(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
27 May 2004 (27.05.2004)

PCT

(10) International Publication Number
WO 2004/044405 A1

(51) International Patent Classification[7]: F02B 43/08

(21) International Application Number:
PCT/US2003/020555

(22) International Filing Date: 1 July 2003 (01.07.2003)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
10/293,518 13 November 2002 (13.11.2002) US

(71) Applicant: **ARVIN TECHNOLOGIES, INC.** [US/US]; 2135 West Maple Road, Troy, MI 48084 (US).

(72) Inventors: **TAYLOR, William, III.**; 2136 Franklin Street, Columbus, IN 47201 (US). **SMALING, Rudolf, M.**; 3 Mudge Way, Bedford, MA 01730 (US). **BAUER, Shawn, D.**; 4817 Graceland Avenue, Indianapolis, IN 46208 (US).

(74) Agent: **BAUER, Shawn, D.**; Barnes & Thornburg, 11 South Meridian Street, Indianapolis, IN 46204 (US).

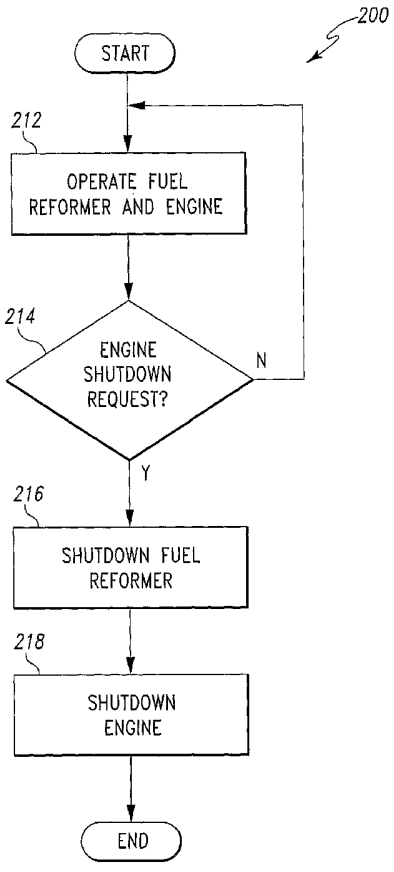
(81) Designated States *(national)*: AE, AG, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, BZ, CA, CH, CN, CO, CR, CU, CZ, DE, DK, DM, DZ, EC, EE, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MA, MD, MG, MK, MN, MW, MX, MZ, NI, NO, NZ, OM, PG, PH, PL, PT, RO, RU, SC, SD, SE, SG, SK, SL, SY, TJ, TM, TN, TR, TT, TZ, UA, UG, UZ, VC, VN, YU, ZA, ZM, ZW.

(84) Designated States *(regional)*: ARIPO patent (GH, GM, KE, LS, MW, MZ, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HU, IE, IT, LU, MC, NL, PT, RO, SE, SI, SK, TR), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

Published:
— *with international search report*
— *with amended claims*

[Continued on next page]

(54) Title: FUEL REFORMER SHUTTING DOWN METHOD AND APPARATUS



(57) Abstract: A method of operating a power system (10) including a fuel reformer (11) and an internal combustion engine (12) is disclosed. The engine is shutdown subsequent to shutdown of the fuel reformer (11). A fuel reformer system for supplying a reformate gas to the engine is also disclosed.

WO 2004/044405 A1

For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

FUEL REFORMER SHUTTING DOWN METHOD AND APPARATUS

FIELD OF THE DISCLOSURE

The present disclosure relates generally to fuel reformers and systems and methods associated therewith.

BACKGROUND OF THE DISCLOSURE

A fuel reformer is used to reform a hydrocarbon fuel into a reformate gas. In the case of an onboard fuel reformer or a fuel reformer associated with a stationary power generator, the reformate gas produced by the fuel reformer may be utilized as fuel or fuel additive in the operation of an internal combustion engine. The reformate gas may also be utilized to regenerate or otherwise condition an emission abatement device associated with an internal combustion engine or as a fuel for a fuel cell.

SUMMARY OF THE DISCLOSURE

According to one aspect of the disclosure, there is provided a method of operating a power system. The power system includes a fuel reformer and an internal combustion engine. During operation of the fuel reformer, reformate gas produced by the fuel reformer is discharged into a passageway. To purge the passageway of the reformate gas, the engine is operated for a period of time subsequent to cessation of operation of the fuel reformer.

According to another aspect of the disclosure, a fuel reformer system for supplying a reformate gas to an internal combustion engine includes the fuel reformer and a reformer controller. The reformer controller detects an engine shutdown request and ceases operation of the fuel reformer in response to detection of the shutdown request, but prior to cessation of operation of the internal combustion engine.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a simplified block diagram of a power system including a fuel reformer, an internal combustion engine, and a passageway to conduct a reformate gas produced by the fuel reformer to the engine wherein the fuel reformer is under the control of a reformer controller and the engine is under the control of an engine control unit which is discrete from the reformer controller;

FIG. 2 is a simplified block diagram similar to FIG. 1 except that the reformer controller is integrated into the engine control unit;

FIG. 3 is a simplified block diagram showing a flow of reformate gas from the fuel reformer through a passageway to an emission abatement device; and

FIG. 4 is a flowchart of a control routine for performing a sequenced shutdown of the fuel reformer and the engine.

DETAILED DESCRIPTION OF ILLUSTRATIVE EMBODIMENTS

While the concepts of the present disclosure are susceptible to various modifications and alternative forms, specific exemplary embodiments thereof have been shown by way of example in the drawings and will herein be described in detail. It should be understood, however, that there is no intent to limit the disclosure to the particular forms disclosed, but on the contrary, the intention is to cover all modifications, equivalents, and alternatives following within the spirit and scope of the disclosure as defined by the appended claims.

Referring now to FIG. 1, there is shown a power system 10. The power system 10 includes a fuel reformer 11 and an internal combustion engine 12. A passageway 14 interconnects the fuel reformer 11 and the engine 12. The fuel reformer 11 reforms (i.e., converts) hydrocarbon fuel into a reformate gas 16 that includes, among other things, hydrogen gas. The passageway 14 conducts the reformate gas 16 to the engine 12 so that the reformate gas 16 may be used as a fuel

or a fuel additive in the operation of the engine 12 thereby increasing the efficiency of the engine 12 while also reducing emissions produced by the engine 12.

The fuel reformer 11 may be embodied as any type of fuel reformer such as, for example, a catalytic fuel reformer, a thermal fuel reformer, a steam fuel reformer, or any other type of partial oxidation fuel reformer. The fuel reformer 11 may also be embodied as a plasma fuel reformer. A plasma fuel reformer uses plasma to convert a mixture of air and hydrocarbon fuel into a reformate gas which is rich in, among other things, hydrogen gas and carbon monoxide. Systems including plasma fuel reformers are disclosed in U.S. Patent No. 5,425,332 issued to Rabinovich et al.; U.S. Patent No. 5,437,250 issued to Rabinovich et al.; U.S. Patent No. 5,409,784 issued to Bromberg et al.; and U.S. Patent No. 5,887,554 issued to Cohn, et al., the disclosures of which are hereby incorporated by reference.

As shown in FIG. 1, the fuel reformer 11 and its associated components are under the control of the reformer controller 18. In particular, components such as temperature, pressure, or gas composition sensors (not shown), a fuel inlet assembly such as a fuel injector (not shown), and air inlet valve(s) (not shown) are each electrically coupled to the reformer controller 18. Moreover, the power supply 20 is electrically coupled to the reformer controller 18 via a signal line 22. Although the signal line 22 is shown schematically as a single line, it should be appreciated that the signal line 22, along with the signal line associated with each of the other components of the fuel reformer 11, may be configured as any type of signal carrying assembly which allows for the transmission of electrical signals in either one or both directions between the reformer controller 18 and the corresponding component. For example, any one or more of the signal lines may be embodied as a wiring harness having a number of signal lines which transmit electrical signals between the reformer controller 18 and the corresponding component. It should be appreciated that any number of other wiring configurations may also be used. For

example, individual signal wires may be used, or a system utilizing a signal multiplexer may be used for the design of any one or more of the signal lines. Moreover, the signal lines may be integrated such that a single harness or system is utilized to electrically couple some or all of the components associated with the fuel reformer 11 to the reformer controller 18.

The reformer controller 18 is, in essence, the master computer responsible for interpreting electrical signals sent by sensors associated with the fuel reformer 11 and for activating electronically-controlled components associated with the fuel reformer 11 in order to control the fuel reformer 11. For example, the reformer controller 18 of the present disclosure is operable to, amongst many other things, actuate or shutdown the fuel reformer 11, determine the beginning and end of each injection cycle of fuel into the fuel reformer 11, calculate and control the amount and ratio of air and fuel to be introduced into the fuel reformer 11, determine the temperature of the fuel reformer 11, and determine the power level to supply to the fuel reformer 11.

To do so, the reformer controller 18 includes a number of electronic components commonly associated with electronic units which are utilized in the control of electromechanical systems. For example, the reformer controller 18 may include, amongst other components customarily included in such devices, a processor such as a microprocessor 32 and a memory device 34 such as a programmable read-only memory device ("PROM") including erasable PROM's (EPROM's or EEPROM's). The memory device 34 is provided to store, amongst other things, instructions in the form of, for example, a software routine (or routines) which, when executed by the microprocessor 32, allows the reformer controller 18 to control operation of the fuel reformer 11.

The reformer controller 18 also includes an analog interface circuit (not shown). The analog interface circuit converts the output signals from the various

fuel reformer sensors into a signal which is suitable for presentation to an input of the microprocessor 32. In particular, the analog interface circuit, by use of an analog-to-digital (A/D) converter (not shown) or the like, converts the analog signals generated by the sensors into a digital signal for use by the microprocessor 32. It should be appreciated that the A/D converter may be embodied as a discrete device or number of devices, or may be integrated into the microprocessor. It should also be appreciated that if any one or more of the sensors associated with the fuel reformer 11 generate a digital output signal, the analog interface circuit may be bypassed.

Similarly, the analog interface circuit converts signals from the microprocessor 32 into an output signal which is suitable for presentation to the electrically-controlled components associated with the fuel reformer 11 (e.g., the power supply 20). In particular, the analog interface circuit, by use of a digital-to-analog (D/A) converter (not shown) or the like, converts the digital signals generated by the microprocessor 32 into analog signals for use by the electronically-controlled components associated with the fuel reformer 11 such as the power supply 20. It should be appreciated that, similar to the A/D converter described above, the D/A converter may be embodied as a discrete device or number of devices, or may be integrated into the microprocessor 32. It should also be appreciated that if any one or more of the electronically-controlled components associated with the fuel reformer 11 operate on a digital input signal, the analog interface circuit may be bypassed.

Hence, the reformer controller 18 may be operated to control operation of the fuel reformer 11. In particular, the reformer controller 18 executes a routine including, amongst other things, a closed-loop control scheme in which the reformer controller 18 monitors outputs of the sensors associated with the fuel reformer 11 in order to control the inputs to the electronically-controlled components associated therewith. To do so, the reformer controller 18 communicates with the sensors associated with the fuel reformer in order to determine, amongst numerous other

things, the amount, temperature, and/or pressure of air and/or fuel being supplied to the fuel reformer 11, the amount of oxygen in the reformate gas, the temperature of the reformate gas being produced thereby, and the composition of the reformate gas. Armed with this data, the reformer controller 18 performs numerous calculations each second, including looking up values in preprogrammed tables, in order to execute algorithms to perform such functions as determining when or how long the fuel reformer's fuel injector or other fuel input device is opened, controlling the power level input to the fuel reformer, controlling the amount of air advanced through the air inlet valve(s), etcetera.

The reformer controller 18 is electrically coupled to a power supply 20 associated with the fuel reformer 11 via a signal line 22. As such, the reformer controller 18 communicates with the power supply 20 to selectively operate and shutdown the fuel reformer 11. Collectively, the fuel reformer 11 and the reformer controller 18 define a fuel reformer system 24 which, among other uses, may be used in the construction of an onboard system for a vehicle or as part of a stationary power generator.

The engine 12, on the other hand, is under the control of an engine control unit 26. In particular, the engine control unit 26 is electrically coupled to a number of electronically-controlled components associated with the engine 12 (e.g., a fuel injector assembly, ignition assembly, etcetera) via a signal line 28. As with the signal lines associated with the fuel reformer 11, the signal line 28 may be any type of signal carrying connector including a wiring harness for carrying the electrical signals associated with numerous engine components.

The reformer controller 18 and the engine control unit 26 are in communication with one another. In particular, the reformer controller 18 is electrically coupled to the engine control unit 26 via a signal line 30.

The reformer controller 18 and the engine control unit 26 are shown as discrete components in FIG. 1. It should be appreciated, however, that the reformer controller 18 may be integrated into an engine control unit 26 as shown in FIG. 2. In such a way, a single hardware component may be utilized to control both the fuel reformer 11 and the engine 12.

Hence, the aforedescribed control scheme may be utilized to control operation of the fuel reformer 11 and the engine 12. In an exemplary embodiment, the aforedescribed control scheme includes a routine for purging reformate gas 16 from the passageway 14. In particular, in certain system designs, it may be desirable to have the passageway 14 between the outlet of the fuel reformer 11 and the engine 12 substantially devoid of reformate gas 16 when the engine 12 is not being operated. To do so, the passageway 14 may be selectively purged of reformate gas 16.

To purge the passageway 14 of reformate gas 16, the engine 12 may be operated for a predetermined period of time subsequent to shutdown (i.e., cessation of operation) of the fuel reformer 11. In particular, as shall be discussed in more detail below, during shutdown of the engine 12, the reformer controller 18 and the engine control unit 26 cooperate to continue operation of the engine 12 for a predetermined period of time subsequent to shutdown of the fuel reformer 11 to purge reformate gas 16 from the passageway 14. More specifically, by operating the engine 12 for a predetermined period of time subsequent to shutdown of the fuel reformer 11, reformate gas 16 present in the passageway 14 is advanced into the intake of the engine 12 and subsequently combusted by the engine 12 prior to shutdown thereof.

As shown in FIG. 3, the reformate gas 16 produced by the fuel reformer 11 may be used to regenerate or otherwise condition an emission abatement device 31 associated with the engine 12 to treat exhaust gases discharged from the engine 12. The emission abatement device 31 may be embodied as any type of

emission device such as an absorber catalyst including a NOX and/or SOX trap, a soot trap, or any other type of device.

A passageway 114 interconnects the fuel reformer 11 and the emission abatement device 31 to conduct reformate gas 16 to the emission abatement device 31. As with the systems described above in regard to FIGS. 1 and 2, in certain system designs, it may be desirable to have the passageway 114 substantially devoid of reformate gas 16 when the engine 12 is not being operated. To do so, the passageway 114 may be purged of reformate gas 16 by operation of the engine 12 for a predetermined period of time subsequent to shutdown of the fuel reformer 11 in the manner described above.

It should be appreciated that reformate gas produced by the fuel reformer 11 may also be supplied to a fuel cell (not shown) via a passageway extending from the fuel reformer 11 to the fuel cell. If desired, the passageway extending between the fuel reformer 11 and the fuel cell may also be purged by operation of the engine 12 for a predetermined period of time subsequent to shutdown of the fuel reformer 11.

Referring now to FIG. 4, there is shown a control routine 200 for controlling operation of the fuel reformer 11 and the engine 12 during the performance of a sequenced shutdown of the fuel reformer 11 and the engine 12 to purge reformate gas 16 from the reformer's outlet passageway (e.g., passageways 14, 114). For purposes of the following description, the reformer controller 18 and the engine control unit 26 are presumed to be discrete (i.e., separate) devices (such as shown in FIG. 1). However, it should be appreciated that a similar control routine could be executed by a control system in which the reformer controller 18 and the engine control unit 26 are embodied as an integrated device.

As shown in FIG. 4, the routine 200 begins with step 212 in which the fuel reformer 11 and the engine are being operated under the control of the respective

controllers. Specifically, the fuel reformer 11 is being operated under the control of the reformer controller 18 so as to produce reformate gas which may be supplied to, for example, the intake of the engine 12, the emission abatement device 31, a fuel cell (not shown), etcetera. The engine 12, on the other hand, is operated under the control of the engine control unit 26 so as to produce mechanical output.

During such operation of the fuel reformer 11 and the engine 12, the control routine 200, at step 214, determines if a request to shutdown the engine 12 (i.e., an engine shutdown request) has been executed. An example of an engine shutdown request is turning an ignition key associated with the engine 12 from an on position to an off position. However, it should be appreciated that an engine shutdown request may take many different forms including, for example, an automatic shutdown request generated by a software control routine or the like, a timed shutdown request, or any other manual, software, or hardware-driven shutdown request. As such, in step 214, if the control routine 200 detects an engine shutdown request, a control signal is generated and the routine 200 advances to step 216. If the control routine 200 does not detect an engine shutdown request, the routine 200 loops back to step 212 to continue operation of the fuel reformer 11 and the engine 12.

In step 216, the reformer controller 18 shuts down (i.e., ceases operation of) the fuel reformer 11. In particular, the reformer controller 18 generates an output signal on the signal line 22 so as to cease operation of the fuel reformer 11. More specifically, the reformer controller 11 communicates with the power supply 20 so as to shutdown the fuel reformer 11 thereby ceasing production of reformate gas by the fuel reformer 11. A control signal is generated, and the routine 200 advances to step 218.

In step 218, the engine is shutdown. In particular, the reformer controller 18 communicates with the engine control unit 26 to indicate to the engine control unit 26 that the fuel reformer 11 has been shut down. In response, the engine

control unit 26 shuts down (i.e., ceases operation of) the engine 12. It should be appreciated that the engine control unit 26 may continue operation of the engine 12 for a predetermined period of time subsequent to when the fuel reformer 11 is shut down. In particular, upon receipt of the signal from the reformer controller 18 indicating that the fuel reformer 11 has been shutdown, the engine control unit 26 may be configured to continue operation of the engine 12 for a predetermined period of time prior to shutting down the engine 12.

In such a way, reformate gas is purged from the outlet passageway of the fuel reformer (e.g., passageways 14, 114). In particular, in the case of when the reformate gas produced by the fuel reformer 11 is being supplied to the input of the engine 12 (see FIGS. 1 and 2), operation of the engine 12 for a period of time subsequent to shutdown of the fuel reformer 11 causes the reformate gas in the passageway 14 to be advanced into the intake of the engine 12 and subsequently combusted. In the case of when the reformate gas produced by the fuel reformer 11 is being supplied to an emission abatement device 31 (see FIG. 3), operation of the engine 12 for a period of time subsequent to shutdown of the fuel reformer 11 causes the reformate gas in the passageway 114 to be advanced to the emission abatement device 31 thereby purging the reformate gas from the passageway 114.

While the concepts of the present disclosure have been illustrated and described in detail in the drawings and foregoing description, such an illustration and description is to be considered as exemplary and not restrictive in character, it being understood that only illustrative embodiments have been shown and described and that all changes and modifications that come within the spirit of the disclosure are desired to be protected.

There are a plurality of advantages of the present disclosure arising from the various features of the system and method described herein. It will be noted that alternative embodiments of the system and method of the present disclosure may

not include all of the features described yet still benefit from at least some of the advantages of such features. Those of ordinary skill in the art may readily devise their own implementations of a system and method that incorporate one or more of the features of the present disclosure and fall within the spirit and scope of the present invention as defined by the appended claims.

CLAIMS:

1. A method of operating a power system, the method comprising:

operating a fuel reformer to reform a fuel to produce a reformate gas;

advancing the reformate gas into an internal combustion engine;

detecting an engine shutdown request;

ceasing operation of the fuel reformer in response to detection of the shutdown request; and

ceasing operation of the engine after cessation of operation of the fuel reformer.

2. The method of claim 1, wherein:

the advancing step comprises advancing the reformate gas from the fuel reformer into the engine via a passageway; and

the step of ceasing operation of the engine after cessation of operation of the fuel reformer comprises operating the engine for a predetermined period of time subsequent to cessation of operation of the fuel reformer to purge the reformate gas produced by the fuel reformer from the passageway.

3. The method of claim 1, wherein:

the step of ceasing operation of the fuel reformer comprises ceasing operation of the fuel reformer and generating a reformer-shutdown control signal in response thereto; and

the step of ceasing operation of the engine comprises ceasing operation of the engine in response to generation of the reformer-shutdown control signal.

4. The method of claim 3, wherein:

the advancing step comprises advancing the reformate gas from the fuel reformer into the engine via a passageway; and

the step of ceasing operation of the engine in response to generation of the reformer-shutdown control signal comprises operating the engine for a predetermined period of time subsequent to cessation of operation of the fuel reformer to purge the reformate gas produced by the fuel reformer from the passageway.

5. The method of claim 1, wherein the step of ceasing operation of the engine comprises:

determining when a predetermined period of time has elapsed since cessation of operation of the fuel reformer and generating a time-lapsed control signal in response thereto; and

ceasing operation of the engine in response to generation of the time-lapsed control signal.

6. The method of claim 5, wherein:

the advancing step comprises advancing the reformate gas from the fuel reformer into the engine via a passageway; and

the step of ceasing operation of the engine in response to generation of the time-lapsed control signal comprises operating the engine for a predetermined period of time subsequent to cessation of operation of the fuel reformer to purge the reformate gas produced by the fuel reformer from the passageway.

7. The method of claim 1, further comprising generating a commence-shutdown control signal in response to detecting the engine shutdown request and the step of ceasing operation of the fuel reformer comprises ceasing operation of the fuel reformer in response to the commence-shutdown control signal.

8. The method of claim 1, wherein:

the fuel reformer comprises a plasma fuel reformer, and

the step of ceasing operation of the fuel reformer comprises ceasing operation of the plasma fuel reformer.

9. A fuel reformer system for supplying a reformate gas to an internal combustion engine, the fuel reformer system comprising:

a fuel reformer; and

a reformer controller electrically coupled to the fuel reformer, the controller comprising (i) a processor, (ii) and a memory device electrically coupled to the processor, the memory device having stored therein a plurality of instructions which, when executed by the processor, causes the processor to:

detect an engine shutdown request, and

cease operation of the fuel reformer in response to detection of the shutdown request, but prior to cessation of operation of the internal combustion engine.

10. The fuel reformer system of claim 9, wherein the reformer controller is integrated into an engine control unit associated with the internal combustion engine.

11. The fuel reformer system of claim 9, wherein the reformer controller is electrically coupled to an engine control unit associated with the internal combustion engine.

12. The fuel reformer system of claim 9, wherein the plurality of instructions, when executed by the processor, further causes the processor to:

generate a reformer-shutdown control signal in response to cessation of operation of the fuel reformer, and

communicate the reformer-shutdown signal to an engine control unit associated with the engine.

13. The fuel reformer system of claim 9, wherein the plurality of instructions, when executed by the processor, further causes the processor to:

determine when a predetermined period of time has elapsed since cessation of operation of the fuel reformer and to generate a time-lapsed control signal in response thereto, and

communicate the time-lapsed control signal to an engine control unit associated with the engine.

14. The fuel reformer system of claim 9, wherein the plurality of instructions, when executed by the processor, further causes the processor to generate a commence-shutdown control signal in response to detection of the engine shutdown request and to cease operation of the fuel reformer in response to generation of the commence-shutdown control signal.

15. The fuel reformer system of claim 9, wherein the fuel reformer comprises a plasma fuel reformer.

16. A method of controlling a fuel reformer, comprising:

detecting an engine shutdown request and generating a commence-shutdown control signal in response thereto; and

ceasing operation of a fuel reformer in response to generation of the commence-shutdown control signal.

17. The method of claim 16, wherein the step of ceasing operation of the fuel reformer comprises ceasing operation of the fuel reformer before cessation of operation of an internal combustion engine associated with the fuel reformer.

18. The method of claim 16, further comprising purging a reformate gas produced by the fuel reformer from a passageway fluidly coupled to the fuel reformer and an internal combustion engine after cessation of operation of the fuel reformer but before cessation of operation of the engine.

19. The method of claim 16, further comprising purging a reformate gas produced by the fuel reformer from a passageway fluidly coupled to the fuel reformer and an emission abatement device subsequent to cessation of operation of the fuel reformer but before cessation of operation of an internal combustion engine fluidly coupled to the emission abatement device.

20. The method of claim 16, wherein:

the fuel reformer comprises a plasma fuel reformer, and

the ceasing step comprises ceasing operation of the plasma fuel reformer in response to generation of the commence-shutdown control signal .

AMENDED CLAIMS

[received by the International Bureau on 13 March 2004 (13.03.04);
original claims 1, 2, 4, 5 and 9 replaced by amended claims 1, 2, 4, 5 and 9;
claims 3 and 14 deleted; remaining claims unchanged]

1. A method of operating a power system, the method comprising:

operating a fuel reformer to reform a fuel to produce a reformate gas;

advancing the reformate gas into an internal combustion engine;

detecting an engine shutdown request;

ceasing operation of the fuel reformer in response to detection of the shutdown request and generating a reformer-shutdown control signal in response thereto; and

ceasing operation of the engine in response to generation of the reformer-shutdown control signal.

2. The method of claim 1, wherein:

the advancing step comprises advancing the reformate gas from the fuel reformer into the engine via a passageway; and

the step of ceasing operation of the engine comprises operating the engine for a predetermined period of time subsequent to generation of the reformer-shutdown control signal to purge the reformate gas produced by the fuel reformer from the passageway.

3. Cancelled.

4. The method of claim 1, wherein:

the advancing step comprises advancing the reformate gas from the fuel reformer into the engine via a passageway; and

the step of ceasing operation of the engine in response to generation of the reformer-shutdown control signal comprises operating the engine for a predetermined period of time subsequent to cessation of operation of the fuel reformer to purge the reformate gas produced by the fuel reformer from the passageway.

5. The method of claim 1, wherein the step of ceasing operation of the engine comprises:

determining when a predetermined period of time has elapsed since generation of the reformer-shutdown control signal and generating a time-lapsed control signal in response thereto; and

ceasing operation of the engine in response to generation of the time-lapsed control signal.

6. The method of claim 5, wherein:

the advancing step comprises advancing the reformate gas from the fuel reformer into the engine via a passageway; and

the step of ceasing operation of the engine in response to generation of the time-lapsed control signal comprises operating the engine for a predetermined period of time subsequent to cessation of operation of the fuel reformer to purge the reformate gas produced by the fuel reformer from the passageway.

7. The method of claim 1, further comprising generating a commence-shutdown control signal in response to detecting the engine shutdown request and the step of ceasing operation of the fuel reformer comprises ceasing operation of the fuel reformer in response to the commence-shutdown control signal.

8. The method of claim 1, wherein:

the fuel reformer comprises a plasma fuel reformer, and

the step of ceasing operation of the fuel reformer comprises ceasing operation of the plasma fuel reformer.

9. A fuel reformer system for supplying a reformate gas to an internal combustion engine, the fuel reformer system comprising:

a fuel reformer; and

a reformer controller electrically coupled to the fuel reformer, the controller comprising (i) a processor, (ii) and a memory device electrically coupled to the processor, the memory device having stored therein a plurality of instructions which, when executed by the processor, causes the processor to:

detect an engine shutdown request and generate a commence-shutdown control signal in response thereto, and

cease operation of the fuel reformer in response to generation of the commence-shutdown control signal, but prior to cessation of operation of the internal combustion engine.

10. The fuel reformer system of claim 9, wherein the reformer controller is integrated into an engine control unit associated with the internal combustion engine.

11. The fuel reformer system of claim 9, wherein the reformer controller is electrically coupled to an engine control unit associated with the internal combustion engine.

12. The fuel reformer system of claim 9, wherein the plurality of instructions, when executed by the processor, further causes the processor to:

generate a reformer-shutdown control signal in response to cessation of operation of the fuel reformer, and

communicate the reformer-shutdown signal to an engine control unit associated with the engine.

13. The fuel reformer system of claim 9, wherein the plurality of instructions, when executed by the processor, further causes the processor to:

determine when a predetermined period of time has elapsed since cessation of operation of the fuel reformer and to generate a time-lapsed control signal in response thereto, and

communicate the time-lapsed control signal to an engine control unit associated with the engine.

14. Cancelled.

15. The fuel reformer system of claim 9, wherein the fuel reformer comprises a plasma fuel reformer.

16. A method of controlling a fuel reformer, comprising:

detecting an engine shutdown request and generating a commence-shutdown control signal in response thereto; and

ceasing operation of a fuel reformer in response to generation of the commence-shutdown control signal.

17. The method of claim 16, wherein the step of ceasing operation of the fuel reformer comprises ceasing operation of the fuel reformer before cessation of operation of an internal combustion engine associated with the fuel reformer.

18. The method of claim 16, further comprising purging a reformate gas produced by the fuel reformer from a passageway fluidly coupled to the fuel reformer and an internal combustion engine after cessation of operation of the fuel reformer but before cessation of operation of the engine.

19. The method of claim 16, further comprising purging a reformate gas produced by the fuel reformer from a passageway fluidly coupled to the fuel reformer and an emission abatement device subsequent to cessation of operation of the fuel reformer but before cessation of operation of an internal combustion engine fluidly coupled to the emission abatement device.

20. The method of claim 16, wherein:

the fuel reformer comprises a plasma fuel reformer, and

the ceasing step comprises ceasing operation of the plasma fuel reformer in response to generation of the commence-shutdown control signal.

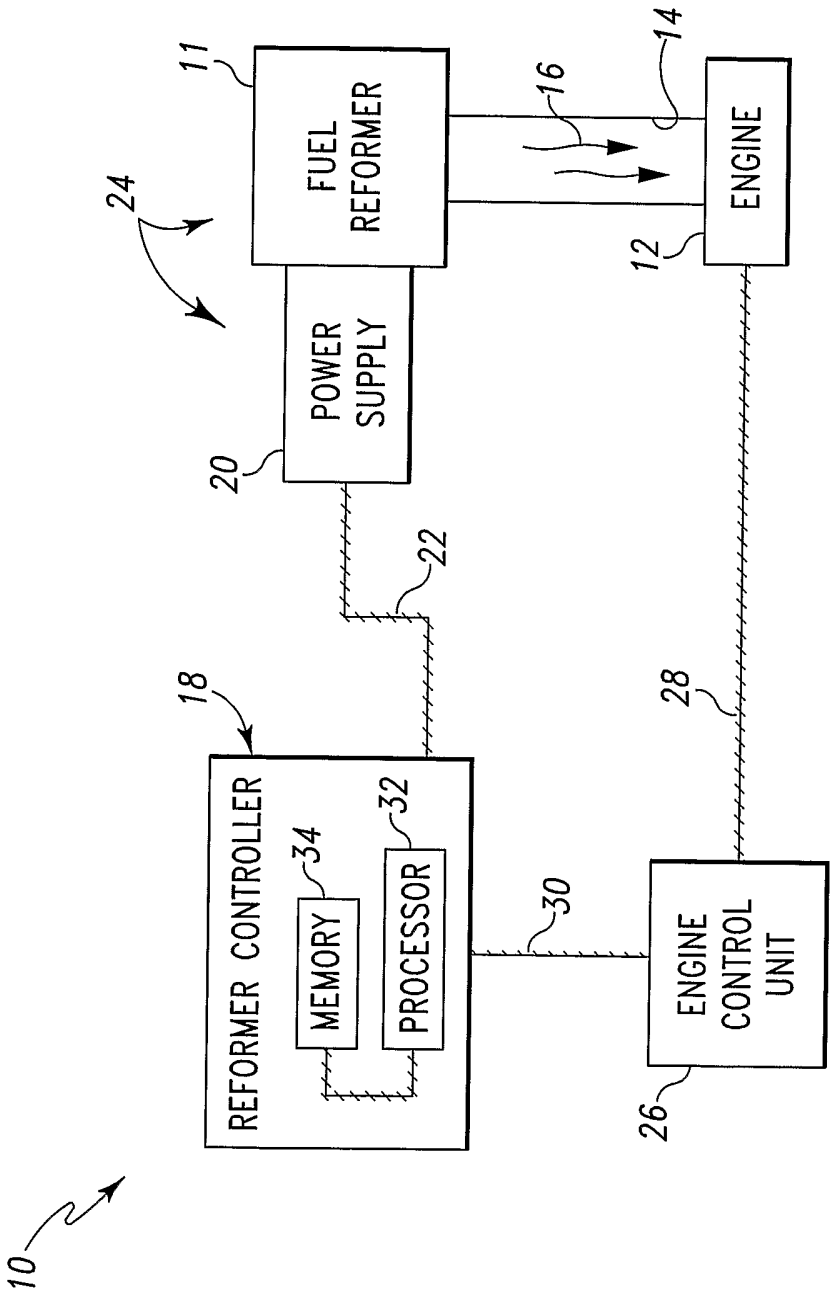

10
11
FUEL REFORMER
14
16
ENGINE
12
24
POWER SUPPLY
20
22
18
REFORMER CONTROLLER
MEMORY
34
PROCESSOR
32
30
28
ENGINE CONTROL UNIT
26

Fig. 1

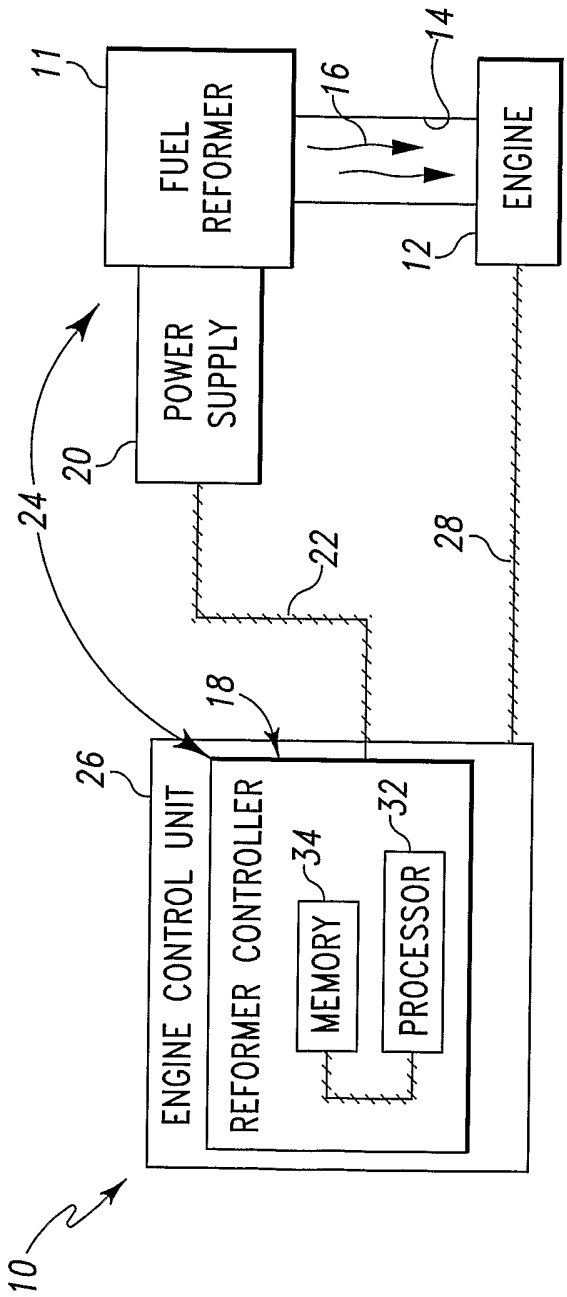

11
FUEL REFORMER
16
14
ENGINE
12
POWER SUPPLY
20
24
22
28
18
26
ENGINE CONTROL UNIT
REFORMER CONTROLLER
MEMORY
34
PROCESSOR
32
10

Fig. 2

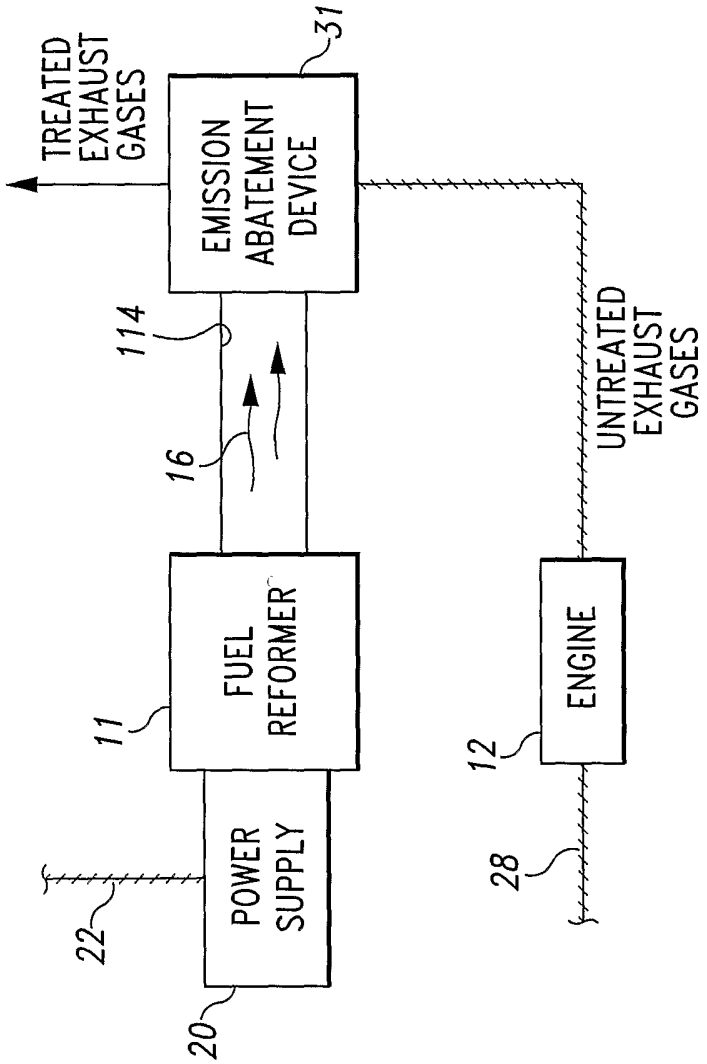

TREATED EXHAUST GASES
EMISSION ABATEMENT DEVICE
31
114
16
FUEL REFORMER
11
POWER SUPPLY
22
20
UNTREATED EXHAUST GASES
ENGINE
12
28

Fig. 3

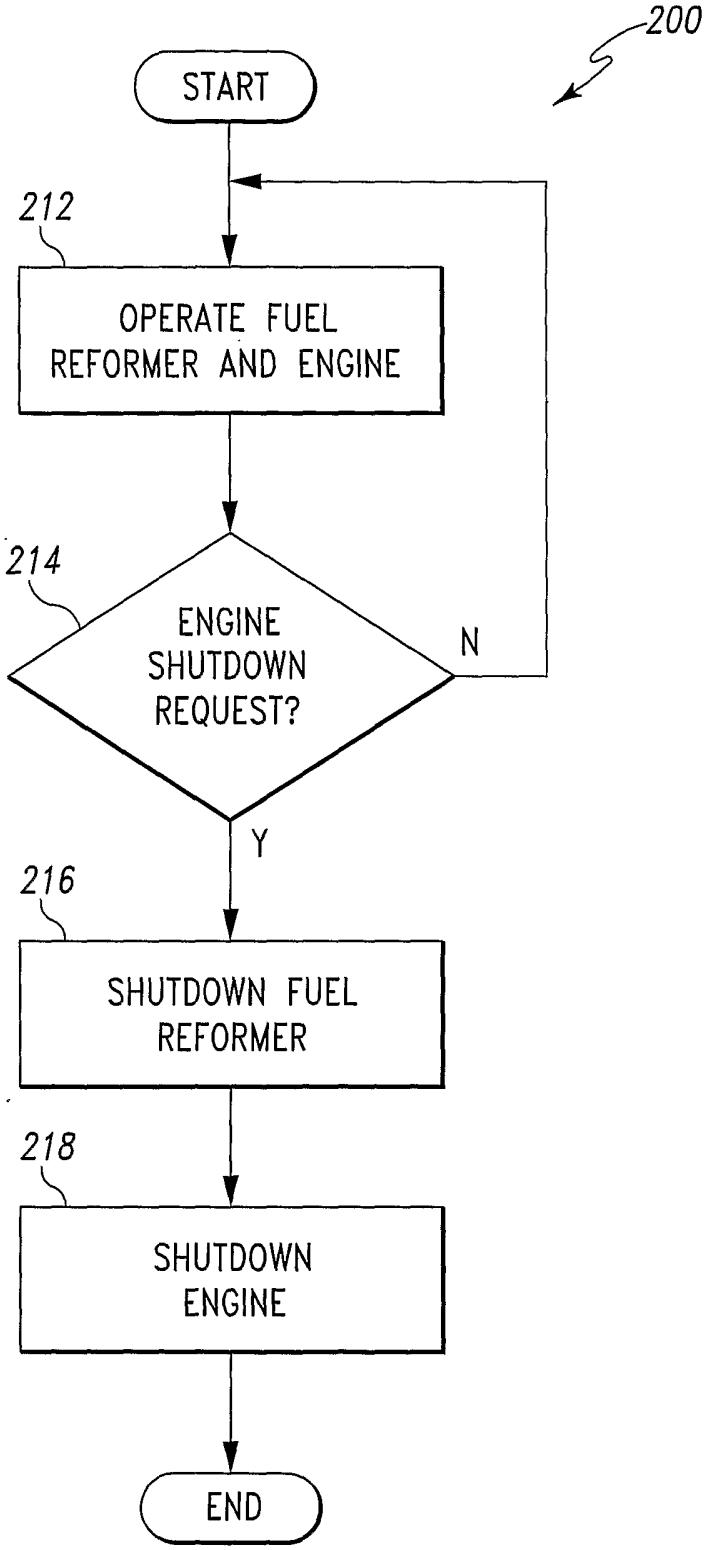

200
START
212
OPERATE FUEL REFORMER AND ENGINE
214
ENGINE SHUTDOWN REQUEST?
N
Y
216
SHUTDOWN FUEL REFORMER
218
SHUTDOWN ENGINE
END

Fig. 4

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US03/20555

A. CLASSIFICATION OF SUBJECT MATTER

IPC(7) : F02B 43/08
US CL : 123/3, DIG.12, 1A, 538, 537, 536

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
U.S. : 123/3, DIG.12, 1A, 538, 537, 536

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
NONE

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
NONE

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 5,887,554 A (COHN et al) 30 March 1999 (30.03.1999), column 6, lines 7-65.	1,2,8,9,15
Y	US 5,092,281 A (IWAKI et al) 03 March 1992 (03.03.1992), column 10, lines 17-40.	1,2,8,9,15
A	US 5,785,136 A (FALKENMAYER et al) 28 July 1998 (28.07.1998), see entire document.	1-20

☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search
09 September 2003 (09.09.2003)

Date of mailing of the international search report
30 SEP 2003

Name and mailing address of the ISA/US
Mail Stop PCT, Attn: ISA/US
Commissioner for Patents
P.O. Box 1450
Alexandria, Virginia 22313-1450
Facsimile No. (703)305-3230

Authorized officer
Henry C Yuen
Telephone No. (703) 308-0861

Form PCT/ISA/210 (second sheet) (July 1998)