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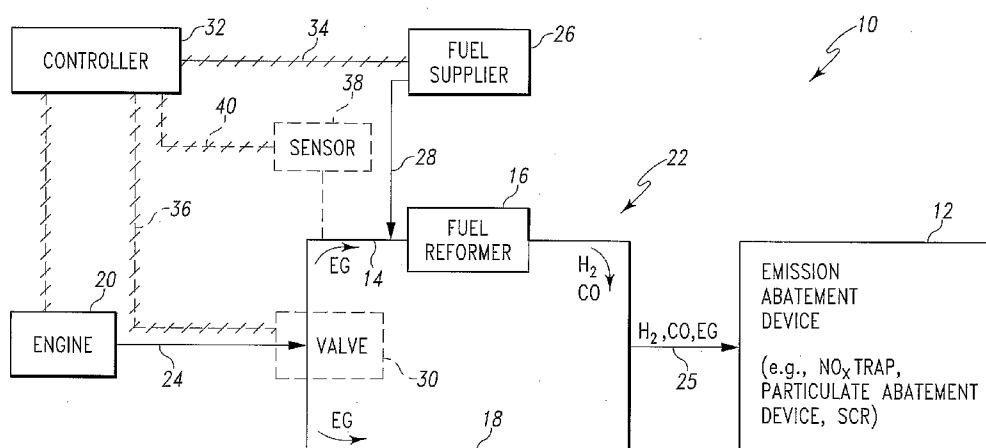
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[Continued on next page]

(54) Title: APPARATUS WITH IN SITU FUEL REFORMER AND ASSOCIATED METHOD



(57) Abstract: An apparatus (1) includes parallel and coaxial first and second exhaust gas passageways (14, 18), a fuel reformer (16) positioned in the first exhaust gas passageway (14) to generate partial combustion product (e.g., H₂ and/or CO), and a component such as an emission abatement device (12) or an internal combustion engine (20) positioned to receive the partial combustion product from the first exhaust gas passageway (14) and exhaust gas from the second exhaust gas passageway (18). An associated method is disclosed.

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- *as to the applicant's entitlement to claim the priority of the earlier application (Rule 4.17(iii))*

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APPARATUS WITH IN SITU FUEL REFORMER AND ASSOCIATED METHOD

5 FIELD OF THE DISCLOSURE

The present disclosure relates generally to exhaust systems and fuel reformers.

BACKGROUND OF THE DISCLOSURE

10 Fuel reformers may be used for a variety of purposes. In some cases, for example, fuel reformers are used in the process of regenerating emission abatement devices such as NO_x traps and particulate traps. In other cases, fuel reformers are used to provide hydrogen (H₂) to an internal combustion engine to enhance the fuel combustion process.

15

SUMMARY OF THE DISCLOSURE

According to a first aspect of the present disclosure, there is provided an apparatus having parallel and coaxial first and second exhaust gas passageways. A fuel reformer is positioned in the first exhaust gas passageway and configured to
20 partially combust fuel supplied to the first exhaust gas passageway with oxygen from exhaust gas present in the first exhaust gas passageway to generate partial combustion product. Placement of the fuel reformer in the first exhaust gas passageway facilitates control of the air-to-fuel ratio of the flow delivered to the fuel reformer and thus facilitates generation of the partial combustion product.

25

A component is fluidly coupled to the first and second exhaust gas passageways to receive the partial combustion product from the first exhaust gas passageway and exhaust gas from the second exhaust gas passageway. The component may be, for example, an emission abatement device (e.g., a NO_x trap, a particulate abatement device, a selective catalytic reduction device, or any
30 combination thereof) or an internal combustion engine.

According to a second aspect of the disclosure, the fuel reformer is a catalyst. The catalyst is activated by the heat of the exhaust gas in the first exhaust gas passageway and catalyzes a chemical reaction to partially combust the fuel into hydrogen (H_2) and carbon monoxide (CO) which are useful in the regeneration of
5 NOx traps and particulate abatement devices and may also be useful with selective catalytic reduction devices. The hydrogen (H_2) is also useful for enhancement of combustion of an internal engine.

The above and other features of the present disclosure will become apparent from the following description and the attached drawings.

10

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a simplified block diagram showing a first apparatus with an “in situ” fuel reformer positioned in an exhaust gas passageway to generate partial combustion product (e.g., H_2 and CO) for use in conjunction with an emission
15 abatement device;

Fig. 2 is a simplified block diagram showing a second apparatus with the “in situ” fuel reformer configured to generate partial combustion product provided to an internal combustion engine to enhance the combustion process in the engine;

Fig. 3 is a diagrammatic view showing a first coaxial parallel flow
20 arrangement for use with the first and second apparatus;

Fig. 3a is a diagrammatic view showing a second coaxial parallel flow arrangement for use with the first and second apparatus; and

Fig. 4 is a diagrammatic view showing a non-coaxial parallel flow arrangement for use with the first and second apparatus.

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DETAILED DESCRIPTION OF THE DRAWINGS

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 invention as defined by the appended claims.

Referring to FIG. 1, there is shown an apparatus 10 configured to generate partial combustion product such as hydrogen (H_2) and/or carbon monoxide (CO) for use in conjunction with a downstream component such as an emission abatement device 12. It does so by diverting a portion of a stream of exhaust gas (“EG” in the drawings) to flow into a first exhaust gas passageway 14 containing an “in situ” fuel reformer 16 configured, for example, as a catalyst. The fuel reformer 16 partially combusts a hydrocarbon fuel (e.g., diesel fuel) supplied to the passageway 14 with oxygen from exhaust gas present in the passageway 14 to produce the partial combustion product for delivery to the emission abatement device 12. The remainder of the exhaust gas passes through an exhaust gas passageway 18 parallel to the passageway 14.

Such an arrangement facilitates control of the air-to-fuel ratio of the flow delivered to the fuel reformer 16 and thus facilitates generation of the partial combustion product. Further, since oxygen of the exhaust gas is used, it avoids the need for a supplemental source of oxygen. In addition, an ignition source is not needed because the heat of the exhaust gas is sufficient for the partial combustion reaction.

The system 10 includes an internal combustion engine 20 (e.g., a diesel engine), a parallel flow arrangement 22, and the emission abatement device 12. The engine 20 produces the exhaust gas which flows through an exhaust gas supply passageway 24. The parallel flow arrangement 22 then divides the exhaust gas stream to flow into the parallel passageways 14, 18. A portion of the exhaust gas flows into the passageway 14 containing the fuel reformer 16. The other portion of the exhaust

gas flows into the passageway 18. The passageways 14, 18 recombine downstream from the fuel reformer 16 into a downstream exhaust gas passageway 25 which delivers the H₂ and/or CO produced by the fuel reformer 16 and the exhaust gas from the passageway 18 to the emission abatement device 12.

5 The emission abatement device 12 may be, for example, a NO_x trap, a selective catalytic reduction (SCR) device, or a particulate abatement device. A NO_x trap is used to remove NO_x from the exhaust gas. It does so by trapping NO_x present in the exhaust gas under lean conditions (as is normally the case in diesel exhaust) and reducing the trapped NO_x to nitrogen under rich conditions when the fuel reformer 16
10 is operated to produce the partial combustion product. The partial combustion product (e.g., H₂, CO) is thus useful as a NO_x-reducing agent. If the fuel reformer 16 is operated to produce the partial combustion product for a longer time, the partial combustion product can be used to desulphate the NO_x trap 16.

 An SCR device operates in conjunction with the partial combustion
15 product to convert NO_x into nitrogen without the need to first trap the NO_x and then release and reduce the NO_x. The SCR device is "selective" in the sense that it catalyzes a reaction between the partial combustion product (e.g., H₂, CO) generated by the fuel reformer 16 and NO_x present in the exhaust gas. The NO_x is thereby removed from the exhaust gas.

20 A particulate abatement device is used to remove particulates from the exhaust gas. It may take the form of a particulate trap (catalyzed or uncatalyzed) alone or in combination with an upstream oxidation catalyst (e.g., diesel oxidation catalyst). The partial combustion product (e.g., H₂, CO) may be oxidized in the presence of the catalyst of a catalyzed particulate trap or in the presence of an
25 upstream oxidation catalyst to generate heat useful for burning off particulate matter trapped by the particulate trap so as to regenerate the particulate trap.

 It is within the scope of this disclosure for the emission abatement device 12 to include any combination of a NO_x trap, an SCR device, and a particulate

abatement device. One such combination example is an SCR device and a particulate trap.

Fuel is supplied to the passageway 14 by a fuel supplier 26. A fuel line 28 of the fuel supplier 26 is coupled to the passageway 14 to supply fuel to
5 passageway 14 upstream from the fuel reformer 16. The fuel may be, for example, diesel fuel in liquid form or as a vapor. The fuel supplier 26 is not coupled to the passageway 18.

The system 10 may be used with or without an exhaust gas valve 30 to control flow of the exhaust gas between passageways 14, 18. In the case in which the
10 system 10 has the valve 30, the valve 30 may be located in either passageway 14, 18 or at the upstream junction of the two passageways 14, 18.

A controller 32 is electrically coupled to the fuel supplier 26 via an electrical line 34 and, when the valve 30 is included, it is electrically coupled to the valve 30 via an electrical line 36 to control operation of the fuel supplier 26 and the
15 valve 30. The controller 32 is thus able to vary the injection rate of fuel into passageway 14 and/or vary admission of exhaust gas and thus oxygen into passageway 14. In so doing, the controller 32 is able to control the air-to-fuel ratio of the flow delivered to the fuel reformer 16 to facilitate generation of the partial combustion product by the fuel reformer 16. Exemplarily, in the case where the
20 emission abatement device 12 is a NO_x trap, the controller 32 may cycle operation of the fuel supplier 26 so as to provide fuel to the passageway 14 for a predetermined period of time (e.g., three seconds) followed by a predetermined period of time (e.g., 60 seconds) in which fuel is not supplied to passageway 14.

To further facilitate the control of the air-to-fuel ratio, the system 10
25 may employ a sensor 38 and/or engine mapping to provide input(s) to the controller 32 for control of the fuel supplier 26 and/or the valve 30. The sensor 38 may be, for example, a lambda sensor coupled to the passageway 14 upstream from the fuel reformer 16 for sensing the air-to-fuel ratio of the flow in the passageway 14. In such

a case, the sensor 38 is electrically coupled to the controller 32 via an electrical line 40 to provide its sensor output to controller 32. The controller 32 may also have stored therein engine mapping information for control of the fuel supplier 26 and/or the valve 30 based on operational parameters associated with the engine 20 (e.g.,
5 engine rpm, temperature, throttle position).

The fuel reformer 16 is configured, for example, as a catalyst in the form of a catalyzed substrate. The catalyst is, for example, a metallic catalyst. In the case where the fuel reformer 16 is a catalyst, the temperature of the catalyst is elevated to its activation temperature by the heat of the exhaust gas. Moreover, use of
10 a catalyst obviates the need for an ignition source with its own power supply to ignite the combustible mixture in the passageway 14.

The apparatus 10 is thus able to generate partial combustion product through the use of relatively "fine" control of the air-to-fuel ratio of the flow delivered to the fuel reformer 16. Moreover, it does so by use of the oxygen and heat content of
15 the exhaust gas so that there is no need for supplemental oxygen or an ignition source. It is within the scope of this disclosure, however, to include such supplemental oxygen and an ignition source.

Referring to FIG. 2, there is shown a second apparatus 110 employing many of the components of the apparatus 10 for use in combustion enhancement of
20 the engine 20. In particular, the "in situ" fuel reformer 16 of the parallel flow arrangement 22 is used to generate partial combustion product such as H_2 which is advanced to the engine 20 to enhance the combustion of fuel (e.g., gasoline) in the engine 20. The system 110 is otherwise similar in structure and function to the system 10 so that identical reference numbers refer to similar components.

25 Referring to FIG. 3, there is shown a coaxial parallel flow arrangement 222 for use as the parallel flow arrangement 22 in the systems 10, 110. The arrangement 222 has a housing 224 and an inner tube 226 mounted in the housing 224. The housing 224 has an inlet port 228 that receives exhaust gas from the exhaust

gas supply passageway 24 and an outlet port 230 that discharges exhaust gas and partial combustion product to the downstream exhaust gas passageway 25.

An annular outer exhaust gas passageway 214 corresponding to the first exhaust gas passageway 14 of the systems 10, 110 is defined between the housing 224 and the inner tube 226. The passageway 214 contains the fuel reformer 16 which has an annular shape to fit in the passageway 214 around the inner tube 226 and an inner exhaust gas passageway 218 defined therein. A fuel dispenser ring 231 is secured to the housing 224 to dispense fuel received from the fuel line 28 into the passageway 214.

The inner tube 226 defines the inner exhaust gas passageway 218 which corresponds to the second exhaust gas passageway 18 of the systems 10, 110 to conduct exhaust gas so as to bypass the fuel reformer 16. The passageways 214, 218 are parallel and have a common axis 233 such that the passageways 214, 218 are coaxial. The optional valve 30 may be configured, for example, as a butterfly valve positioned in the inner exhaust gas passageway 218.

Referring to FIG. 3a, there is shown another coaxial parallel flow arrangement 222a for use as the parallel flow arrangement 22 in the systems 10, 110. The arrangement 222a is configured in a manner similar to the arrangement 222 except that the fuel reformer 16 is non-annular and is mounted in the inner tube 226 so as to be positioned in the passageway 218 rather than the passageway 214. A fuel dispenser 231a receives fuel from the fuel line 28 and is mounted to dispense fuel supplied thereby into the passageway 218. The valve 30 may also be used with the arrangement 222a to control flow of exhaust gas into the passageway 218.

Referring to both FIGS. 3 and 3a, the coaxial feature of the passageways 214, 218 of the arrangements 222, 222a provides a number of benefits. For example, the coaxial feature provides that each of the arrangements 222, 222a is relatively compact, which may be especially useful in environments where space economy is a factor (e.g., on board vehicles).

In addition, the coaxial feature promotes transfer of exhaust gas heat to the reformer 16 to facilitate operation of the reformer 16. More specifically, in the arrangement 222, heat of exhaust gas in the passageway 218 may be transferred to the surrounding reformer 16 and, in the arrangement 222a, heat of exhaust gas in the passageway 214 may be transferred to the reformer 16 surrounded by the passageway 214. Indeed, more heat may be transferred to the reformer 16 in the arrangement 222a than in the arrangement 222 since, in the arrangement 222a, the reformer 16 is spaced apart from the housing 224 which may be exposed to atmosphere. Such heat transfer to the reformer 16 may be especially useful when the reformer 16 is a catalyst having an activation temperature at which the catalyst becomes operational. Production of the partial combustion product is thus enhanced.

Referring to FIG. 4, there is shown a non-coaxial parallel flow arrangement 322 for use as the parallel flow arrangement 22 in the systems 10, 110. The arrangement 322 has a first conduit 324 and a second conduit 326. The conduits 324, 326 are secured to one another at upstream and downstream junctions and extend between such junctions outside of one another.

Exhaust gas is divided at the upstream junction to flow into a first exhaust gas passageway 314 corresponding to the passageway 14 of the systems 10, 110 and a second exhaust gas passageway 318 corresponding to the passageway 18 of the systems 10, 110. The passageways 314, 318 are parallel but not co-axial. A fuel dispenser 331 is secured to the first conduit 324 to dispense fuel from the fuel line 28 into the passageway 314. The reformer 16 is configured, for example, as a catalyst positioned in the first exhaust gas passageway 314 to partially combust the fuel with oxygen from the exhaust gas present in the passageway 314 into H_2 and/or CO. The passageways 314, 318 recombine at the downstream junction between the conduits 324, 326 for delivery of the H_2 and/or CO to the downstream exhaust gas passageway 25.

The optional valve 30 may be configured, for example, as a butterfly valve positioned in either passageway 314, 318 to control flow of exhaust into passageways 314, 318. Illustratively, the valve 30 is located in the passageway 318.

5 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 the 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.

10 There are a plurality of advantages of the concepts of the present disclosure arising from the various features of the systems described herein. It will be noted that alternative embodiments of each of the systems 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
15 own implementations of a system that incorporate one or more of the features of the present disclosure and fall within the spirit and scope of the invention as defined by the appended claims.

CLAIMS:

1. A method, comprising the steps of:
dividing a stream of exhaust gas to flow into parallel and coaxial first
5 and second exhaust gas passageways upstream from a component,
introducing fuel into the first exhaust gas passageway,
partially combusting the fuel introduced into the first exhaust gas
passageway with oxygen from the exhaust gas present in the first exhaust gas
passageway so as to generate partial combustion product, and
10 advancing the partial combustion product to the component.
2. The method of claim 1, wherein the dividing step comprises
advancing a first exhaust gas stream in the first exhaust gas passageway and a second
exhaust gas stream in the second exhaust gas passageway such that the first exhaust
15 gas stream either surrounds the second exhaust gas stream or is surrounded by the
second exhaust gas stream.
3. The method of claim 1, wherein the dividing step comprises
operating an exhaust gas valve to direct a portion of the exhaust gas stream into the
20 first exhaust gas passageway and a portion of the exhaust gas stream into the second
exhaust gas passageway.
4. The method of claim 1, wherein the combusting step comprises
operating a fuel reformer positioned in the first exhaust gas passageway.

5. The method of claim 4, wherein:
the fuel reformer is a catalyst, and
the operating step comprises partially combusting the fuel into
hydrogen (H₂) and carbon monoxide (CO) with the catalyst.
- 5
6. The method of claim 4, wherein the operating step comprises
the fuel reformer generating at least one of hydrogen (H₂) and carbon monoxide (CO)
by use of the oxygen and heat content of the exhaust gas present in the first exhaust
gas passageway without the assistance of additional oxygen from a supplemental
10 oxygen source and without the assistance of heat from an ignition source.
7. The method of claim 1, further comprising varying introduction
of at least one of fuel and exhaust gas into the first exhaust gas passageway so as to
control the air-to-fuel ratio of the flow supplied to the fuel reformer.
- 15
8. The method of claim 1, wherein:
the component comprises at least one of an emission abatement device
and an internal combustion engine, and
the advancing step comprises advancing the partial combustion product
20 from the first exhaust gas passageway to at least one of the emission abatement device
and the internal combustion engine.

9. An apparatus, comprising:
parallel and coaxial first and second exhaust gas passageways,
a fuel reformer positioned in the first exhaust gas passageway and
configured to partially combust fuel supplied to the first exhaust gas passageway with
5 oxygen from exhaust gas present in the first exhaust gas passageway to generate
partial combustion product, and
a component fluidly coupled to the first and second exhaust gas
passageways to receive the partial combustion product from the first exhaust gas
passageway and exhaust gas from the second exhaust gas passageway.

10

10. The apparatus of claim 9, wherein the first exhaust gas
passageway surrounds the second exhaust gas passageway.

15

11. The apparatus of claim 10, wherein:
the first exhaust gas passageway is annular, and
the fuel reformer is an annular catalyst positioned in the annular first
exhaust gas passageway so as to surround the second exhaust gas passageway.

20

12. The apparatus of claim 9, wherein the second exhaust gas
passageway surrounds the first exhaust gas passageway.

13. The apparatus of claim 9, wherein the first exhaust gas
passageway or the second exhaust gas passageway is annular.

25

14. The apparatus of claim 9, wherein the fuel reformer is a catalyst
configured to partially combust the fuel into at least one of hydrogen (H₂) and carbon
monoxide (CO).

15. The apparatus of claim 9, further comprising a fuel supplier that is fluidly coupled to the first exhaust gas passageway, but not fluidly coupled to the second exhaust gas passageway, to supply fuel to the fuel reformer.

5 16. The apparatus of claim 15, further comprising (i) an exhaust gas valve positioned to direct exhaust gas between the first and second exhaust gas passageways and (ii) a controller coupled to the fuel supplier and the valve to control operation thereof.

10 17. The apparatus of claim 9, wherein the component is a NO_x trap.

18. The apparatus of claim 9, wherein the component is a particulate abatement device.

15 19. The apparatus of claim 9, wherein the component is a selective catalytic reduction device.

20 20. The apparatus of claim 9, wherein the component is an internal combustion engine.

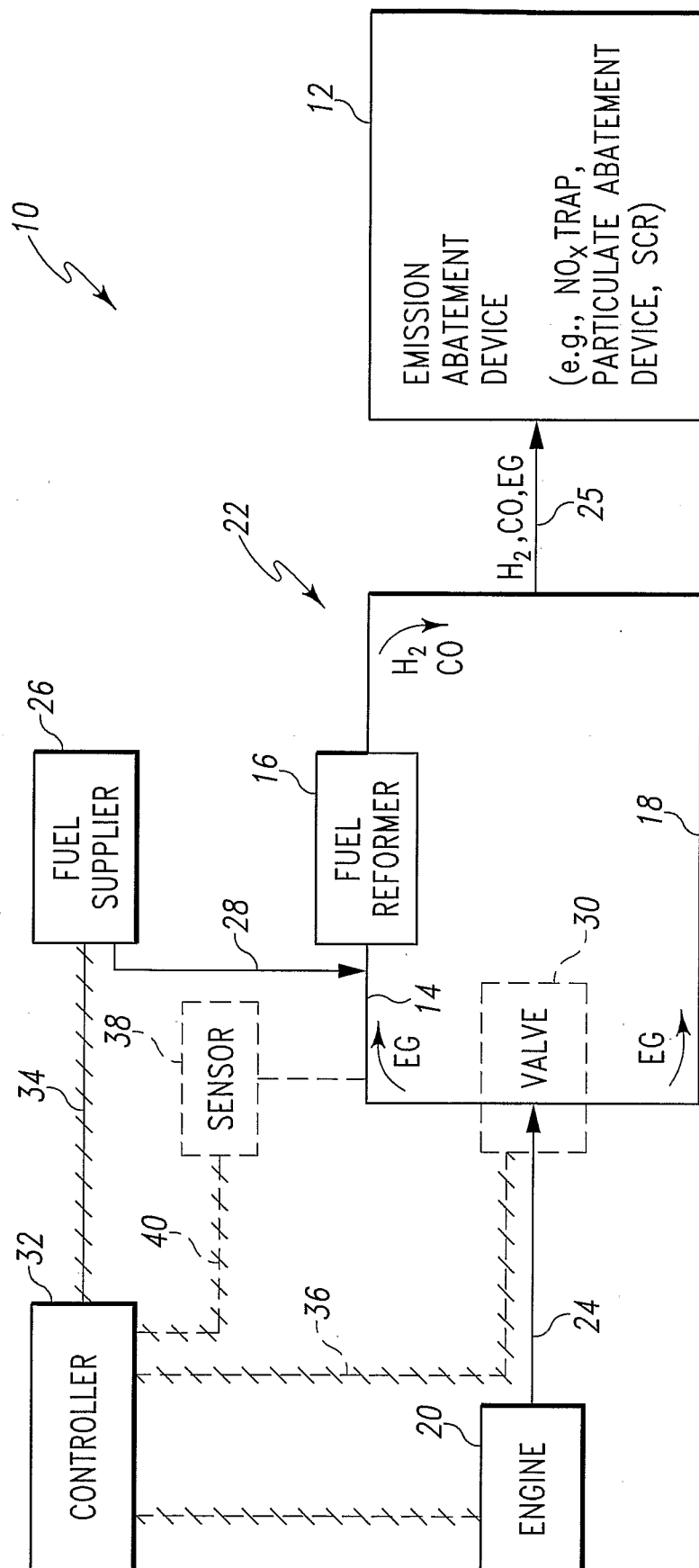


Fig. 1

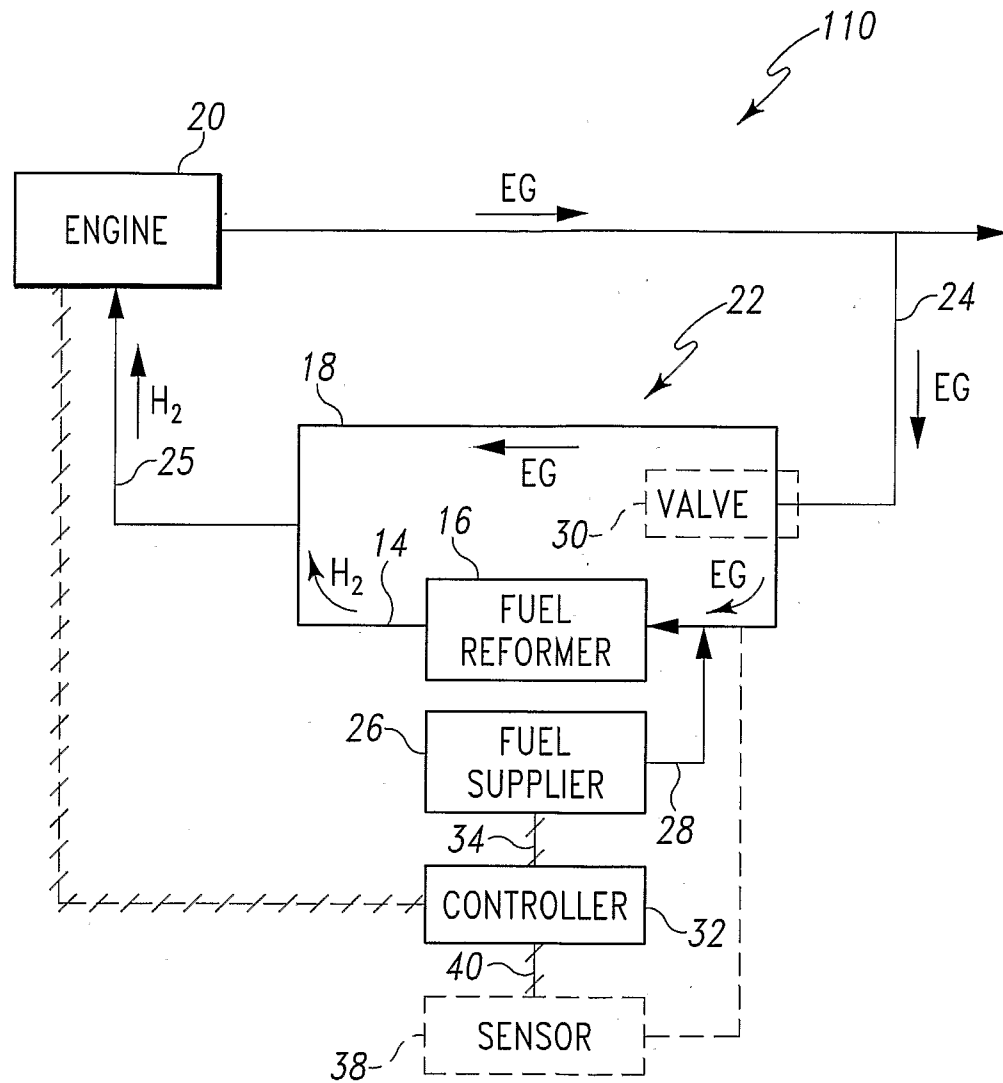


Fig. 2

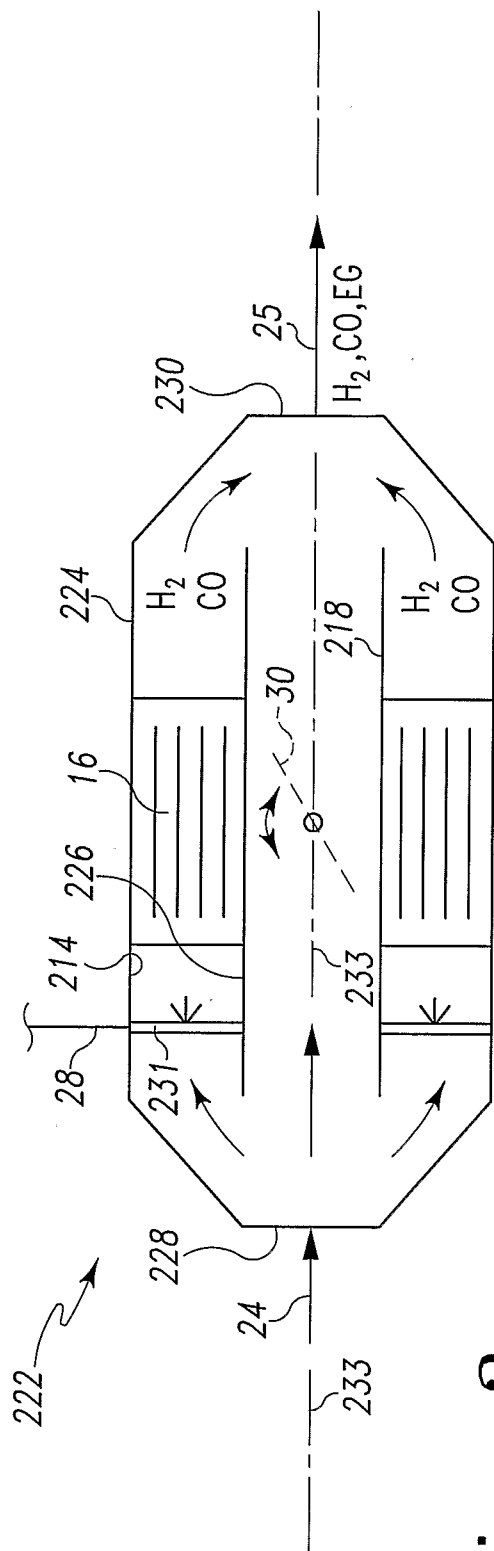


Fig. 3

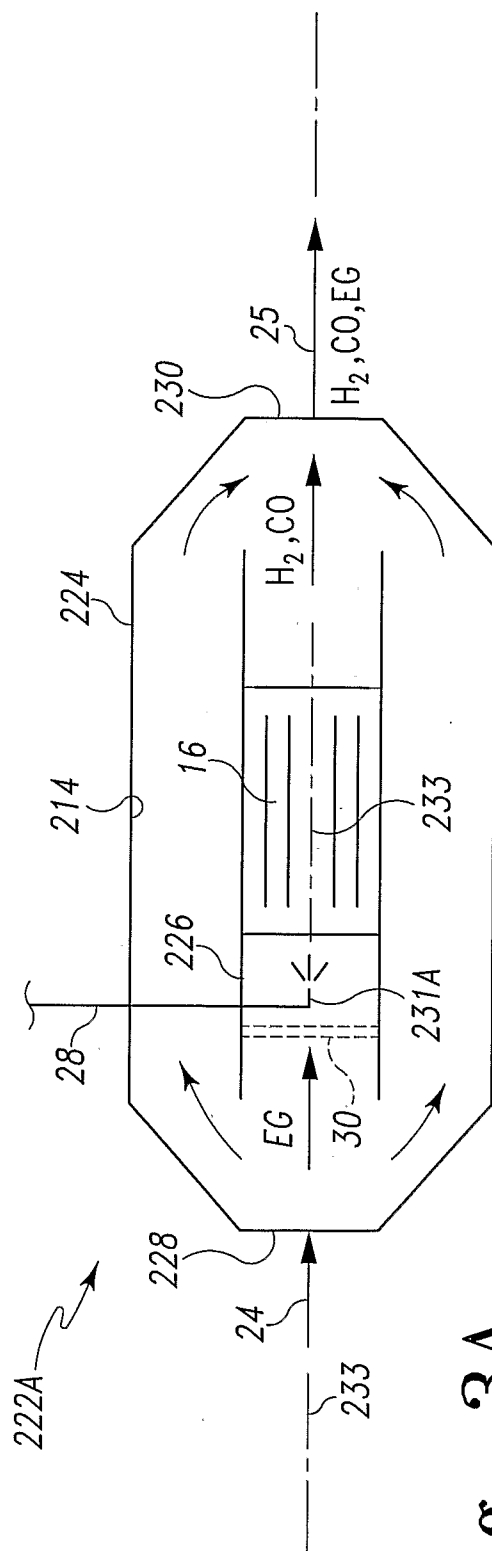


Fig. 3A

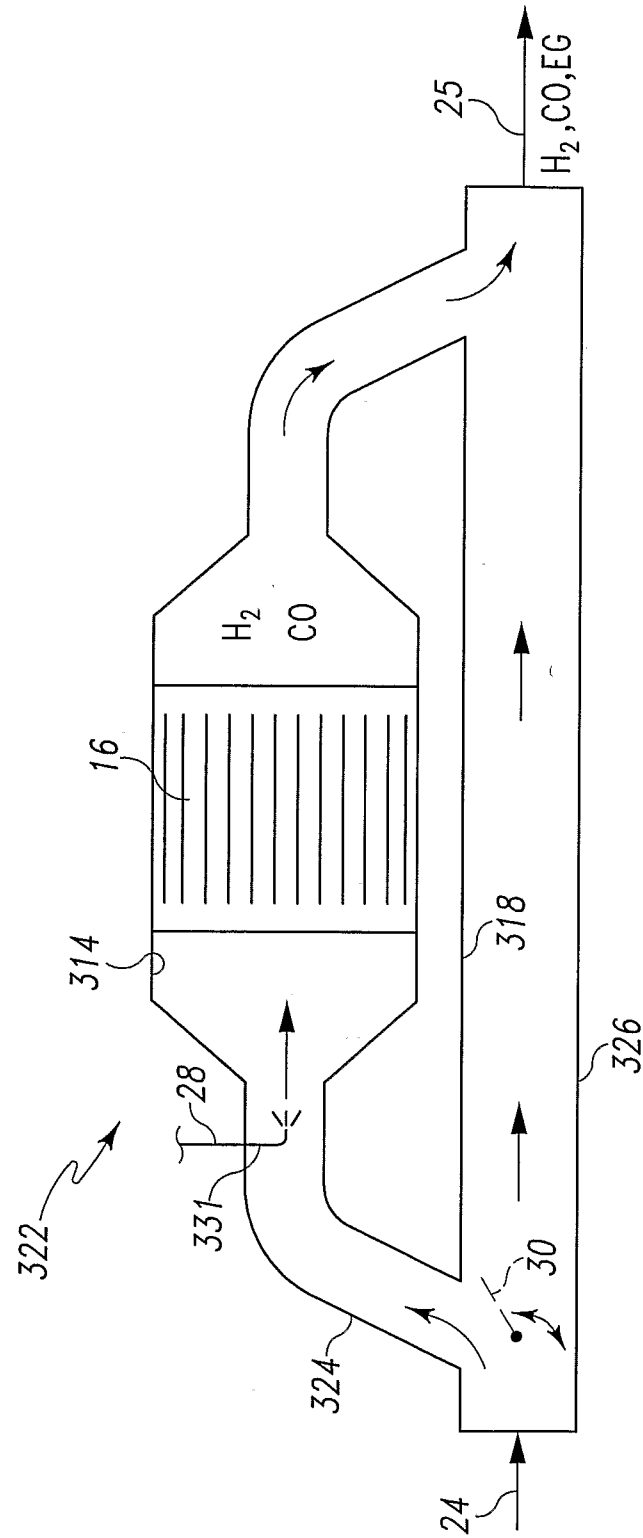


Fig. 4