US005590518A

United States Patent [19]

Janes

[11] **Patent Number: 5,590,518**

[45] **Date of Patent: Jan. 7, 1997**

[54] **HYDROGEN-RICH FUEL, CLOSED-LOOP COOLED, AND REHEAT ENHANCED GAS TURBINE POWERPLANTS**

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[21] Appl. No.: **546,729**

[22] Filed: **Oct. 23, 1995**

Related U.S. Application Data

[63] Continuation-in-part of Ser. No. 182,661, Jan. 12, 1994, Pat. No. 5,490,377, which is a continuation-in-part of Ser. No. 139,525, Oct. 19, 1993, abandoned.

[51] **Int. Cl.**[6] **F02C 3/28**

[52] **U.S. Cl.** **60/39.12**; 60/39.17; 60/39.511

[58] **Field of Search** 60/39.04, 39.12, 60/39.17, 39.511, 39.58, 39.59, 728, 736, 744, 745; 415/114

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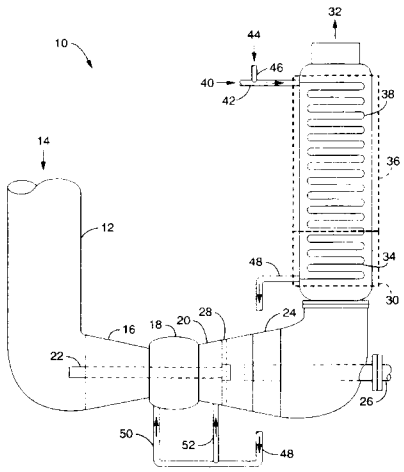
[57] **ABSTRACT**

A gas turbine driven powerplant in which a mixture of steam and a combustible effluent, such as methane, is reformed or partially oxidized to produce a hydrogen-rich fuel which is used to fuel both the primary combustor and a reheat combustor positioned upstream of the final turbine stage, such as the power turbine. Reheat combustion is effected by injecting the hydrogen-rich fuel through the cooling orifices of the first turbine upstream of the final turbine stage and into the gas turbine flow path from the trailing edge of the stationary vanes and/or rotating blades, where the fuel auto ignites with complete combustion occurring at a nominal distance after injection into the air stream. Further, the hydrogen-rich fuel can be used as a coolant for the final turbine stage to allow higher reheat temperatures to be achieved. This reheat design, which will simultaneously provide turbine cooling and supply a reheat fuel that will auto-ignite and burn cleanly, provides the efficiency benefits of reheat without significant or costly redesign of the final turbine stage, and without adding new equipment.

15 Claims, 10 Drawing Sheets



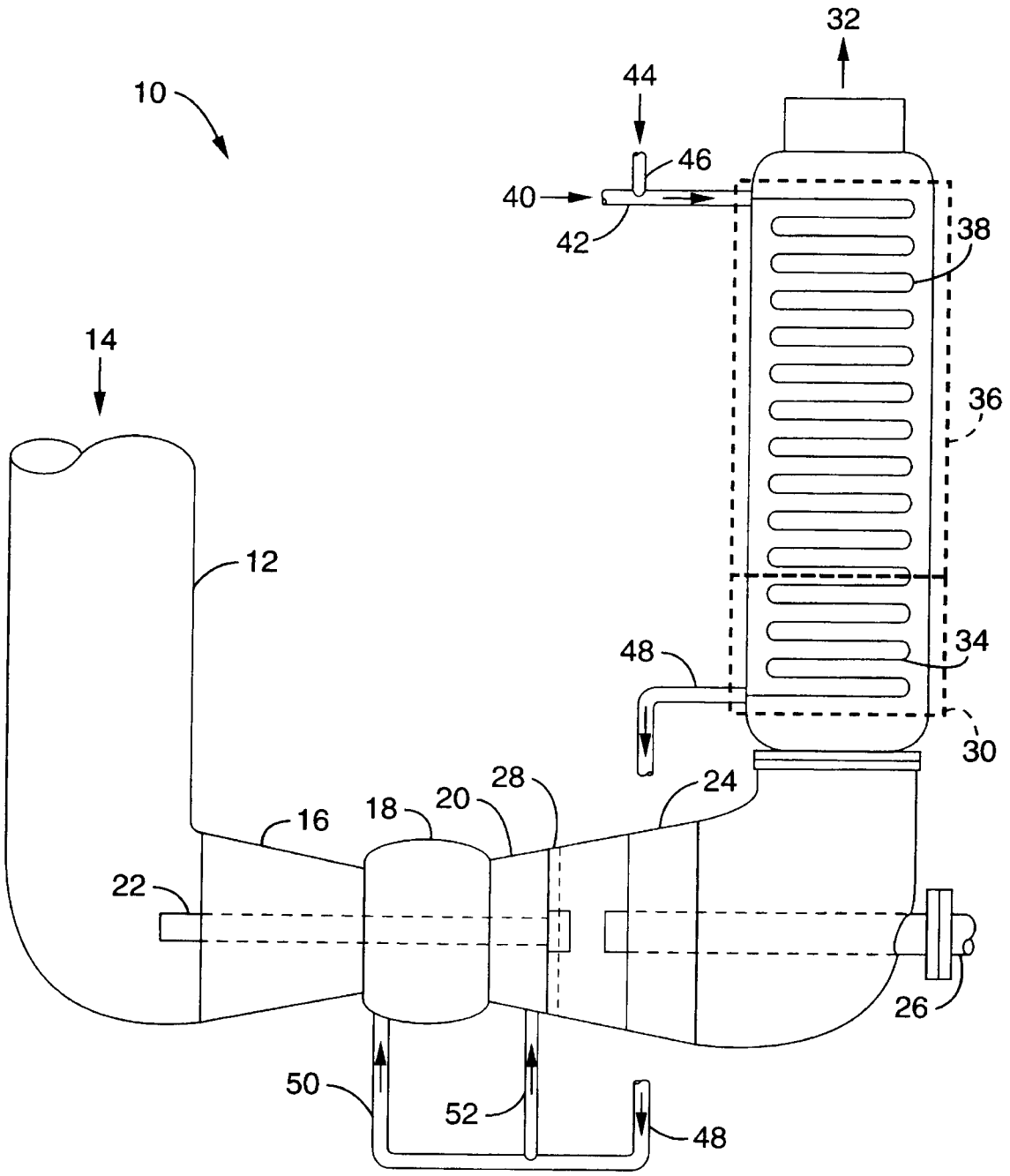


FIG. – 1

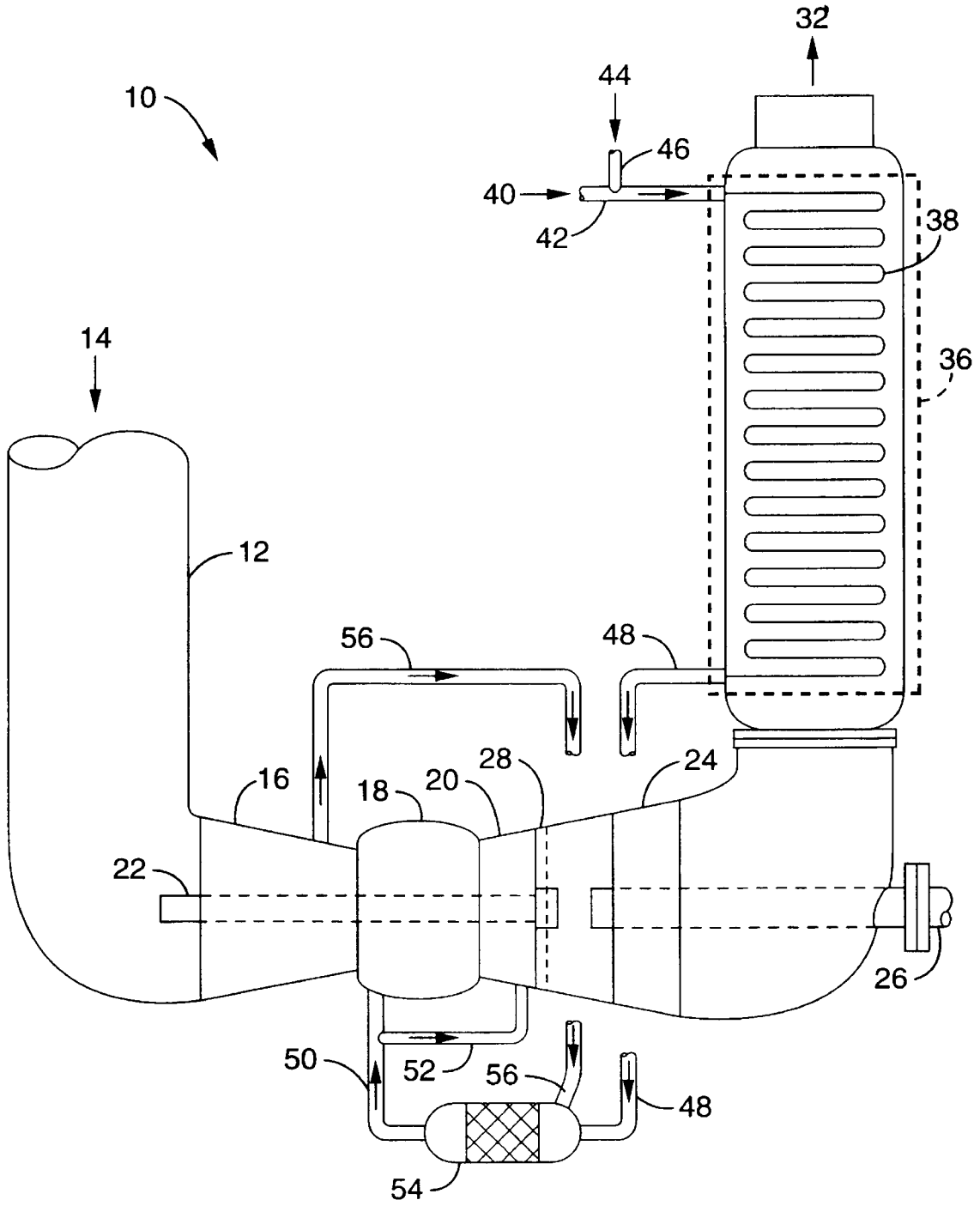


FIG. – 2

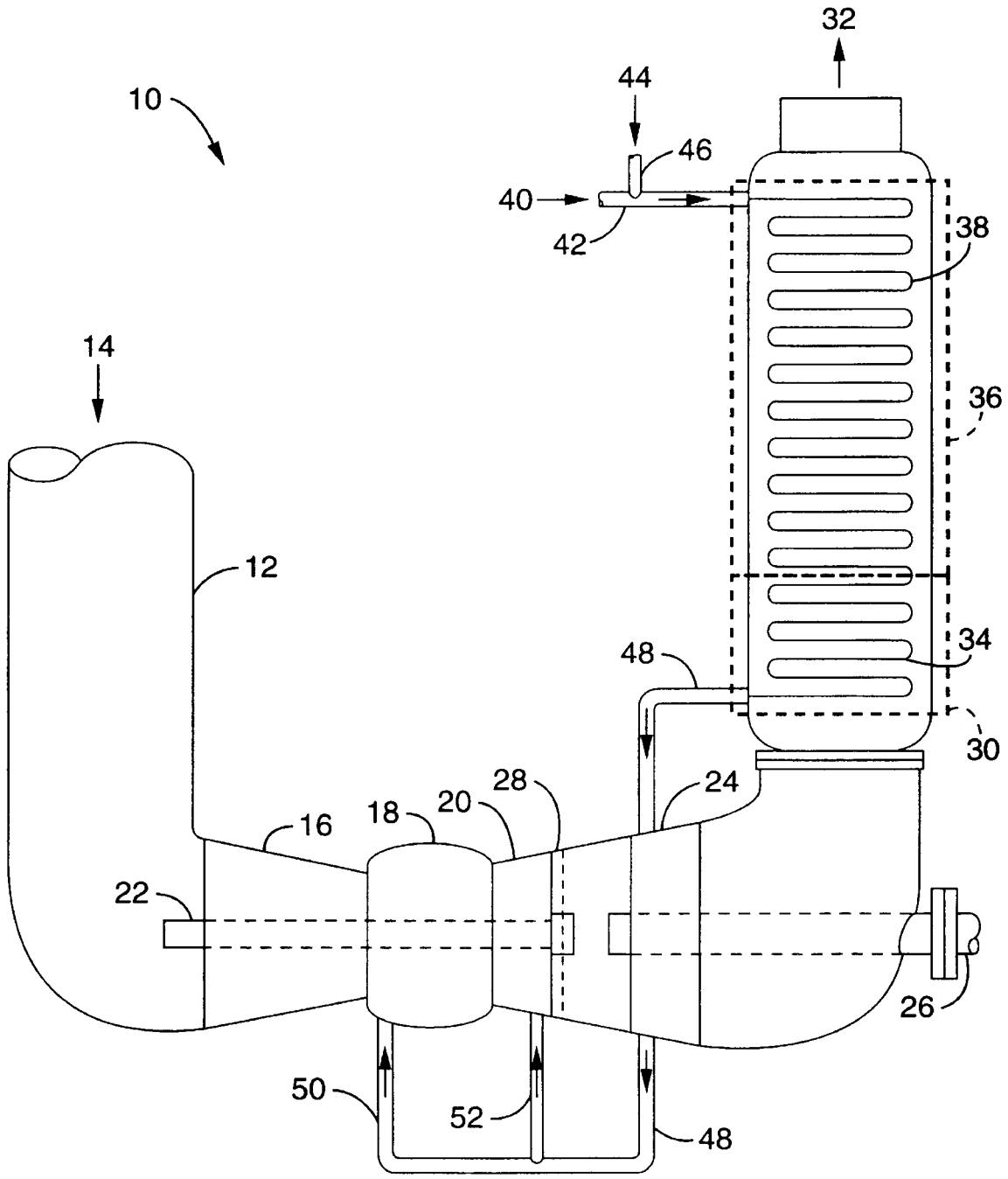


FIG. – 3

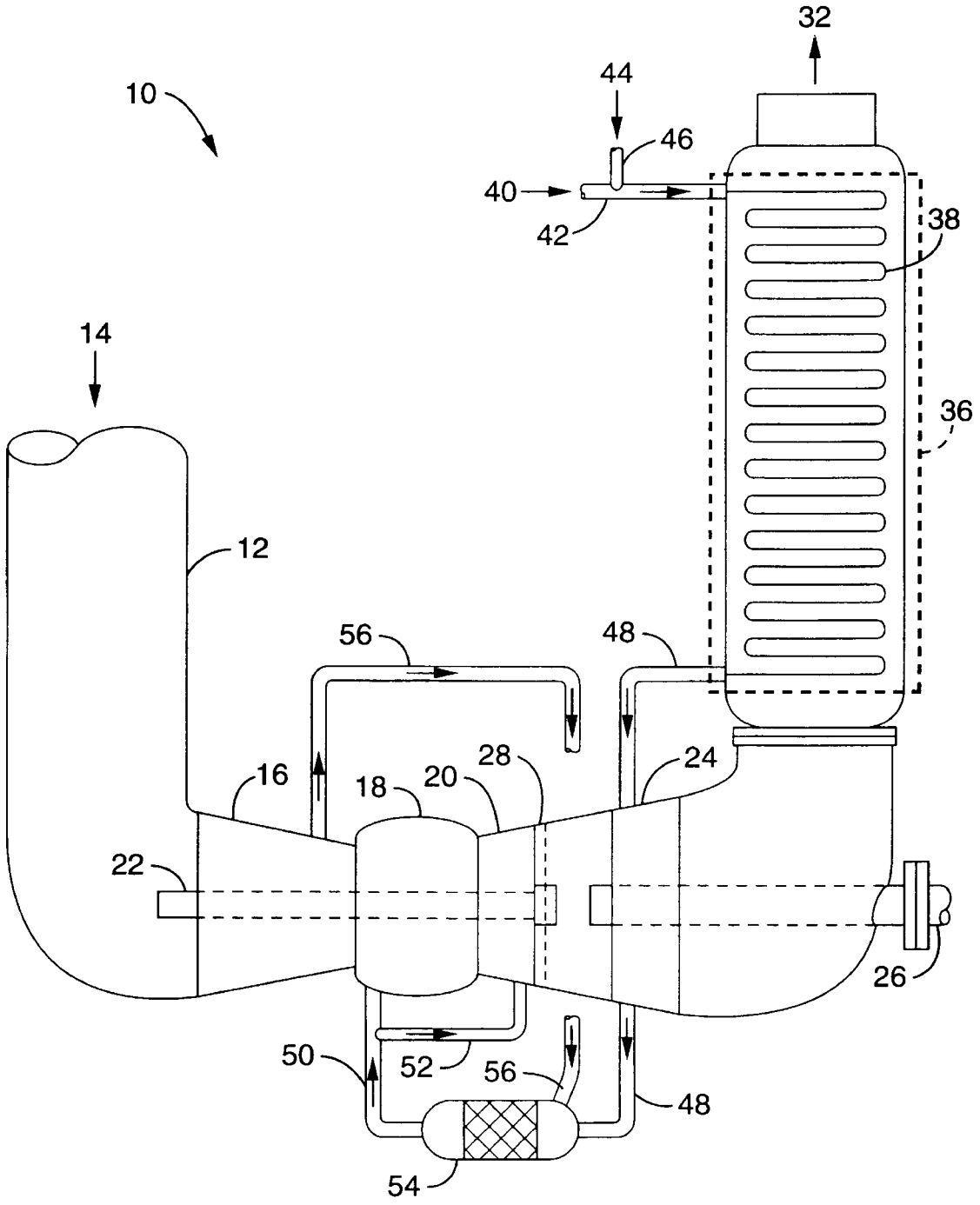


FIG. – 4

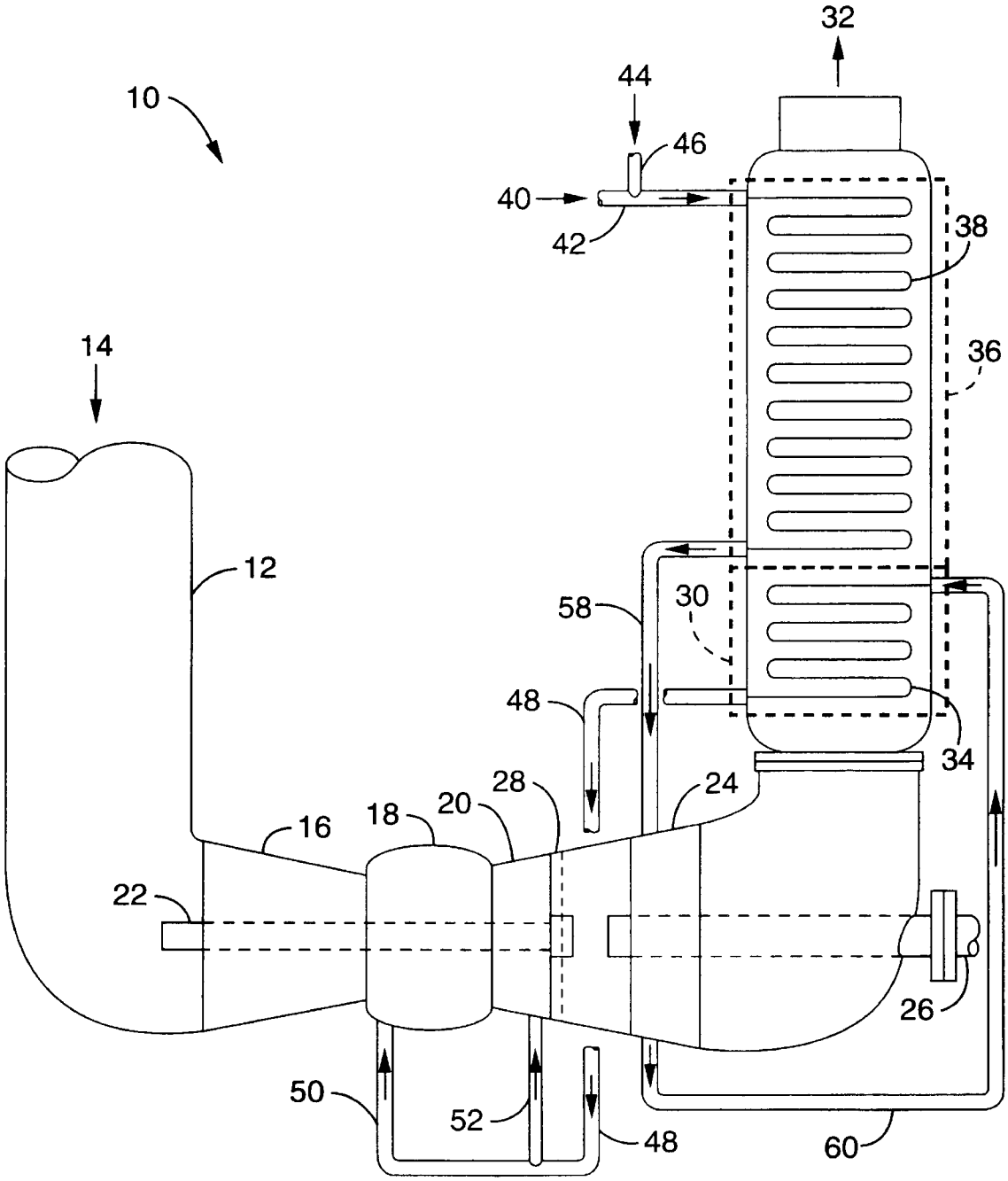


FIG. – 5

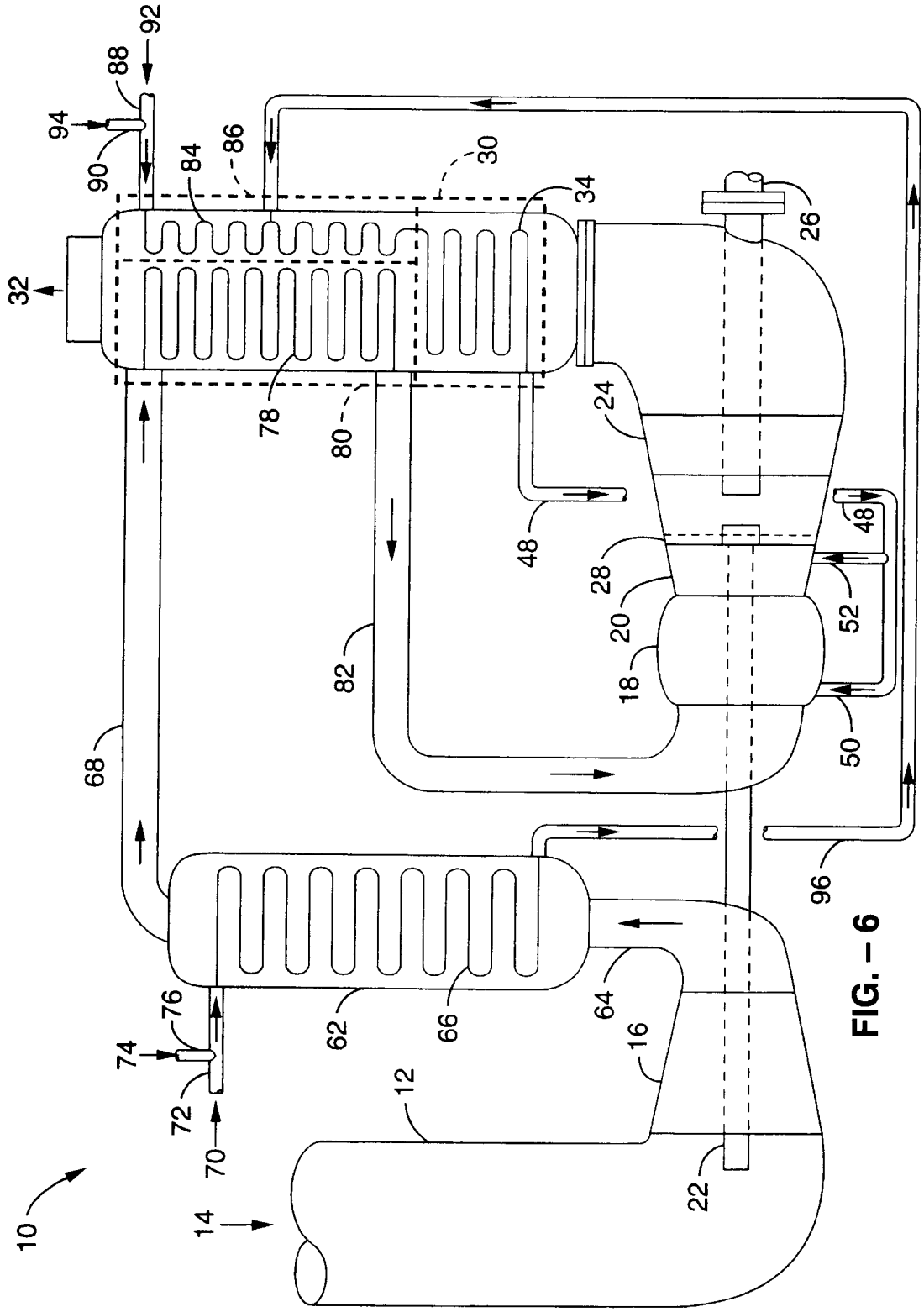

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FIG. – 6

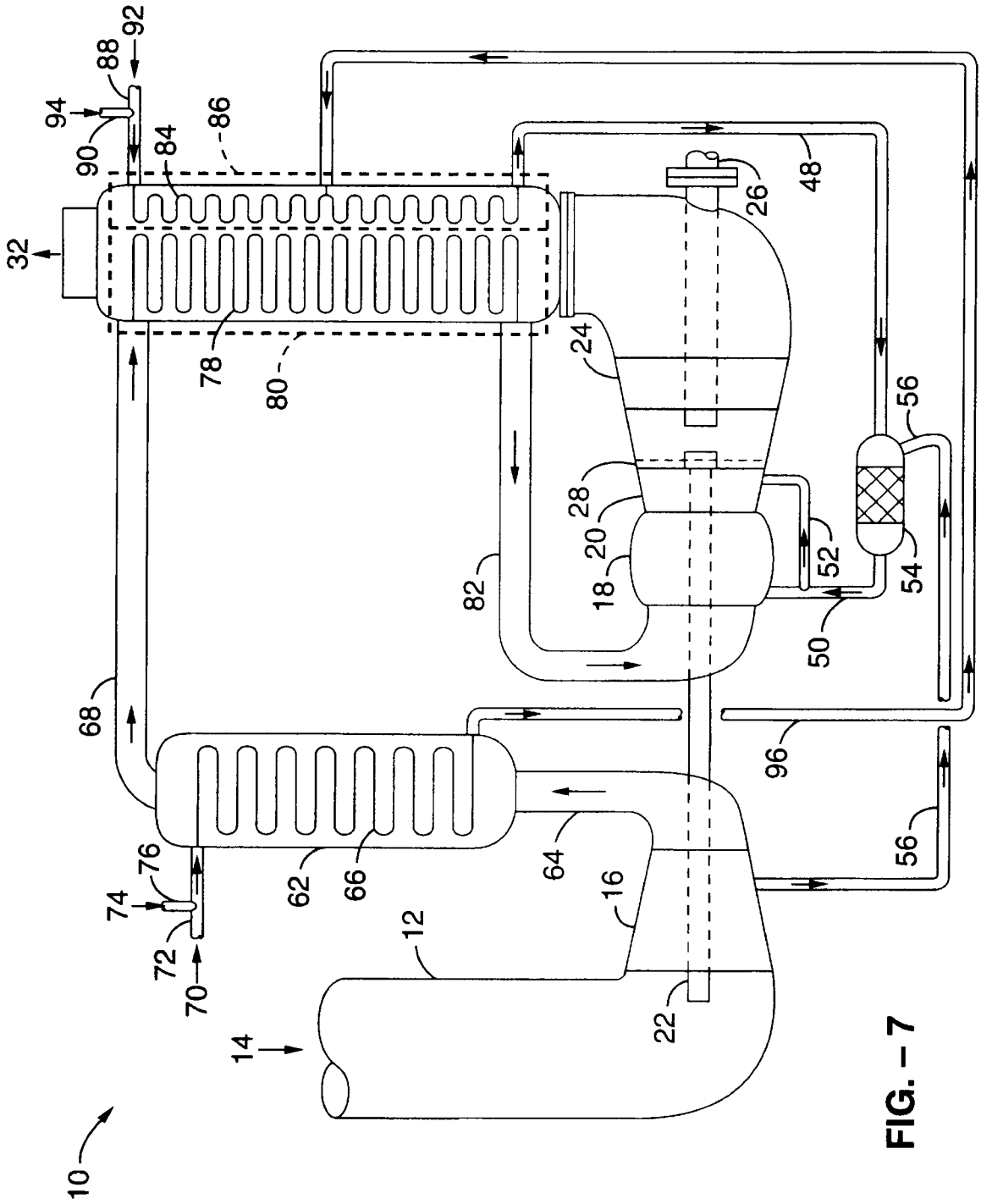
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FIG. – 7

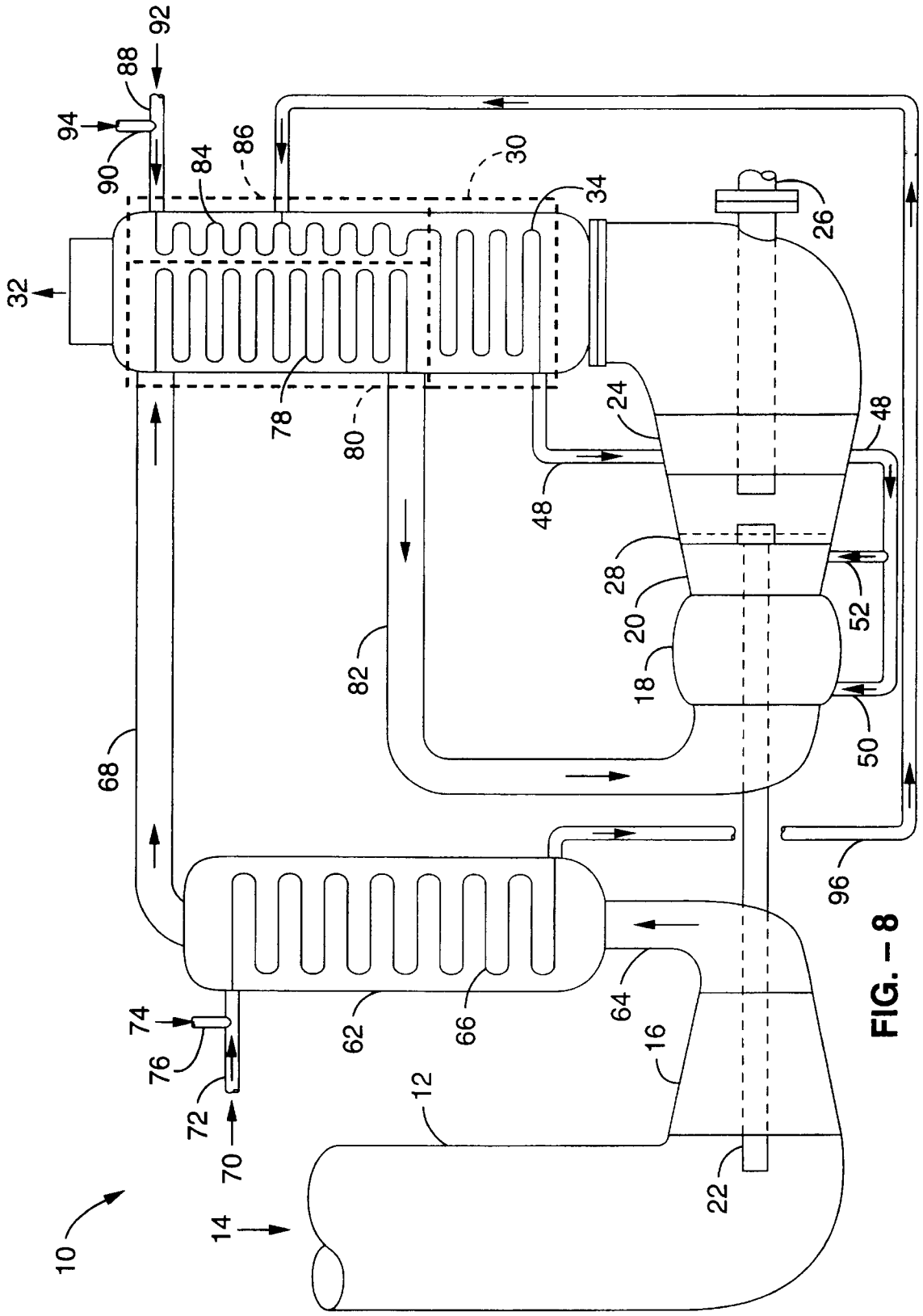
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FIG. – 8

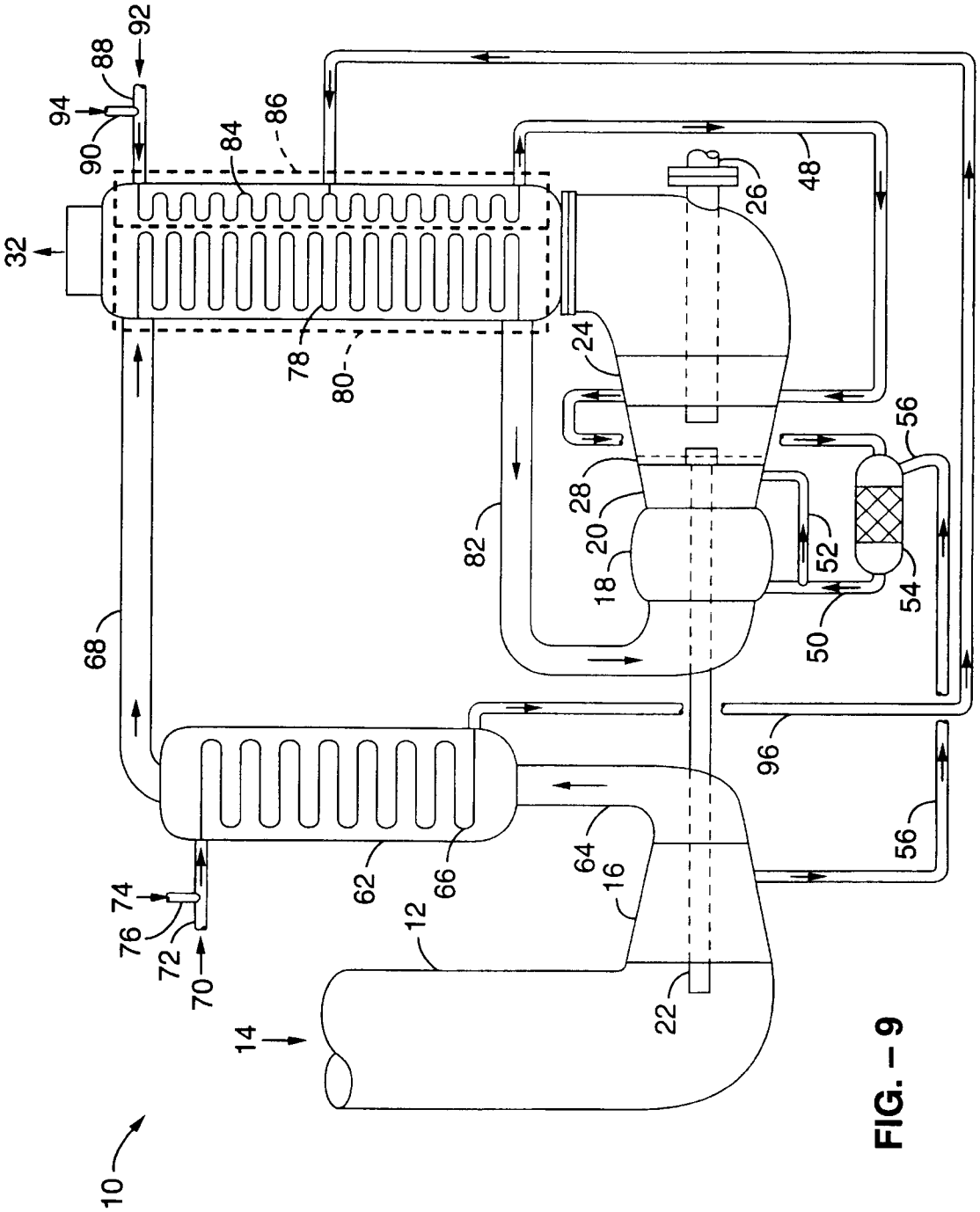
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FIG. – 9

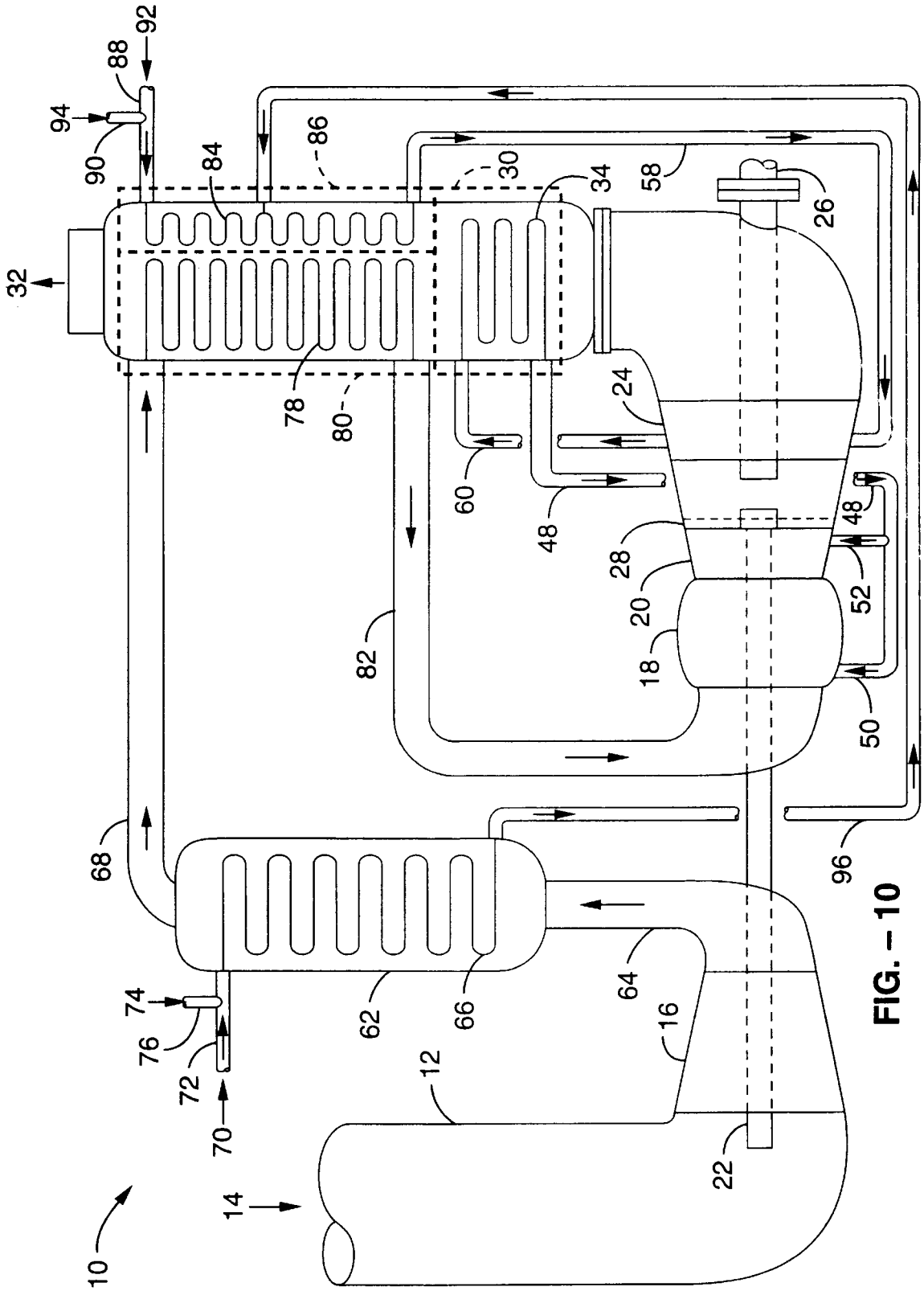
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FIG. – 10

HYDROGEN-RICH FUEL, CLOSED-LOOP COOLED, AND REHEAT ENHANCED GAS TURBINE POWERPLANTS

CROSS-REFERENCE TO RELATED APPLICATIONS

This application is a continuation-in-part of application Ser. No. 08/182,661 filed on Jan. 12, 1994 U.S. Pat. No. 5,490,377, which is a continuation-in-part of application Ser. No. 08/139,525 filed on Oct. 19, 1993, now abandoned.

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention pertains generally to gas turbine driven powerplants, and more particularly to a gas turbine driven powerplant in which a mixture of steam and methane, or another combustible fuel, is reformed or partially oxidized to produce a hydrogen-rich fuel which is used to fuel both the primary combustor and a reheat combustor. This invention also pertains to use of said fuel, or the steam/combustible feed that becomes said fuel, as turbine coolant in order to allow higher reheat temperatures to be achieved and/or to reduce the need to bleed compressed air for cooling purposes.

2. Description of the Background Art

In GB-A-2232721, published on Dec. 19, 1990, the concept of a chemically recuperated gas turbine ("CRGT") is discussed and certain CRGT designs are presented. However, while that patent discusses the advantages of developing a methane/steam reaction within the exhaust stream of the gas turbine-driven powerplant to produce a hydrogen-rich fuel which can be used to fire the powerplant with low emissions of oxides of nitrogen, it also dismisses much of the advantage as impractical based on cost, efficiency and design considerations. The patent explains that exhaust temperatures required to develop an efficient hydrogen-producing steam/methane reaction (1150° F. to 1800° F.) can only be developed through the use of a reheat combustor and a power turbine designed to withstand temperatures considerably higher than the current capabilities of such turbines. The patent apparently assumes that development of a reheat combustor would be costly based on the development history of flame holders and combustion cans for the primary combustors of existing gas turbine engines. Development of a suitable power turbine for such a cycle is commonly deemed problematic by turbine manufacturers. If one addresses this problem through the traditional approach of bleeding cooling air from the compressors, much or all of the efficiency advantage would likely be lost because the power turbine is larger than the high pressure turbine and requires more air for cooling and/or a lower temperature limit.

The patent goes on to explain that the complexity and expense of developing a reheat combustor and associated power turbine makes it desirable to develop a chemically recuperated gas turbine that avoids this expense and complexity. The patent then describes five embodiments which all avoid the use of a reheat combustor either by the use of a duct burner positioned downstream of the power turbine and upstream of the reformer or by postulation that super-activated catalysts may allow the methane/steam reforming reaction to occur at lower temperatures, minimizing or eliminating the need for duct-firing. However, this problem cannot be resolved by development of new catalysts. The problem is one of thermodynamics, rather than of inadequacy of the catalyst. The chemical equilibrium at lower temperatures is not favorable in that insufficient hydrogen will be produced. Today's catalysts already produce nearly equilibrium compositions, but high temperatures are still required to produce the quantities of hydrogen required to control NO_x and recuperate exhaust heat. The patent goes on to recognize that duct firing reduces efficiency since fuel is consumed by the burner but notes that chemical recuperation increases cycle efficiency and, therefore, even when the burner is utilized the efficiency enhancements obtained through chemical recuperation will at least offset a portion of any efficiency reduction and the system may provide an overall increase in efficiency.

Thus, while GB-A-2232721 teaches the potential advantages of combining chemical reformers with gas turbines, it teaches away from development of reheat combustors and power turbines that can withstand the temperatures typically required to make the chemically recuperated cycle work efficiently. Further, while reheat combustion will increase power output, it also raises the temperatures throughout the power turbine thus requiring a major bleed of cooling air which significantly reduces the net efficiency gains. Therefore, there is a need for a gas turbine driven powerplant which includes a reheat combustor which does not require a flame holder, does not entail the development cost associated with turbine cooling, and which requires little or no modification of existing gas turbine engine technology. The present invention satisfies that need, as well as others, and overcomes the deficiencies in conventional reheat technology.

SUMMARY OF THE INVENTION

In my co-pending application Ser. No. 08/139,525 filed on Oct. 19, 1993 and continued as Ser. No. 08/182,661 filed on Jan. 12, 1994, now U.S. Pat. No. 5,490,377, which is incorporated herein by reference, I explained that in order to effect reheat combustion a hydrogen-rich fuel gas effluent from a reformer could be introduced into the gas turbine flow path from the trailing edge of the stationary vanes and/or rotating blades of the low pressure turbine up stream of the power turbine. Because of the unique combustion characteristics of the hydrogen component, the high temperature of the low-NO_x fuel and the high air temperature, the fuel will auto-ignite with complete combustion occurring at a nominal distance after injection into the air stream and, therefore, a flame holder apparatus is not required. Thus, reheat combustion can be readily accomplished using available stationary vanes and/or rotating blades with their existing internal air cooling passages to also effect metal cooling and, particularly, to convey the low NO_x fuel to the trailing edge injection orifices for injection into the main gas stream, thus ensuring rapid and complete combustion, maximum fuel dilution/mixing, and minimum NO_x generating potential.

Therefore, the hydrogen-rich, low NO_x fuel, which can be created in a reformer or through a partial oxidation process, allows both reheat and turbine cooling to be effected without significant changes to the design of existing gas turbines or adding new equipment. No flame holder apparatus need be designed to withstand the prevailing temperatures because the hydrogen-rich fuel will spontaneously auto-ignite. Where a power turbine is employed, however, this reheat strategy would be limited by the ability of the power turbine to withstand the increased temperatures created by the reheat combustor. Therefore, I propose that a simple, efficient, and effective way to solve this problem is to use the hydrogen-

rich, low NO_x fuel or the steam/fuel mixture which is converted to a hydrogen-rich fuel as a coolant for the final turbine stage prior to injection into the gas stream as described above. This is achieved through closed circuit cooling of the power turbine, that is, by routing some or all of the fuel through passages within the power turbine where it will simultaneously cool the metal parts of the power turbine and recover heat from the turbine's metal pans, making combustion of the fuel even more efficient, and then routing the fuel from there to the combustor and/or the reheat combustor.

Closed-loop cooling of turbines is now a well-established practice in advanced combined cycle powerplants where steam developed in the exhaust heat recuperation boiler is routed through turbine pans to simultaneously effect cooling and increase the heat in the steam prior to directing it through a steam turbine cycle. By applying the same approach to the final turbine stage, my unique reheat combustor can develop temperatures approaching the temperatures in earlier stages of the turbine which would allow exhaust temperatures following the final turbine stage to reach levels high enough to effect efficient methane/steam reforming. Thus an aspect of this invention is the combination of (1) the availability of a large volume of hydrogen-rich, low NO_x fuel to effect final turbine stage cooling that allows (2) effective reheat through the use of that same auto-igniting fuel by injection through turbine cooling orifices which, in turn, (3) elevates exhaust temperatures and thus allows the hydrogen-rich, low NO_x fuel to be created in the exhaust stream through the endothermic methane/steam reforming reaction that absorbs heat and returns it to the cycle in the fuel produced by the reformer.

It will be appreciated by those skilled in the an that, while there are clear advantages to creating the hydrogen-rich, low NO_x fuel in a reformer in the exhaust stream, it could also be created through auto-thermal reforming (in which air is injected as the methane and steam flow across the reforming catalyst in order to keep the temperature high enough to produce the desired reformed fuel) or through a process known as partial oxidation which uses a different catalyst. Partial oxidation might be used, for example, with liquid or gaseous fuels that do not readily lend themselves to be reformed in a conventional methane/steam reformer.

Thermodynamic losses in most gas turbine cycles are primarily a function of stack temperature, latent heat of water vapor that flows up the stack, and the amount of excess air (air beyond that which is necessary to effectuate combustion) that flows up the stack. The most efficient cycle would be one that simultaneously minimized stack temperature, used no water for recuperation of heat (or at least allowed no water vapor to escape), and minimized excess air by burning all of the oxygen in the air flow (stoichiometric cycle). Of course, these factors cannot all be achieved at once. Stack temperature is normally decreased through the production of steam whose latent heat is later lost up the stack or in a cooling tower, and thus the goal of minimization of latent heat losses generally runs counter to the goal of minimization of stack temperature. However, as described in my co-pending application referenced above, use of water for recuperation can be minimized by using a two-phased feed of water and methane or water and air to allow vaporization of the water to occur throughout the initial portion of the heat exchange path. By facilitating vaporization, the two-phase feed generates a nonlinear temperature approach to the heating fluid, allowing a significant reduction in the heating surface and reducing thermodynamic irreversibilities. Thus, this invention can be expected to be improved by use of one or more heat exchangers in which a two-phase feed of combustible and water are used to extract as much heat as possible from the exhaust stream, using less water than in traditional boilers and creating a steam/fuel mixture that can be further superheated and/or reformed prior to use in closed circuit cooling and reheat as described above.

In addition to providing this ready opportunity for efficient recuperation of exhaust heat, thus reducing stack temperature with less use of water for that purpose, the present invention also works to reduce thermal losses from the escape of excess air up the stack by approaching or achieving stoichiometric combustion in the reheat combustor. By effectively burning more oxygen out of the air stream through reheat, the invention achieves overall cycle efficiencies that would not be possible in a single-fired gas turbine unless the firing temperature were raised several hundred degrees higher which would present serious problems in effectively cooling turbine parts as well as NO_x control problems. The invention not only avoids these problems by using the hydrogen-rich, low NO_x fuel in the manner described to effect cooling of the power turbine, but may also increase efficiency of the cycle by permitting less air to be bled from the compressor(s) for cooling of turbine hot section components.

An object of the invention is to allow effective reheat in gas turbine engines using existing turbine cooling strategies and without requiring costly development of new reheat combustor equipment.

Another object of the invention is to allow effective reheat in gas turbine engines without significant changes to the design of existing gas turbines or adding new equipment.

Another object of the invention is to employ closed-loop cooling of the power turbine in a steam injected gas turbine cycle in order to permit reheat to temperatures approaching those in the high pressure turbines of such engines.

Another object of the invention is to generate a low-NO_x fuel that will, when burned in a low-NO_x combustor, reduce emissions of NO_x to meet or exceed emission limitations without the use of SCR/ammonia (e.g. generate a hydrogen-rich sulfur free, highly steam diluted fuel).

Another object of the invention is to generate more thermal power (heat release) per mass flow of inlet air to the gas turbine than conventional gas turbine powerplants (i.e. achieve practical levels of oxygen depletion from reheat combustion at temperatures made possible by this invention and from the use of dilute fuels available as a result of this invention).

Another object of the invention is to convert the energy released in the combustion of fuel into shaft work with greater efficiency than conventional gas turbine powerplants (i.e. leave a minimum of residual energy in the stack gas, the only significant source of energy unconverted to shaft work).

Further objects and advantages of the invention will be brought out in the following portions of the specification, wherein the detailed description is for the purpose of fully disclosing preferred embodiments of the invention without placing limitations thereon.

BRIEF DESCRIPTION OF THE DRAWINGS

The invention will be more fully understood by reference to the following drawings which are for illustrative purposes only:

FIG. **1** is a schematic diagram of a gas turbine driven power plant in accordance with the present invention show-

ing a flow of hydrogen-rich fuel to a combustor and reheat combustor wherein the flow of such fuel is generated in a reformer downstream of the final turbine stage and the steam and combustible mixture that feeds the reformer is generated in a once-through boiler located downstream of the reformer.

FIG. **2** is a schematic diagram of an alternative embodiment of the gas turbine driven powerplant shown in FIG. **1**, in which the flow of hydrogen-rich fuel is generated in an auto-thermal reformer or in a bed of partial oxidation catalyst.

FIG. **3** is a schematic diagram of the gas turbine driven powerplant shown in FIG. **1**, in which the flow of hydrogen-rich fuel is first directed through cooling orifices in the final turbine stage prior to being directed to the combustor and the reheat combustor.

FIG. **4** is a schematic diagram of an alternative embodiment of the gas turbine driven powerplant shown in FIG. **2**, in which the flow of steam and combustible that feeds the auto-thermal reformer or bed of partial oxidation catalyst is first directed through cooling orifices in the final turbine stage prior to being directed to the auto-thermal reformer or bed of partial oxidation catalyst.

FIG. **5** is a schematic diagram of an alternative embodiment of the gas turbine driven powerplant shown in FIG. **3**, in which the flow of steam and combustible that is generated in the once-through boiler is directed through cooling orifices in the final turbine stage prior to being directed to the reformer.

FIG. **6** through FIG. **10** are schematic diagrams of alternative embodiments of the gas turbine driven powerplants shown in FIG. **1** through FIG. **5**, respectively, in which a heat exchanger is positioned downstream of the compressor, a recuperator is positioned downstream of the heat exchanger and downstream of the final turbine stage, the combustor is positioned downstream of the recuperator, a preheat exchanger is positioned downstream of the final turbine stage, and the exhaust stream is divided between the recuperator and the preheat exchanger.

DESCRIPTION OF PREFERRED EMBODIMENTS

Referring more specifically to the drawings, for illustrative purposes the present invention is embodied in the apparatus generally shown in FIG. **1** through FIG. **10**, where like reference numerals denote like parts. It will be appreciated, however, that the apparatus may vary as to configuration and as to details of the parts without departing from the basic concepts as disclosed herein.

Referring first to FIG. **1**, a gas turbine powerplant **10** according to the present invention is shown. Powerplant **10** typically includes a compressor inlet **12** for receiving filtered air **14** for compression, at least one compressor **16** for producing a downstream flow of air, a combustor **18** positioned down stream of compressor **16**, at least one turbine **20** positioned downstream of the combustor **18** and mechanically connected to compressor **16** by a shaft **22**, and a final turbine **24** positioned down stream of turbine **20** and mechanically connected to a load by a shaft **26**. The final turbine **24** may be either a separate power turbine connected only aerodynamically to the last turbine/compressor stage as shown, or it may be the turbine that drives the lowest pressure compressor in a multiple compressor configuration. Those skilled in the art will appreciate that the powerplant configuration described can include additional compressor/turbine stages, and that shaft **26** can be used to power an electrical generator or another form of mechanical load.

In a conventional turbine **20**, one or more of the stationary vanes and/or rotating blades contain internal passages through which a coolant can be directed. In the present invention, however, a hydrogen-rich fuel is injected through those internal passages into the main gas stream flow to effect reheat combustion. Not only will the hydrogen-rich fuel act as a coolant for the turbine but, because of the unique combustion characteristics of the hydrogen component as well as the high temperatures of the low-NO_x fuel and air, the fuel exiting the trailing edge of the stationary vanes and/or rotating blades of turbine **20** will auto-ignite, with complete combustion occurring at a nominal distance after injection into the gas stream flowing between turbine **20** and final turbine **24**. In this manner, a reheat combustor **28** is created in the flow path between turbine **20** and final turbine **24**. It will be appreciated, therefore, that reheat combustion can be readily accomplished using available stationary vanes and/or rotating blades with their existing internal air cooling passages to convey the low NO_x fuel to the trailing edge injection orifices for injection into the main gas stream. This allows the manufacturer to obtain the efficiency benefits of reheat without significant or costly redesign of the final turbine, and without adding new equipment. Also, because the methane/steam reformation reaction is also a function of temperature, this reheat will enhance the chemical recuperation of heat from the exhaust gas stream.

The hydrogen-rich fuel feeding reheat combustor **28** also feeds combustor **18**. In the powerplant configuration shown in FIG. **1**, the fuel is generated by at least one reformer **30** positioned in the exhaust stream **32** following the final turbine **24**. Reformer **30** includes fuel carrying coils **34** over which the hottest portion of the exhaust from final turbine **24** flows, and through which a mixture of combustible hydrocarbon and steam flows, reacting with a catalyst to form the hydrogen-rich effluent that fuels combustor **18** and reheat combustor **28**. This mixture of combustible hydrocarbon and steam is generated in at least one heat exchanger **36**, which is a conventional once-through boiler or the like. Lower grade heat from exhaust stream **32** which would otherwise escape the cycle flows over fuel carrying coils **38** in heat exchanger **36**, converting a mixture of a combustible hydrocarbon **40** such as methane introduced into fuel inlet **42**, and water **44** introduced into water inlet **46**, into a mixture of combustible hydrocarbon and steam. As can be seen, coils **34** in reformer **30** and coils **38** in heat exchanger **36** are connected in series. It will further be appreciated that the colder end of fuel carrying coils **38** is coupled to the fuel and water inlets, while the hotter end of fuel carrying coils feeds reformer **30** at the colder end of its coils.

As can further be seen in FIG. **1**, the hydrogen-rich fuel (combustible and steam) exits reformer **30** through fuel outlet **48**, which is coupled to the output of coils **34**, and is directed to combustor **18** through combustor inlet **50** and to reheat combustor **28** through turbine inlet **52**. It will be appreciated, however, that instead of using a reformer **30**, the hydrogen-rich fuel can be generated in an autothermal reformer **54** located outside the exhaust gas path as shown in FIG. **2**, in which case fuel outlet **48** is coupled to the output of coils **38** in heat exchanger **36**. Auto-thermal reformer **54** uses the same feed of steam and combustible as shown in FIG. **1**, but adds a small flow of air from compressor **16** through air duct **56** in order to burn a portion of the combustible and maintain temperatures that will sustain the hydrogen-producing reaction in the reformer. This configuration is particularly suited where exhaust temperatures

are not high enough to sustain that reaction or in any situation in which it is not technically or economically desirable to place a reformer in the turbine exhaust stream.

Those skilled in the art will appreciate that, instead of using an autothermal reformer to produce the hydrogen-rich fuel, a partial oxidation catalyst can be used instead to produce the same hydrogen-rich fuel. This configuration is particularly suited where the primary fuel does not readily produce hydrogen in a steam/combustible reformer or where, for technical or economic reasons, the partial oxidation process is preferred.

The amount of reheat that can be achieved using the powerplant designs heretofore described is limited only by the ability of final turbine **24** to withstand the elevated temperatures provided by the reheat combustion. Accordingly, it is desirable to cool the final turbine stage to the extent practicable. In the present invention, this can be achieved by using the hydrogen-rich fuel from reformer **30**, or the unconverted steam/combustible mixture fed to auto-thermal reformer/partial oxidation catalyst **54** from heat exchanger **36**, as a coolant for final turbine **24** in a closed-loop cooling configuration as shown in FIG. **3** and FIG. **4**, respectively. To do so, final turbine **24** is constructed with internal passages to allow the fuel (steam/combustible mixture) to pass through the metal components of said turbine. Such internal passages can be constructed in a conventional manner as where a coolant is used to cool turbine hot metal components. However, in the present invention, the coolant is not released to the gas path but is recollected with minimal leakage and used as described below.

The hydrogen-rich fuel or the unconverted steam/combustible feed flowing through fuel outlet **48** will be directed through the cooling passages in final turbine **24** to simultaneously effect cooling of the final turbine stage and to return heat from the turbine components to the hydrogen-rich fuel or unconverted steam/combustible feed prior to combustion or conversion. After the hydrogen-rich fuel or unconverted steam/combustible flows through the cooling orifices in final turbine **24**, it is directed to combustor **18** and reheat combustor **28** as shown in FIG. **3**, or to auto-thermal reformer/partial oxidation catalyst **54** as shown in FIG. **4**, in the same manner as shown in FIG. **1** and FIG. **2**, respectively.

It will be appreciated that, in the powerplant configuration shown in FIG. **4**, the unconverted steam/combustible feed from heat exchanger **36** is used for final turbine cooling prior to being converted into a hydrogen-rich fuel for reheat combustion by autothermal reformer/partial oxidation catalyst **54**, whereas in FIG. **3** the unconverted steam/combustible feed from heat exchanger **36** is converted to a hydrogen-rich fuel by reformer **30** prior to being used for final turbine cooling. Alternatively, reformer **30** could be used to convert the unconverted steam/combustible feed from heat exchanger **36** to a hydrogen-rich fuel after being used for final turbine cooling as shown in FIG. **5**, if a lower temperature fuel/coolant is desired than that which is produced by the configuration shown in FIG. **3**. Here, the unconverted steam/combustible feed from heat exchanger **36** is directed to the cooling orifices in final turbine **24** through heat exchanger outlet **58** and is returned to reformer **30** through return line **60**.

It will further be appreciated that, when dealing with rotating turbines, there may be slight leakage of fluids which are directed through those turbines. In the configuration shown in FIG. **3**, if the hydrogen-rich fuel flowing through the cooling orifices in final turbine **24** were to leak into the main gas stream, it would auto-ignite and provide an additional degree of reheating.

The designs shown in FIG. **3** through FIG. **5** will allow greater reheat combustion to be achieved through the unique reheat strategy described in my co-pending application referenced above, because the final turbine stage will be cooled by the flow of hydrogen-rich fuel or steam/combustible mixture through its internal passages. Further, it is anticipated that the designs of FIG. **3** and FIG. **5** will permit the exhaust temperature following final turbine **24** to be sufficiently high to allow the hydrogen-rich fuel to be formed efficiently in reformer **30**, thus taking advantage of the opportunity to chemically recuperate some of the exhaust heat of the cycle, thereby providing for greater efficiency than the configuration shown in FIG. **4**.

Referring now to FIG. **6** through FIG. **10**, alternative embodiments of the reheat designs corresponding to the configurations of FIG. **1** through FIG. **5**, respectively, can be seen. In each of these embodiments, instead of the air flowing from compressor **16** being directed to combustor **18**, the air flow enters a heat exchanger **62** through compressed air inlet **64**, flows over fuel carrying coils **66**, and exits heat exchanger **62** through compressed air outlet **68**. Heat exchanger **62** is a conventional once-through boiler or the like, which functions to transfer heat from the flow of air to a mixture of combustible hydrocarbon **70**, such as methane introduced into fuel inlet **72**, and water **74** introduced into water inlet **76**, thereby generating a mixture of combustible hydrocarbon and steam and cooling the flow of air.

The cooled compressed air from heat exchanger **62** flows through air carrying coils **78** in a recuperator **80** and is routed through an air duct **82** which feeds combustor **18**. Exhaust gas exiting final turbine **24** flows across air carrying coils, and the heat from the exhaust gas passing over air carrying coils **78** is thereby transferred to and heats the air flowing through those coils. The air is heated to a temperature approaching the temperature of the exhaust gas and is suitable for use as combustion air for combustor **18**. Therefore, not only is the cooled air reheated for use as combustion air, but the exhaust gases are cooled before they exit the exhaust stack.

The exhaust gas flow from final turbine **24** is divided between recuperator **80** and the fuel carrying coils **84** of a preheat exchanger **86**, respectively. Through mechanical design of recuperator **80** (given expected pressures and volumes of exhaust stream gas and cooled compressed air from the heat exchanger **62**), enough of the exhaust gas stream heat will be directed through recuperator **80** to simultaneously bring the cooled compressed air flow from heat exchanger **62** up to a close approach to the temperature of the exhaust gas stream while bringing the temperature of the exhaust gas stream down to a close approach to the temperature of the cooled compressed air exiting heat exchanger **62**. The remaining heat contained in the exhaust gas stream is available for use in preheat exchanger **86** which is designed to extract enough of that heat to cool this second portion of the exhaust gas stream to approximately the same pressure and temperature as the portion of the exhaust gas stream exiting recuperator **80**. This division of exhaust gas flow into two parallel flows will yield a thermodynamically matched heat exchange regenerator.

Referring specifically to FIG. **6**, reformer **30** is positioned downstream from power turbine **24** and the entire exhaust gas stream flows over the fuel carrying coils **34** in the same manner as in FIG. **1**. Down stream of reformer **30**, however, the partially cooled exhaust gas flow from final turbine **24** is mechanically divided between recuperator **80** and preheat exchanger **86**, respectively. Division of the exhaust gas flow is accomplished in the same manner as described above.

Preheat exchanger **86** is a conventional once-through boiler or the like. The cooler end of fuel carrying coils **84** of preheat exchanger **86** is coupled to fuel inlet **88** and water inlet **90**; the hotter end is coupled to coils **34** of reformer **30**. A combustible hydrocarbon **92** such as methane is introduced into fuel inlet **88**, while water **94** is introduced into water inlet **90**. As a result of heat transferred from the exhaust gas, the mixture is convened to a mixture of combustible hydrocarbon and steam as it flows through fuel carrying coils **84**. In addition, fuel outlet **96** of heat exchanger **62** is coupled to the approximate midpoint of coils **84** in preheat exchanger **86**. Accordingly, the mixture of combustible hydrocarbon and steam generated by heat exchanger **62** is introduced into the fuel carrying coils **84** of preheat exchanger **86** and further heated. In this manner, two flows of a mixture of combustible hydrocarbon and steam pass through preheat exchanger **86** and feed reformer **30**.

It will be appreciated, therefore, that heat exchanger **62** serves as a first preheat exchanger to increase the fuel temperature prior to reforming and, further, serves to cool the compressor discharge air. By doing so, use of a recuperator to return the majority of exhaust heat to the cycle in the compressed air flow is permitted. This design can be expected to produce higher plant efficient where exhaust temperatures entering the recuperator are significantly higher than the temperature of the compressed air exiting the compressor. Heat exchanger **62** and preheat exchanger **86** together perform the same function as heat exchanger **36** shown in the configurations of FIG. **1** through FIG. **5**, creating a flow of steam and combustible ready for reforming or partial oxidation conversion to a hydrogen rich fuel and lowering stack temperature with minimum practical use of water in order to reduce latent heat losses. The hydrogen-rich combustible effluent from reformer **30** is then fed to combustor **18**, as well as to reheat combustor **28** through the cooling orifices in turbine **20**, via fuel outlet **48**.

Referring also to FIG. **7**, it will be appreciated that reformer **30** could be eliminated if desired and, instead, the hydrogen-rich fuel needed for reheat combustion could be generated by an autothermal reformer/partial oxidation catalyst **54** in the same manner as described with reference to FIG. **2** above. Further, referring to FIG. **8** and FIG. **9**, the hydrogen-rich fuel (FIG. **8**) or unconverted steam/combustible mixture (FIG. **9**) can be used for cooling final turbine **24** if desired as described with reference to FIG. **3** and FIG. **4** above. Also, as shown in FIG. **10**, it will be appreciated that reformer **30** could be used to convert the unconverted steam/combustible feed from preheat exchanger **86** to a hydrogen-rich fuel after being used for final turbine cooling in the manner described with reference to FIG. **5** if a lower temperature fuel/coolant is desired than that which is produced by the configuration shown in FIG. **8**.

Although the description above contains many specificities, these should not be construed as limiting the scope of the invention but as merely providing illustrations of some of the presently preferred embodiments of this invention. It will further be appreciated that the invention presented herein can be incorporated into many alternative powerplant designs. Thus the scope of this invention should be determined by the appended claims and their legal equivalents.

What is claimed is:

1. A gas turbine driven powerplant, comprising:

(a) compressor means for producing a downstream flow of air;

(b) a combustor positioned downstream of said compressor means;

(c) a first turbine positioned downstream of said combustor, said turbine coupled to said compressor by a shaft;

(d) a reheat combustor positioned downstream of said turbine; and

(e) a second turbine positioned downstream of said reheat combustor;

(f) said reheat combustor receiving a flow of hydrogen-rich fuel through cooling orifices in said first turbine, wherein said hydrogen-rich fuel auto-ignites upon discharge from said cooling orifices into the flow of air from said first turbine to said second turbine.

2. A gas turbine driven powerplant as recited in claim **1**, further comprising:

(a) heat exchanger means for producing a mixture of combustible hydrocarbon and steam, said heat exchanger means positioned downstream of said compressor means;

(b) a recuperator positioned downstream of said heat exchanger, upstream of said combustor, and downstream of said second turbine; and

(c) a preheat exchanger positioned downstream of said second turbine;

(d) wherein exhaust gases from said second turbine are divided between said recuperator and said preheat exchanger.

3. A gas turbine driven powerplant as recited in claim **1**, further comprising heat exchanger means for producing a mixture of combustible hydrocarbon and steam, said heat exchanger means positioned downstream of said second turbine.

4. A gas turbine driven powerplant as recited in claim **3**, further comprising fuel conversion means for producing said flow of hydrogen-rich fuel from said mixture of combustible hydrocarbon and steam.

5. A gas turbine driven powerplant as recited in claim **1**, wherein said hydrogen-rich fuel flows through cooling orifices in said second turbine.

6. A gas turbine driven powerplant as recited in claim **3**, wherein said mixture of combustible hydrocarbon and steam flows through cooling orifices in said second turbine.

7. A gas turbine driven powerplant as recited in claim **4**, wherein said heat exchanger means comprises a heat exchanger, said heat exchanger including a fuel carrying coil, said fuel carrying coil having a colder first end coupled to a fuel inlet and a water inlet, said fuel carrying coil having a hotter second end coupled to said fuel conversion means.

8. A gas turbine driven powerplant as recited in claim **7**, wherein said fuel conversion means comprises a reformer positioned downstream of said second turbine and upstream of said heat exchanger, said reformer including a second fuel carrying coil, said second fuel carrying coil having a colder first end coupled to hotter second end of said fuel carrying coil in said heat exchanger, said second fuel carrying coil having a hotter second end coupled to said combustor and said cooling orifices in said first turbine.

9. A gas turbine driven powerplant as recited in claim **7**, wherein said fuel conversion means comprises an autothermal reformer positioned between said hotter second end of said fuel carrying coil in said heat exchanger, and said combustor and said cooling orifices in said first turbine.

10. A gas turbine driven powerplant as recited in claim **7**, wherein said fuel conversion means comprises an oxidation catalyst positioned between said hotter second end of said fuel carrying coil in said heat exchanger, and said combustor and said cooling orifices in said first turbine.

11. A gas turbine driven powerplant, comprising:

(a) a compressor means for producing a downstream flow of air;

(b) a combustor positioned downstream of said compressor means;

(c) a first turbine positioned downstream of said combustor, said turbine coupled to said compressor by a shaft;

(d) a reheat combustor positioned downstream of said turbine, said reheat combustor receiving a flow of hydrogen-rich fuel through cooling orifices in said first turbine, wherein said hydrogen-rich fuel auto-ignites upon discharge from said cooling orifices into the flow of air from said first turbine toward a second turbine;

(e) said second turbine positioned downstream of said reheat combustor;

(f) a heat exchanger positioned downstream of said second turbine, said heat exchanger including a fuel carrying coil, said fuel carrying coil coupled to a fuel inlet and a water inlet; and

(g) fuel conversion means for producing said hydrogen-rich fuel from a mixture of combustible hydrocarbon and steam received from said fuel carrying coil and delivering said hydrogen-rich fuel to said combustor and to said cooling orifices in said first turbine.

12. A gas turbine driven powerplant as recited in claim **11**, wherein said hydrogen-rich fuel flows through cooling orifices in said second turbine.

13. A gas turbine driven powerplant as recited in claim **11**, wherein said fuel conversion means comprises a reformer positioned downstream of said second turbine and upstream of said heat exchanger, said reformer including a second fuel carrying coil, said second fuel carrying coil having a first end coupled to said fuel carrying coil in said heat exchanger, said second fuel carrying coil having a second end coupled to said combustor and said cooling orifices in said first turbine.

14. A gas turbine driven powerplant as recited in claim **11**, wherein said fuel conversion means comprises an autothermal reformer positioned between said fuel carrying coil and said combustor and said cooling orifices in said first turbine.

15. A gas turbine driven powerplant as recited in claim **11**, wherein said fuel conversion means comprises an oxidation catalyst positioned between said fuel carrying coil and said combustor and said cooling orifices in said first turbine.

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