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(54) **RICH CATALYTIC CLEAN BURN FOR LIQUID FUEL WITH FUEL STABILIZATION UNIT**

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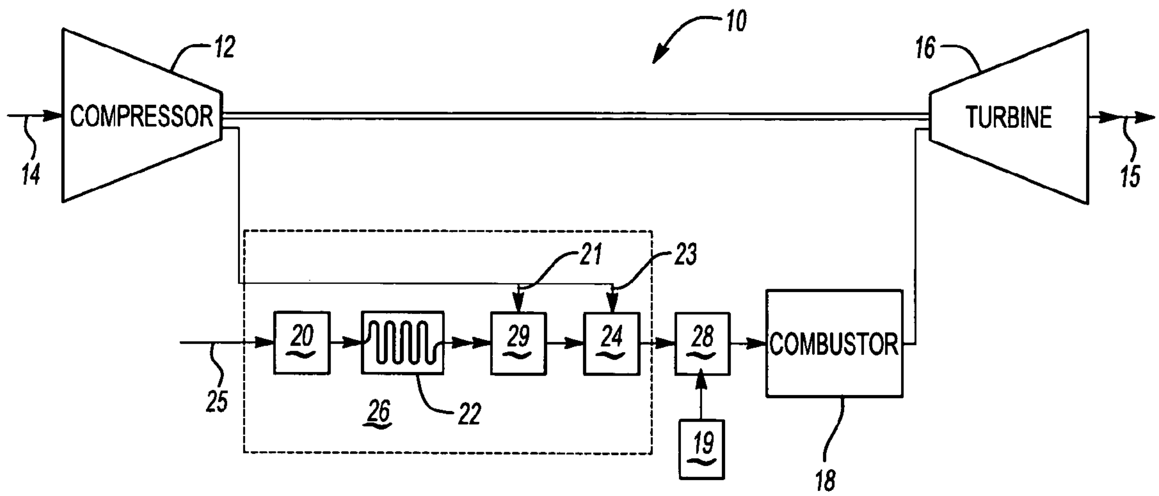
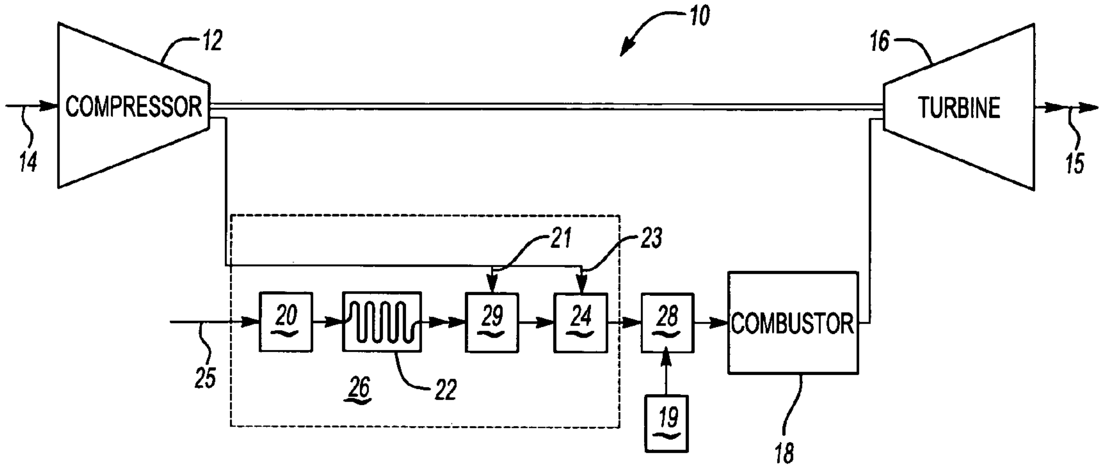
(57) **ABSTRACT**

A fuel stabilization system removes dissolved oxygen from a liquid fuel to allow vaporization of the liquid fuel without the undesirable production of insoluble materials and byproducts. The vaporized fuel is then mixed with oxidizers and reformed in the catalytic reactor. The resulting vaporized fuel provides for moderately low temperature sustained combustion with reduced emission of undesirable byproducts.




10
12
COMPRESSOR
16
TURBINE
14
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COMBUSTOR
25
26
22
19
18

Fig-1

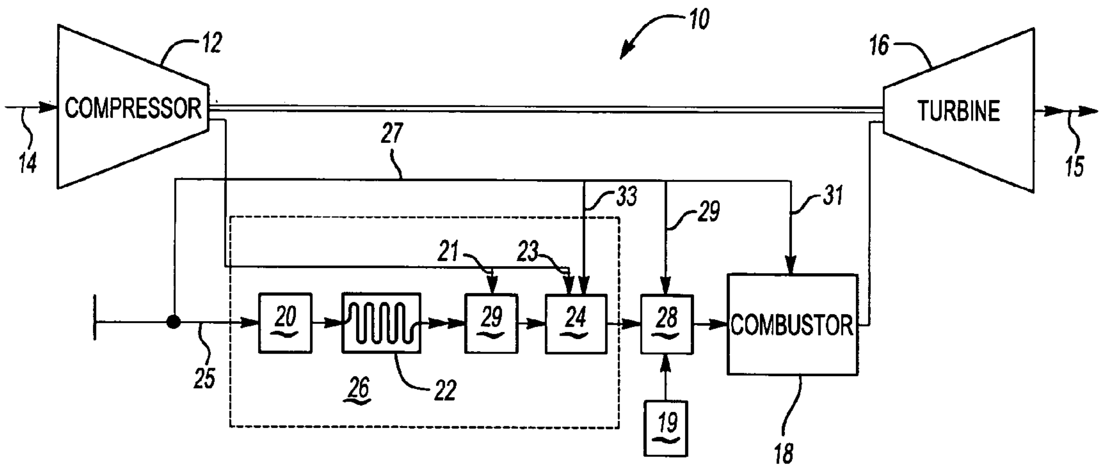
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Fig-2

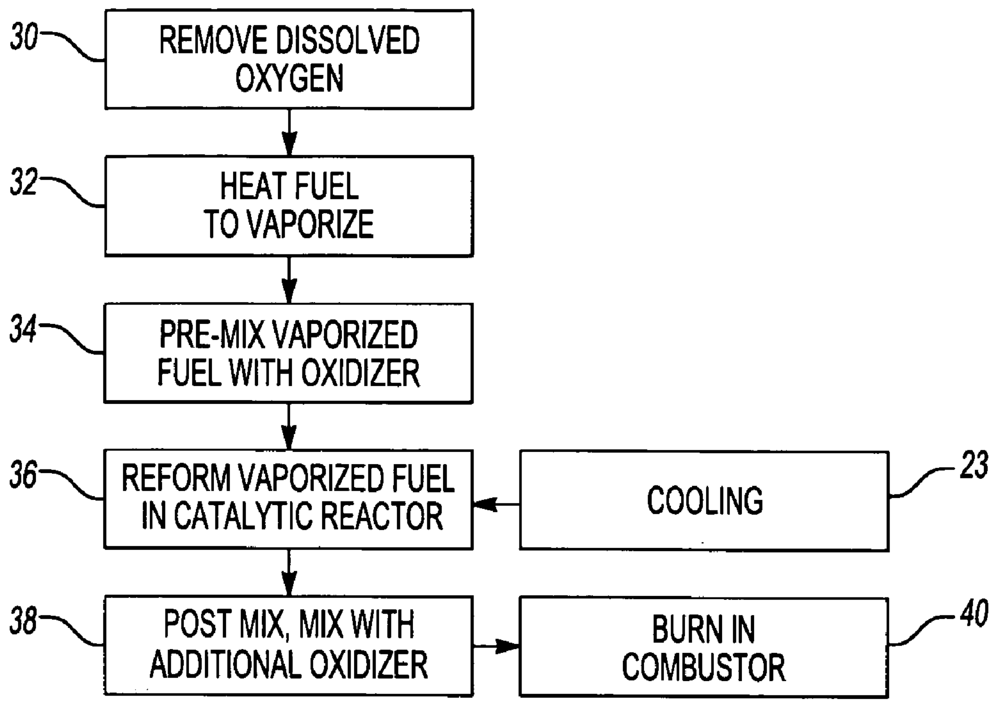
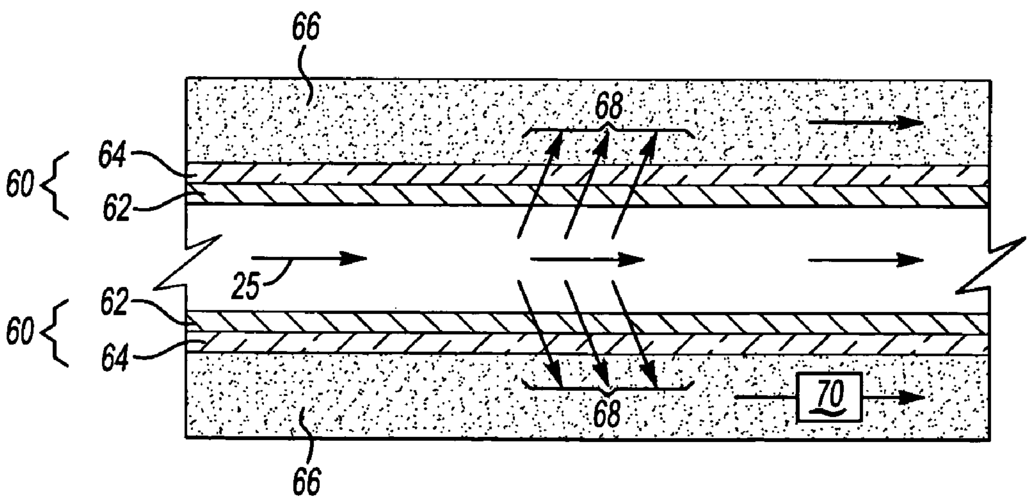

30
REMOVE DISSOLVED OXYGEN
32
HEAT FUEL TO VAPORIZE
34
PRE-MIX VAPORIZED FUEL WITH OXIDIZER
36
REFORM VAPORIZED FUEL IN CATALYTIC REACTOR
COOLING
23
38
POST MIX, MIX WITH ADDITIONAL OXIDIZER
BURN IN COMBUSTOR
40

Fig-3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68
64
60
62
25
62
60
64
68
70
66

Fig-4

RICH CATALYTIC CLEAN BURN FOR LIQUID FUEL WITH FUEL STABILIZATION UNIT

BACKGROUND OF THE INVENTION

[0001] This invention generally relates to a fuel delivery system for an energy conversion device. More particularly, this invention relates to a fuel delivery system including a fuel deoxygenator for removing dissolved oxygen providing for vaporizing fuel to improve combustion.

[0002] A gas turbine engine is an energy conversion device commonly used in aircraft and power generation applications. A gas turbine engine typically includes a compressor, a combustor and a turbine. Oxidizer entering the compressor is compressed and directed toward a combustor. Fuel is combined with the high-pressure oxidizer and ignited. Combustion gases produced in the combustor drive the turbine.

[0003] Turbine engines that burn liquid fuel produce emissions that can include oxides of nitrogen (NOx), carbon monoxide (CO), unburned hydrocarbons (UHC) and other particulates. It is desirable to reduce the level of these elements emitted from the engine. Using fuel in a gas form such as natural gas that is premixed to form a lean mixture substantially reduces emission of undesirable elements. Vaporization and premixing of a liquid fuel also provide for the reduction of undesirable emissions.

[0004] However, heating to vaporize a liquid hydrocarbon fuel can result in the production of undesirable insoluble materials commonly known as "coking". Coking can cause formation of coke deposits within the fuel system, clogging passages and degrading overall engine performance. The formation of coke deposits is dependent on the amount of dissolved oxygen present within the fuel due to prior exposure to oxidizer. Reducing the amount of oxygen dissolved within the fuel decreases the rate of coke deposition and increases the maximum allowable temperature in which the fuel can be heated without forming coke deposits.

[0005] Further, adding additional compounds to a vaporized fuel can provide a lean mixture for burning in the combustor that provides for reduced emissions. The addition of an oxidizer within a catalytic reactor provides a reformed fuel that improves the combustion process. It is therefore desirable to develop a process and design a system for improving combustion that provides for the vaporization of a liquid fuel without generating undesirable coke deposits.

SUMMARY OF THE INVENTION

[0006] An example low emission rich catalytic combustion system according to this invention removes dissolved oxygen from a liquid fuel to allow vaporization without the undesirable production of insoluble materials and byproducts.

[0007] The example fuel transforming system conditions fuel to optimize the combustion process and includes a fuel deoxygenator, a heat transfer device and a catalytic reactor. The fuel deoxygenator removes dissolved oxygen from liquid hydrocarbon fuel, allowing the fuel to be vaporized without the detrimental effects and production of unmanageable amounts of insoluble materials. The vaporized fuel is then mixed with oxidizers and reformed in the catalytic reactor. The resulting reformed fuel mixed with more oxidizer provides for low temperature sustained combustion with reduced emission of undesirable byproducts. The vaporization of the liquid fuel improves the combustion process by improving mixing of oxidizer and fuel, that in turn provides improved flame stabilization and a more complete and efficient burn.

[0008] Accordingly, the fuel transforming system and method of this invention improves combustion by providing for the vaporization of a liquid fuel without generating undesirable by-products.

[0009] These and other features of the present invention can be best understood from the following specification and drawings, the following of which is a brief description.

BRIEF DESCRIPTION OF THE DRAWINGS

[0010] FIG. **1** is a schematic illustration of an example engine system with a fuel stabilization unit according to this invention.

[0011] FIG. **2** is another schematic illustration of an example engine system with a fuel stabilization unit according to this invention.

[0012] FIG. **3** is a block diagram of a method of preparing fuel for combustion according to this invention.

[0013] FIG. **4** is a schematic cross-section of an example permeable membrane according to this invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

[0014] Referring to FIG. **1** an example gas turbine engine **10** according to this invention is schematically shown and includes a fuel transforming system **26** that conditions fuel to optimize the combustion process. As appreciated, although a gas turbine engine is discussed as the illustrated example, other combustion processes and devices such as reciprocating engines, steam engines and other know energy conversion devices will also benefit from this invention.

[0015] The gas turbine engine **10** includes a compressor **12** that compresses intake air **14**, a combustor **18** for igniting a fuel oxidizer mixture and a turbine **16** that turns in response to a flow of exhaust gases **15** produced in the combustor **18**.

[0016] The gas turbine engine **10** of this invention includes a fuel transforming system **26** that includes a fuel deoxygenator **20**, a heat transfer device **22** and a catalytic reactor **24**. Hydrocarbon fuel typically includes dissolved oxygen due to exposure with oxidizer during transport and storage. Dissolved oxygen within the fuel combines with other compounds within the fuel at elevated temperatures. The resulting interactions produce undesirable insoluble materials commonly referred to as "coke". The insoluble materials that build up due to these interactions can build up on the interior walls of the fuel transforming system **26** and combustor **18** causing an undesirable degradation in performance.

[0017] Removal of dissolved oxygen from the hydrocarbon fuel increases the temperature at which formation of insoluble materials begins appreciably, along with reducing the amount of insoluble material produced. The deoxygenator **20** removes dissolved oxygen from the fuel without significantly interfering with fuel.

[0018] In many combustion processes the fuel oxidizer mixture is a critical component to engine efficiency and emissions. A mixture including a greater percentage of fuel than that in stoichiometric mixture is known as a rich mixture and can be ignited and sustained at relatively lower combustion temperatures compared to stoichiometric combustion temperature. A mixture with a greater percentage of oxidizer than that in stoichiometric mixture is known as a lean mixture and operates at lower temperatures compared to stoichiometric combustion temperature. Operating the combustor at lower temperatures is preferable in some applications to produce lower level of oxides of nitrogen and to avoid the heat management devices and structures required to sustain high temperature combustion. However, combustion with too low temperature produces emissions with undesirable levels of byproducts such as carbon monoxides and unburned hydrocarbons and various other undesirable substances. The lean mixture operating at moderately low temperatures does not produce the high levels of NOx, CO and UHC. However, such lean mixtures are currently practical only with fuel in a gas state and are not practical utilizing common liquid hydrocarbon fuels.

[0019] The fuel transforming system **26** of this invention removes dissolved oxygen from a liquid hydrocarbon fuel supplied from a fuel source **25**, allowing the fuel to be vaporized without the appreciable detrimental effects and production of unmanageable amounts of insoluble materials. The vaporized fuel is then mixed with oxidizers **21** in premixer **29** to form a rich mixture and reformed in the catalytic reactor **24** which may need cooling as is schematically indicated by arrow **23** to ensure durability. The resulting vaporized fuel provides for low temperature sustained reaction that reduces the production of NOx in the catalytic reactor **24**. The vaporization of the liquid fuel improves the combustion process by improving mixing of oxidizer and fuel that in turn improves reaction in the catalytic reactor **24**. The transformed fuel processed in fuel transforming system **26** is then mixed with proper amount of oxidizer **19** in a post-mixer **28**, and becomes a lean mixture and reacted in combustor stably with minimal NOx, CO and UHC. Oxidizer **19** can be partly or fully supplied by part or all the cooling flow **23**.

[0020] Referring to FIG. **2**, another example of a gas turbine engine **10** and fuel transformation system **26** includes a quantity of fuel that flows through a bypass line **27** that bypasses the fuel transformation system **26** and is directly injected into the post-mixer **28** or the combustor **18**. As is appreciated, a substantial improvement in fuel conditioning is provided with only a portion of fuel being flowed through the fuel transformation system. Each component of the fuel transformation system **26** can induce a pressure drop or affect other fuel flow parameters. Balancing the amount of fuel that flows through the fuel transformation system **26** and the amount of fuel that is bypassed through the bypass **27** provides a means for tailoring fuel flow characteristics to improve combustion. For example, adding liquid fuel in the combustor **18** can improve the flame stability. Further, the bypass **27** is shown supplying fuel through line **29** to the post-mixer **28** and through line **31** directly to the combustor. Either or both lines maybe utilized to provide the desired fuel flow properties to achieve the desired combustion performance. Additionally, liquid fuel from the fuel source **25** may be directly injected through line **33** into the catalytic reactor **24**. Accordingly, a portion of liquid fuel can be routed around anyone or all of the components **20**, **22**, **29** and **24** in the system **26** to provide desired combustion performance and conditioning of fuel entering the combustor **18**.

[0021] Referring to FIG. **3**, the fuel transforming system **26** operates by first removing a significant amount of dissolved oxygen from within a stream of liquid hydrocarbon fuel **25** as is indicated at **30**. The dissolved oxygen is removed within the deoxygenator **20**. The amount of dissolved oxygen removed from the fuel is such that vaporization of the fuel will not cause appreciable undesirable production of unmanageable amounts of coke or other insoluble products. In some applications this may require the removal of oxygen such that dissolved oxygen comprises only 0.1 parts per million. Other applications may operate satisfactorily at higher oxygen concentrations.

[0022] Referring to FIG. **4**, the deoxygenator **20** includes an oxygen permeable membrane **60** over which the liquid fuel flows. An oxygen partial pressure differential across the permeable membrane **60** draws out dissolved oxygen **68** from the liquid fuel. Oxygen migrates through the permeable membrane **60** and is exhausted from the deoxygenator. The permeable membrane **60** is comprised of a permeable layer **62** applied over a porous backing **64**.

[0023] The permeable membrane **60** is supported along a porous substrate **66**. A vacuum source **70** creates an oxygen partial pressure differential across the permeable membrane **60** such that dissolved oxygen **68** is driven from the fuel **25** on a continual basis. The dissolved oxygen is then exhausted overboard or to other systems that may utilize it. Although an example of a permeable membrane is illustrated, it should be understood that it is within the contemplation of this invention that other known mechanisms that remove oxygen from fuel or other methods enabling liquid fuel being vaporized without appreciable coking are within the contemplation of this invention.

[0024] Referring to FIG. **3**, liquid fuel from the deoxygenator **20** flows into the heat transfer device **22** and is vaporized as indicated at **32**. Because the fuel is now substantially void of dissolved oxygen, heating or vaporization of the fuel does not result in the formation of undesirable amounts of insoluble materials. The now vaporized fuel is mixed with an oxidizer to aid reforming as is indicated at **36**. The reform products will typically include H2, CO, H2O and CO2. Other oxidizers, elements and compounds for aiding the combustion process may also be combined with the vaporized fuel and are within the contemplation of this invention.

[0025] The vaporized fuel is then reformed within the catalytic reactor **24** as indicated at **36**. The catalytic reactor **24** includes materials that cause favorable reactions within the fuel in preparation for combustion. Reform products emitted from the catalytic reactor **24** can then be mixed with additional oxidizer as indicated at **38**. The mixed fuel and oxidizer is then injected into the combustor **18** for combustion as is indicated at **40**.

[0026] Although a preferred embodiment of this invention has been disclosed, a worker of ordinary skill in this art would recognize that certain modifications would come within the scope of this invention. For that reason, the following claims should be studied to determine the true scope and content of this invention.

What is claimed is:

1. A method of operating a fuel transformation system for preparing liquid fuel for a combustion device comprising the steps of:

a) removing dissolved oxygen from a liquid fuel at a first temperature with a deoxygenation device;

b) heating the liquid fuel to a second temperature greater that the first temperature to vaporize at least a portion of the fuel;

c) mixing the vaporized fuel with an oxidizer; and

d) reforming the vaporized fuel oxidizer mixture in a catalytic reactor.

2. The method as recited in claim 1, including the step of mixing additional oxidizer after the vaporized fuel has reformed in the catalytic reactor.

3. The method as recited in claim 1, wherein said step a) comprises flowing liquid fuel adjacent an oxygen permeable membrane, and generating an oxygen partial pressure differential across said permeable membrane for drawing dissolved oxygen from the liquid fuel.

4. The method as recited in claim 1, wherein said first temperature is below a temperature that generates appreciable insoluble material produced by interactions between the fuel and the dissolved oxygen.

5. The method as recited in claim 1, wherein said second temperature is above a temperature that generates appreciable insoluble material produced by interactions between the fuel and the dissolved oxygen.

6. The method as recited in claim 1, including the step of burning the vaporized fuel oxidizer mixture within a combustor at a moderately low temperature.

7. The method as recited in claim 6, wherein said moderately low temperature comprises a temperature between 2000 and 3000 degrees F.

8. The method as recited in claim 1, including bypassing a portion of liquid fuel around the fuel transforming system, and another portion of the liquid fuel through the fuel transforming system.

9. The method as recited in claim 8, wherein the portion of liquid fuel bypassed around the fuel transforming system is received directly into the combustion device.

10. The method as recited in claim 8, wherein the portion of liquid fuel bypassed around the fuel transforming system is received directly into a post-mixing device.

11. A system for conditioning liquid fuel for a combustion device, said system comprising:

at least one fuel deoxygenator for removing dissolved oxygen from a liquid fuel;

a heating device for vaporizing at least a portion of the liquid fuel;

a mixing device for adding oxidizer to vaporized fuel; and

a catalytic reactor for reforming fuel after mixing with the oxidizer.

12. The system as recited in claim 11, including a second mixing device for adding additional oxidizer after being reformed within said catalytic reactor.

13. The system as recited in claim 11, wherein said fuel deoxygenator receives liquid fuel at a first temperature below a temperature that generates the formation of undesirable insoluble materials.

14. The system as recited in claim 13, wherein said heating device heats the fuel to a second temperature greater than said first temperature.

15. The system as recited in claim 11, wherein said liquid fuel flows through said deoxygenator and adjacent an oxygen permeable membrane.

16. The system as recited in claim 15, including an oxygen pressure differential across said oxygen permeable membrane for drawing dissolved oxygen from fuel flowing adjacent said permeable membrane.

17. The system as recited in claim 11, wherein said combustion device comprises a combustor for a gas turbine engine.

18. The system as recited in claim 11, including a bypass for routing a portion of fuel around at least one of the fuel deoxygenator, the heating device, the mixing device and the catalytic reactor.

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