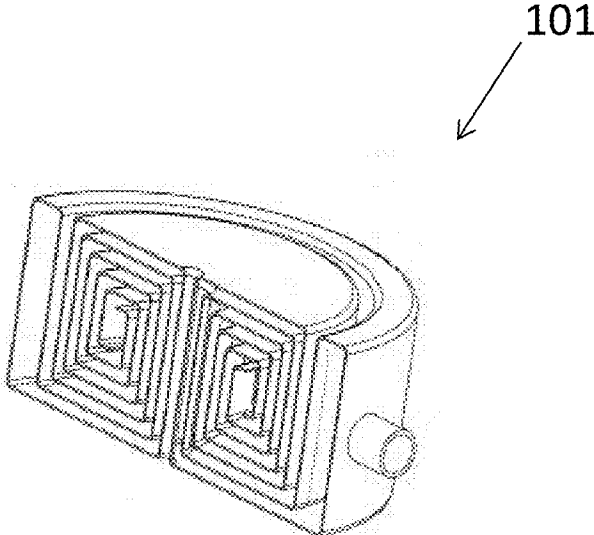
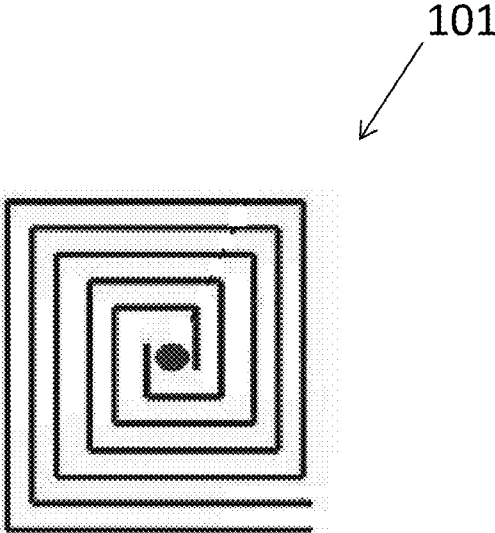


FIG - 4



FUEL REFORMING SYSTEM AND PROCESS

FIELD OF THE INVENTION

The present invention is directed to fuel reforming processes and systems. More particularly, the present invention is directed to fuel reforming processes and systems receiving hydrocarbon-air mixtures in fuel-rich conditions.

BACKGROUND OF THE INVENTION

Electrical power generation devices using hydrocarbons such as natural gas, gasoline, diesel, military logistic fuels, and other similar materials as the energy storage medium have several advantages over batteries. Such advantages include, for example, higher energy density, easier transportation, operation with a variety of supply infrastructures, short recharge periods, and other benefits.

Some devices, including fuel cells, operate using syngas, a mixture of H_2 and CO . Syngas having H_2 and CO can be produced from hydrocarbons by using catalysts in fuel reformers. Using the catalysts permits a rapid reaction rate for fuel-rich reaction that has lower reaction temperature. For example, the catalysts lower the effective activation energy so that products are able to reach their chemical equilibrium state at reduced temperatures resulting in near-theoretical yields (maximum amounts attainable) of H_2 and CO in the syngas. However, sulfur compounds and/or higher hydrocarbons present in the energy storage medium can easily poison or deposit carbon (coking) on the catalyst, which degrades performance and shortens the useful life of the catalyst for reformer operations. Catalysts also suffer from other deactivation mechanisms such as sintering.

To address such drawbacks, expensive noble-metal-based catalysts, such as rhodium, have been used. In addition, sub-systems, for example, for pre-desulfurization and/or water management, and complicated control systems have been used. Such remedies are not well-suited for portable and/or small power scale applications where the system size, weight, and parasitic power consumption are important. In addition, such remedies are expensive.

In addition to using catalyst, syngas having H_2 and CO can also be generated in fuel-rich reaction at elevated temperature, for example, using pure oxygen instead of air as oxidizer to reduce the need for thermal diluents or using an external energy source (for example, plasma) to provide excess energy in the reactants and thus accelerate the reaction rate. However, such systems are very large, very complex, and very expensive.

A known combustor operates with a combustion zone configured for receiving fuel-lean energy storage media from a first spiraling path in a spiral heat exchanger to produce combustion products. The combustion products include H_2O and CO_2 , which are expelled through a second spiraling path and preheat the incoming reactants in the first spiraling path. The known combustor is able to create a higher temperature reaction zone using air as oxidizer without external energy input, but the combustion products are not capable of being used in systems and processes requiring a syngas with a higher concentration of H_2 and CO than the resulting effluent from combustion.

Fuel reforming processes and systems that produce one or more improvements would be desirable in the art.

BRIEF DESCRIPTION OF THE INVENTION

In an exemplary embodiment, a fuel reforming process includes providing a fuel reformer, the fuel reformer includ-

ing a reaction zone configured for exothermic partial oxidation to generate reformates and a heat exchanger extending from the reaction zone, the heat exchanger configured to expel the reformates through a reformatate path and receive fuel-rich reactants through a fuel path. The fuel reforming process also includes generating the reformates by the exothermic partial oxidation of the fuel-rich reactants within the reaction zone and heating the fuel-rich reactants with the heat exchanger by heat from the reformates in the reformatate path. The process is energetically self-sustained and operates without a catalyst.

In another exemplary embodiment, a fuel reforming system includes a fuel reformer, the fuel reformer comprising a reaction zone configured for exothermic partial oxidation to generate reformates and a spiral heat exchanger extending from the reaction zone, the spiral heat exchanger configured to expel the reformates through a first spiraling path and receive fuel-rich reactants through a second spiraling path, and a fuel cell arranged and disposed to receive the reformates from the fuel reformer.

In another exemplary embodiment, a fuel reforming system includes a fuel reformer, the fuel reformer comprising a reaction zone configured for exothermic partial oxidation to generate reformates, and a spiral heat exchanger extending from the reaction zone, the spiral heat exchanger configured to expel the reformates through a first spiraling path and receive fuel-rich reactants through a second spiraling path, and a component capable of operation with the reformates and incompatible with combustion products.

Other features and advantages of the present invention will be apparent from the following more detailed description, taken in conjunction with the accompanying drawings which illustrate, by way of example, the principles of the invention.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a schematic view of a fuel reformer with a spiral arrangement during a fuel reforming process, according to an embodiment of the disclosure.

FIG. 2 is a schematic view of a system having a fuel reformer and a secondary device, according to an embodiment of the disclosure.

FIG. 3 is a schematic view of a fuel reformer with a toroidal arrangement, according to an embodiment of the disclosure.

FIG. 4 is a schematic view of a fuel reformer with a square spiral arrangement, according to an embodiment of the disclosure.

Wherever possible, the same reference numbers will be used throughout the drawings to represent the same parts.

DETAILED DESCRIPTION OF THE INVENTION

Provided are fuel reforming processes and systems. Embodiments of the present disclosure, for example, in comparison to similar processes and systems that do not include one or more of the features disclosed herein, permit higher energy density, permit easier transportation, permit intermittent or continuous operation utilizing existing supply infrastructures, increase yields of H_2 and CO in syngas without catalysts, reduce or eliminate coking and/or catalyst degradation, have a longer operational life, operate without noble-metal-based catalysts (such as rhodium), are less complicated, operate without sub-systems (for example, pre-desulfurization, water management, and/or complicated

3

control sub-systems), are portable, are smaller, are energetically self-sufficient, operate without pure oxygen streams, operate with fuel-rich combustion products, permit lower pressure drops (thus requiring less pump power), other suitable distinctions, or a combination thereof.

FIG. 1 shows an embodiment of a fuel reformer **101** during an embodiment of a fuel reforming process. The fuel reformer **101** includes a reaction zone **103** configured for exothermic partial oxidation of fuel-rich reactants **111**. The reaction zone **103** is arranged and disposed within the fuel reformer **101**, for example, in the middle or substantially in the middle of the fuel reformer **101**. The reaction zone **103** is defined by internal structures (not shown) and/or elements of one or more features described hereinafter. The reaction zone **103** includes any suitable features permitting operation at high temperatures and/or under-oxidizing conditions. As used herein the term "partial oxidation" and grammatical variations thereof, refers to a chemical reaction that occurs in oxygen-deficient conditions (with equivalence ratio being greater than 1), such as, when a fuel-air or fuel-oxygen mixture is partially reacted to produce H₂ and CO. An embodiment of the reforming process using the fuel reformer **101** operates energetically self-sustained and without a catalyst by generating reformates **105** by the exothermic partial oxidation process, while heating the fuel-rich reactants **111** upstream of the reaction zone **103**, for example, with a heat exchanger, that efficiently transfers heat from the reformates **105** in the reformate path **109** to the fuel-rich reactants **111** flowing in adjacent spiral windings (for example, to an adiabatic flame temperature, a super-adiabatic flame temperature, or at least to an adiabatic flame temperature or a super-adiabatic flame temperature).

The fuel reformer **101** and/or one or more components within the fuel reformer **101** are fabricated from any material capable of handling the operational conditions. Such materials include, but are not limited to, stainless steel and nickel-based superalloys.

A fuel path **113** and a reformate path **109** extend from the reaction zone **103**, for example, in a spiraling countercurrent arrangement. In one embodiment, the merger of the fuel path **113** and the reformate path **109** define the reaction zone **103**. In one embodiment, one or both of the fuel path **113** and the reformate path **109** spiral from the reaction zone **103**, for example, along a spiral heat exchanger **107**. The spiral nature of the spiral heat exchanger **107** includes any suitable arrangement with complete or partial overlapping of the fuel path **113** and the reformate path **109** that permits separate fluid transport. Suitable arrangements include, but are not limited to, an arrangement of two or more plates coiled to form a spiral as is shown in FIG. 1, a cuboid arrangement of one or more plates forming a square spiral (see FIG. 4), a three-dimensional toroidal arrangement (see FIG. 3), or a combination thereof. In one embodiment, the spiral heat exchanger **107** includes one or more heat transfer enhancements, for example, as occur naturally (Dean vortices) and/or through including additional inserts or other heat transfer enhancements to increase heat transfer and/or enable the reformate path **109** and/or the fuel path **113** to maintain a desired heat transfer rate.

In general, the spiral arrangement includes any suitable dimensions and/or configuration. The spiral arrangement includes any suitable number of turns, which are substantially extensions around the reaction zone **103**. Suitable numbers of turns include, but are not limited to, 3 or more turns, 6 or more turns, between 3 and 10 turns, between 3 and 12 turns, between 6 and 12 turns, between 10 and 12 turns, between 3 and 16 turns, between 6 and 16 turns,

4

between 10 and 16 turns, 6 or more turns, 10 or more turns, 12 or more turns, 16 or more turns, or any suitable combination, sub-combination, range, or sub-range therein.

The spiral arrangement includes any suitable separation for the fuel path **113** and/or the reformate path **109**. In one embodiment, the fuel path **113** and/or the reformate path **109** have a thickness within one or more of the turns of between 2 mm and 3 mm, between 1 mm and 5 mm, between 1 mm and 4 mm, between 2 mm and 5 mm, 2 mm, 2.5 mm, 3 mm, or any suitable combination, sub-combination, range, or sub-range therein. In one embodiment, the fuel path **113** and/or the reformate path **109** increase in width consistent with increased pressure regions.

The spiral arrangement also includes any suitable dimensions for the axial length of the fuel path **113** and/or the reformate path **109**. Suitable dimensions include, but are not limited to, between 10 mm and 100 mm, between 20 mm and 80 mm, between 30 mm and 70 mm, between 40 mm and 60 mm, between 45 mm and 55 mm, 45 mm, 50 mm, 55 mm, or any suitable combination, sub-combination, range, or sub-range therein. In one embodiment, the reaction zone **103** extends axially along the region between the fuel path **113** and the reformate path **109**, which provides greater heat release to loss (through end plates) ratio and, therefore, more heat recirculation effect.

The spiral arrangement produces multiple heat transfer benefits. In one embodiment, the spiral arrangement increases a heat transfer effect, for example, through centrifugal instability that occurs within the spiral channel. Additionally or alternatively, in one embodiment, the spiral arrangement provides a larger ratio of heat exchange area to heat loss area, thereby increasing exchanger efficiency for a defined volume, in comparison to non-spiraling arrangements. In one embodiment, the configuration of the arrangement and/or the number of the turns is selected to correspond to such properties.

The reaction zone **103** generates the reformates **105** from the exothermic partial oxidation of the fuel-rich reactants **111** provided via the fuel path **113**. The fuel-rich reactants **111** have any suitable composition capable of producing a greater stoichiometric amount of H₂ during the exothermic partial oxidation of the fuel reforming process, for example, in comparison to complete combustion processes. Additionally or alternatively, the fuel-rich reactants **111** have any suitable composition capable of producing a greater stoichiometric amount of CO during the exothermic partial oxidation of the fuel reforming process, for example, in comparison to combustion processes. Suitable compositions of the fuel-rich reactants **111** include, but are not limited to, propane-air mixtures (for example, at an equivalence ratio equal to 3), vaporized liquid fuel-air mixtures (for example, n-heptane, kerosene-based fuel, and/or Jet Propellant 8 jet fuel), pulverized solid fuel-air mixtures (for example, coal-air, and/or biomass-air mixtures), or a combination thereof.

The reformates **105** transfer heat, generated from the exothermic partial oxidation, to the fuel rich reactants **111**, the fuel path **113**, and/or the spiral heat exchanger **107**. In one embodiment, the heat is transferred by the reformate path **109** being in contact with the fuel path **113** and/or the spiral heat exchanger **107**. In a further embodiment, the transfer of the heat permits a high reaction temperature resulting a fast reaction rate and the fuel reforming process to be energetically self-sustained and/or operate without a catalyst.

According to an embodiment of the process, the fuel-rich reactants **111** and/or the fuel path **113** are at a lowest temperature (for example, ambient temperature) upon entry

to the fuel reformer **101**. The temperature of the fuel-rich reactants **111** and/or the fuel path **113** increase in temperature via heat recirculation along the direction of flow until reaching the reaction zone **103** and then the exothermic partial oxidation further increases the temperature to the highest temperature (for example, between 1000° C. and 1300° C., the adiabatic flame temperature for equivalence ratio equal to 3 of propane-air mixture is 808° C.) at or near the reaction zone **103**. The reformates **105** travel from the reaction zone **103** through the reformat path **109**. The reformat path **109** and the reformates **105** are at a highest temperature (for example, between 1000° C. and 1300° C.) at the reaction zone **103** and decrease in temperature along the direction of flow until reaching a lower temperature upon flowing from the fuel reformer **101**.

The composition of the reformates **105** and the arrangement of the fuel path **113** and the reformat path **109** permit the fuel reformer **101** to be used in conjunction with systems incompatible with combustors. As used herein, being "incompatible with combustors" refers to not being operable when receiving combustion products. For example, referring to FIG. 2, in one embodiment, the fuel reformer **101** is arranged within a system **201** having a component **203** or device capable of use or operation with the reformates **105**. The component **203** is a fuel cell (for example, a solid oxide fuel cell, a 250 W fuel cell, a fuel cell having less than 500 W power, or any other suitable fuel cell), a hydrogen and/or syngas storage container, a hydrogen separation unit, an auxiliary power unit, a portable power generation system, a micro-combined heat and power system (m-CHP), a robotic system, another suitable apparatus, an after-treatment system in a diesel engine (for example, to reform part of diesel to syngas and regenerate lean NOx catalyst), a gasoline engine, or a combination thereof. Other devices include, but are not limited to, a water gas shift reactor having water introduced or produced, the water reacting with CO(g) in the reformat to produce additional H₂ by the equation $\text{CO} + \text{H}_2\text{O} \rightarrow \text{CO}_2 + \text{H}_2$ and/or a Fischer-Tropsch reactor having a Fischer-Tropsch catalyst to synthesize liquid fuels. The system **201** is or includes any arrangement including the fuel reformer **101** and the component **203**, such as, a power generation system, a reactor, a diesel engine, a gasoline engine, a vehicle, an independently-powered device, or a combination thereof. In one embodiment, the fuel reformer **101** is separate from other portions of the system **201** and the reformates **105** are transported to the other portions of the system **201**.

The system **201** includes any suitable features for operating the fuel reformer **101** in conjunction with the reformates **105**. Suitable features include, but are not limited to, a blower (not shown) and a fuel injection system (not shown). In one embodiment, additional sub-systems (for example, pre-desulfurization, water management, inert gas protection for start-up and shut-down, and/or complicated control sub-systems) are not utilized.

The fuel reformer **101** and/or the system **201** are capable of being adjusted to increase the concentration of H₂ and/or CO in the process, for example, achieving a mixture having a concentration of H₂ and CO that is at or near their thermodynamic equilibrium concentrations. Achievable molar concentrations of H₂ include, but are not limited to, about 8%, about 14%, about 15%, about 17%, at least 8%, at least 14%, at least 15%, at least 17%, or any suitable combination, sub-combination, range, or sub-range therein, thereby resulting in a ratio of the equilibrium concentration being about 28%, about 49%, about 54%, about 60%, at least 28%, at least 49%, at least 54%, at least 60%, or any suitable

combination, sub-combination, range, or sub-range therein. Achievable molar concentrations of CO include, but are not limited to, about 15%, about 17%, about 18%, about 18.5%, at least 15%, at least 17%, at least 18%, at least 18.5%, or any suitable combination, sub-combination, range, or sub-range therein, thereby resulting in a ratio of the equilibrium concentration being about 70%, about 80%, about 85%, about 87%, at least 70%, at least 80%, at least 85%, at least 87%, or any suitable combination, sub-combination, range, or sub-range therein.

To achieve desired molar concentrations of H₂ and CO, for example, in one embodiment, a flow is adjusted. Suitable flow velocities include, but are not limited to, 50 cm/s, 100 cm/s, 150 cm/s, 200 cm/s, at least 50 cm/s, at least 100 cm/s, at least 150 cm/s, at least 200 cm/s, or any suitable combination, sub-combination, range, or sub-range therein. Suitable flow volumes include, but are not limited to, 62.5 cc/s, 125 cc/s, 187.5 cc/s, 250 cc/s, at least 62.5 cc/s, at least 125 cc/s, at least 187.5 cc/s, at least 250 cc/s, or any suitable combination, sub-combination, range, or sub-range therein.

Flow conditions correlate to a Reynolds number (defined by the channel width, input flow velocity, and viscosity at room temperature), which, in one embodiment, is a ratio of inertial forces to viscous forces and corresponding to the number of transfer units (NTU) of the spiral heat exchanger. Suitable Reynolds numbers include, but are not limited to, 78.7, 157.3, 200, 236.0, 300, 314.7, 400, 800, 1600, at least 78.7, at least 157.3, at least 200, at least 236.0, at least 300, at least 314.7, at least 400, at least 800, at least 1600, or any suitable combination, sub-combination, range, or sub-range therein. Suitable input power conditions for the process include, but are not limited to, 500 W, 575.5 W, 1000 W, 1151.5 W, 1727.2 W, 2000 W, 2303 W, 2500 W, up to 575.5 W, up to 1151.5 W, up to 1727.2 W, up to 2303 W, up to 2500 W, more than 2500 W, or any suitable combination, sub-combination, range, or sub-range therein.

EXAMPLES

In a first example, the fuel reformer **101** receives the fuel-rich reactants **111**. The fuel-rich reactants **111** include a propane-air mixture at an equivalence ratio equal to 3. The fuel reformer **101** includes 3.5-turn spiraling arrangements of the fuel path **113** and the reformat path **109**, with the thickness of the fuel path **113** and the reformat path **109** being 2.5 mm and the dimensions of the axial length of the fuel path **113** and the reformat path **109** being 50 mm. The fuel-rich reactants **111** are introduced to the fuel reformer **101** with conditions of a flow rate of 78.7 ratio of inertial forces to viscous forces (Reynolds number), 50 cm/s flow velocity, 62.5 cc/s flow volume, and 575.7 W input power. Under these conditions, the reformates **105** have a mole fraction of about 8% H₂ and a mole fraction of about 15% CO. In comparison to the equilibrium states of H₂ (28.4%) and CO (21.3%), in this example, the H₂ is at about 28% of the equilibrium concentration (8%/28.4%=28.2%) and the CO is at about 70% of the equilibrium concentration (15%/21.3%=70.4%) of CO compared to their equilibrium states.

In a second example, the fuel reformer **101** receives the fuel-rich reactants **111**. The fuel-rich reactants **111** include the propane-air mixture at an equivalence ratio equal to 3. The fuel reformer **101** includes 3.5-turn spiraling arrangements of the fuel path **113** and the reformat path **109**, with the thickness of the fuel path **113** and the reformat path **109** being 2.5 mm and the dimensions of the axial length of the fuel path **113** and the reformat path **109** being 50 mm. The fuel-rich reactants **111** are introduced to the fuel reformer

101 with conditions of a flow rate of 157.3 ratio of inertial forces to viscous forces (Reynolds number), 100 cm/s flow velocity, 125 cc/s flow volume, and 1151.5 W input power. Under these conditions, the reformates **105** have a mole fraction of about 14% H₂ and a mole fraction of about 17% CO, showing that the concentration of H₂ and CO increases with the Reynolds number, which is believed to be due to increased heat release to loss ratio and more heat recirculation. In comparison to the equilibrium states of H₂ (28.4%) and CO (21.3%), in this example, the H₂ is at about 49% of the equilibrium concentration (14%/28.4%=49.3%) and the CO is at about 80% of the equilibrium concentration (17%/21.3%=79.8%) of CO compared to their equilibrium states.

In a third example, the fuel reformer **101** receives the fuel-rich reactants **111**. The fuel-rich reactants **111** include the propane-air mixture at an equivalence ratio equal to 3. The fuel reformer **101** includes 3.5-turn spiraling arrangements of the fuel path **113** and the reformat path **109**, with the thickness of the fuel path **113** and the reformat path **109** being 2.5 mm and the dimensions of the axial length of the fuel path **113** and the reformat path **109** being 50 mm. The fuel-rich reactants **111** are introduced to the fuel reformer **101** with conditions of a flow rate of 236 ratio of inertial forces to viscous forces (Reynolds number), 150 cm/s flow velocity, 187.5 cc/s flow volume, and 1727.2 W input power. Under these conditions, the reformates **105** have a mole fraction of about 15% H₂ and a mole fraction of about 18% CO, showing that the concentration of H₂ and CO increases with the Reynolds number, which is believed to be due to increased heat release to loss ratio and more heat recirculation. In comparison to the equilibrium states of H₂ (28.4%) and CO (21.3%), in this example, the H₂ is at about 54% of the equilibrium concentration (15%/28.4%=53.5%) and the CO is at about 85% of the equilibrium concentration (18%/21.3%=84.5%) of CO compared to their equilibrium states.

In a fourth example, the fuel reformer **101** receives the fuel-rich reactants **111**. The fuel-rich reactants **111** include the propane-air mixture at an equivalence ratio equal to 3. The fuel reformer **101** includes 3.5-turn spiraling arrangements of the fuel path **113** and the reformat path **109**, with the thickness of the fuel path **113** and the reformat path **109** being 2.5 mm and the dimensions of the axial length of the fuel path **113** and the reformat path **109** being 50 mm. The fuel-rich reactants **111** are introduced to the fuel reformer **101** with conditions of a flow rate of 314.7 ratio of inertial forces to viscous forces (Reynolds number), 200 cm/s flow velocity, 250 cc/s flow volume, and 2303 W input power. Under these conditions, the reformates **105** have a mole fraction of about 17% H₂ and a mole fraction of about 18.5% CO, showing that the concentration of H₂ and CO increases with the Reynolds number, which is believed to be due to increased heat release to loss ratio and more heat recirculation. In comparison to the equilibrium states of H₂ (28.4%) and CO (21.3%), in this example, the H₂ is at about 60% of the equilibrium concentration (17%/28.4%=59.9%) and the CO is at about 87% of the equilibrium concentration (18.5%/21.3%=86.9%) of CO compared to their equilibrium states.

While the invention has been described with reference to one or more embodiments, it will be understood by those skilled in the art that various changes may be made and equivalents may be substituted for elements thereof without departing from the scope of the invention. In addition, many modifications may be made to adapt a particular situation or material to the teachings of the invention without departing from the essential scope thereof. Therefore, it is intended that the invention not be limited to the particular embodiment disclosed as the best mode contemplated for carrying

out this invention, but that the invention will include all embodiments falling within the scope of the appended claims.

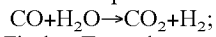
What is claimed is:

1. A fuel reforming process, comprising:
 - providing a fuel reformer, the fuel reformer comprising:
 - a reaction zone configured for exothermic partial oxidation to generate reformates; and
 - a spiral heat exchanger extending from the reaction zone, the heat exchanger configured to expel the reformates through a spiral reformat path and receive fuel-rich reactants through a spiral counter-current fuel path, the spiral reformat path being adjacent to the spiral countercurrent fuel path;
 - generating the reformates by the exothermic partial oxidation of the fuel-rich reactants within the reaction zone;
 - heating the fuel-rich reactants with the heat exchanger by heat from the reformates in the reformat path;
 - wherein the process is energetically self-sustained and operates without a catalyst.
2. The process of claim 1, wherein the spiral heat exchanger comprises a heat transfer enhancements configured to form Dean vortices capable of increasing heat transfer.
3. The process of claim 1, wherein the reformat path and the fuel path spiral from the reaction zone.
4. The process of claim 3, wherein the reformat path and the fuel path spiral each form at least 3 turns.
5. The process of claim 1, comprising introducing the fuel-rich reactants at a flow velocity of at least 200 cm/s.
6. The process of claim 1, comprising introducing the fuel-rich reactants at a flow volume of at least 250 cc/s.
7. The process of claim 1, comprising introducing the fuel-rich reactants with a Reynolds number of at least 314.7.
8. The process of claim 1, wherein H₂ in the reformat is at a molar concentration of at least 17%.
9. The process of claim 1, wherein CO in the reformat is at a molar concentration of at least 18.5%.
10. The process of claim 1, wherein H₂ in the reformat is at a molar ratio of at least 60% compared to the equilibrium concentration.
11. The process of claim 1, wherein CO in the reformat is at a molar ratio of at least 87% compared to the equilibrium concentration.
12. The process of claim 1, wherein the reaction temperature exceeds the adiabatic flame temperature of the fuel-rich reactants.
13. The process of claim 1, wherein the fuel-rich reactants include fluid selected from the group consisting of a methane-air mixture, a propane-air mixture, an n-heptane-air vaporized liquid-fuel mixture, a kerosene-based fuel-air mixture, a Jet Propellant 8 jet fuel-air mixture, a pulverized coal-air mixture, a biomass-air mixture, and combinations thereof.
14. The process of claim 1, comprising operating the fuel reformer in a system incompatible with combustion products.
15. The process of claim 14, wherein the operating of the fuel system is as a hydrogen storage container, an auxiliary power unit, a portable power system, a micro-combined heat and power system, a robotic system, an after-treatment system in a diesel engine, a hydrogen-enhancement combustion engine, or a combination thereof.

16. The process of claim 14, wherein the system is a power generation system, a reactor, a diesel engine, gasoline engine, an independently-powered device, or a combination thereof.

17. The process of claim 1, comprising operating the fuel reformer in conjunction with a device selected from the group consisting of:

a water gas shift reactor having water introduced or produced, the water reacting with CO(g) in the reformato to produce additional H₂ by the equation



a Fischer-Tropsch reactor having a Fischer-Tropsch catalyst to synthesize liquid fuels; and
a fuel cell.

* * * * *