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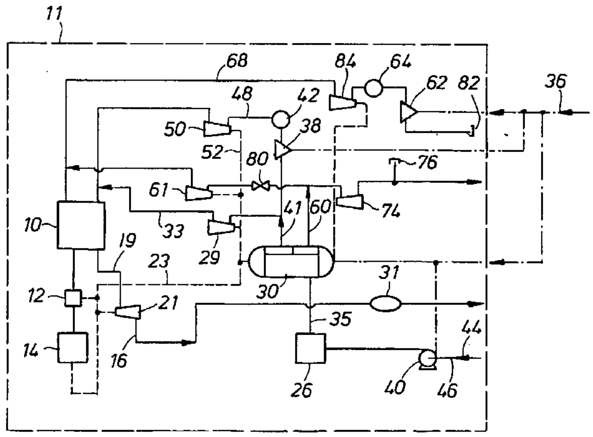

(57) Abstract: A hydrogen fuel system for an internal combustion engine includes an electrolyzer for generating hydrogen and oxygen gases. The engine exhaust may be recycled through the electrolyzer where it is converted to hydrogen and oxygen. A water reservoir in fluid communication with the electrolyzer maintains the water level in the electrolyzer. The hydrogen and oxygen generated by the electrolyzer may be routed to the internal combustion engine and provide the fuel for the engine. Hydrogen and oxygen not consumed by operation of the engine is stored in separate pressurized storage tanks. Expanders lower the pressure of pressurized hydrogen and oxygen for use to power the engine and provide electric power to the electrolyzer.

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HYDROGEN FUEL SYSTEM FOR AN INTERNAL COMBUSTION ENGINE

BACKGROUND OF THE DISCLOSURE

The present invention relates generally to a vehicle having an internal combustion engine, and more particularly, to an internal combustion engine powered by hydrogen fuel.

A typical internal combustion engine that is used in automobiles, trucks or other vehicles is generally powered by gasoline or diesel fuel. A gasoline powered internal combustion engine, however, generates pollutants that are expelled into the atmosphere. Pollution from internal combustion engines is a serious problem and many remedies have been proposed. It is known, for example, that adding oxygen into the fuel stream decreases the pollution caused by internal combustion engines. It is also known that hydrogen provides a source of clean energy. Furthermore, the combustion of hydrogen generates water as a by-product that may be electrolyzed to form hydrogen and oxygen gases.

U.S. Pat. No. 6,257,175 (Mosher et al.) describes apparatus for generating hydrogen and oxygen from an electrolysis unit. The gases are gathered separately in the unit and flow to the intake manifold of the engine in separate conduits. U.S. Pat. No. 6,659,049 (Baumert et al.) describes a vehicle with a fuel cell system. Electric power from the vehicle's alternator is used to power an electrolyzer. Hydrogen produced by the electrolyzer is used as fuel for the fuel cell system. The fuel cell system provides electric power for the low power electrical requirements of the vehicle, i.e., lighting, air conditioner, radio, etc., when the engine of the vehicle is not running. While these apparatus contribute to a reduction of pollutant emissions of internal combustion engines, hydrocarbon fuels still provide the primary energy requirements for the vehicles. Pollutant emissions of motor vehicles, however, must still be drastically reduced to have an environmental impact.

It is therefore an object of the present invention to provide an internal combustion engine powered by a hydrogen fuel system.

It is another object of the present invention to provide a vehicle having an electrolysis unit for generating hydrogen and oxygen.

It is another object of the present invention to provide a vehicle fuel system that recycles engine exhaust as input to an electrolysis unit to generate hydrogen and oxygen which may be re-used as fuel to power the vehicle.

It is another object of the present invention to provide a vehicle fuel system having removable storage capacity for hydrogen or oxygen generated by an electrolysis unit.

It is another object of the present invention to provide a vehicle fuel system utilizing expanders to generate electric power from high pressure gases.

SUMMARY OF THE INVENTION

In accordance with the present invention, a hydrogen fuel system for an internal combustion engine includes an electrolyzer for generating hydrogen and oxygen gases. The exhaust of the engine may be recycled through the electrolyzer where it is converted to hydrogen and oxygen which may be used as fuel for the internal combustion engine. A water reservoir in fluid communication with the electrolyzer is provided to maintain the water level in the elctrolyzer at an optimum operating level. Hydrogen and oxygen generated by the electrolyzer may be routed to the internal combustion engine to provide the fuel for the engine. Hydrogen and oxygen generated by the electrolyzer which is not consumed by operation of the engine may be stored in pressurized storage tanks for use when required to power the internal combustion engine. Expanders are incorporated in the fuel system of the invention for lowering the pressure of the pressurized hydrogen and oxygen to the engine pressure requirements and for utilizing the potential energy stored within the pressurized gases to provide a portion of the electrical power requiremenst of the fuel system. The fuel system includes external ports and electrical outlets for connecting to external water and power sources.

BRIEF DESCRIPTION OF THE DRAWINGS

So that the manner in which the above recited features, advantages and objects of the present invention are attained can be understood in detail, a more particular description of the invention briefly summarized above, may be had by reference to the embodiments thereof which are illustrated in the appended drawings.

It is noted, however, that the appended drawings illustrate only typical embodiments of this invention and are therefore not to be considered limiting of its scope, for the invention may admit to other equally effective embodiments.

Fig. 1 is a block diagram of a preferred embodiment of the invention adapted for using an air and hydrogen fuel mixture and recycled engine exhaust vapor to power an internal combustion engine;

Fig. 2 is a block diagram of an alternate embodiment of the invention depicted in Fig. 1 wherein the engine exhaust vapor is passed through a catalytic converter and vented to the atmosphere;

Fig. 3 is a block diagram of an alternate embodiment of the invention adapted for using a hydrogen and oxygen fuel mixture and recycled engine exhaust vapor to power an internal combustion engine;

Fig. 4 is a block diagram of an alternate embodiment of the invention depicted in Fig. 3 wherein the engine exhaust vapor is vented to the atmosphere;

Fig. 5 is a block diagram of an alternate embodiment of the invention depicted in Fig. 3 adapted for mixing air with pressurized oxygen stored in a storage tank for supplying pressurized air and oxygen to the fuel mixture to power an internal combustion engine;

Fig. 6 is a block diagram of an alternate embodiment of the invention depicted in Fig. 5 wherein the engine exhaust vapor is passed through a catalytic converter and vented to the atmosphere;

Fig. 7 is a block diagram of an alternate embodiment of the invention depicted in Fig. 5 adapted for storing pressurized air in a storage tank for selectively supplying pressurized air and oxygen to the fuel mixture to power an internal combustion engine;

Fig. 8 is a block diagram of an alternate embodiment of the invention depicted in Fig. 7 wherein the engine exhaust vapor is passed through a catalytic converter and vented to the atmosphere; and

Fig. 9 is a block diagram of an alternate embodiment of the invention adapted for use of compressed hydrogen and air as a fuel mixture for a vehicle.

DETAILED DESCRIPTION OF A PREFERRED EMBODIMENT

Referring first to Fig. 1, a block diagram of the fuel system of the present invention is shown operatively connected to an internal combustion engine 10 of a vehicle 11, such as an automobile or the like. The fuel system of the present invention may be retrofit into an existing gasoline powered vehicle or incorporated in a new vehicle design. The internal combustion engine 10 is modified in a known manner to operate with a hydrogen fuel mixture. It is further understood that the vehicle 11 includes an engine control unit and sensors (not shown in the drawings) electrically and communicatively coupled to the fuel system of the present invention.

The vehicle 11 powered by the fuel system of the present invention is equipped with conventional components such as an alternator 12, a battery 14 and other electrical devices. As in conventional vehicles, the alternator 12 produces electric power while the engine 10 is operating. The battery 14 is used for starting the engine 10, storing the output of the alternator 12 and powering the electrical components of the vehicle 11 while the engine 10 is not operating.

Referring still to Fig. 1, air and hydrogen are used to power the internal combustion engine 10. A compressor 15 draws air through a port 17 which is open to the atmosphere. Air is pressurized by the compressor 15 to the required engine pressure and routed to the intake manifold of the engine 10. Hydrogen is also routed to the intake manifold of the engine 10 from an electrolyzer 30 and a hydrogen storage tank 44 to form the fuel mixture for powering the engine 10, described in greater detail hereinafter.

Exhaust vapor exits the engine 10 at a high temperature and moderate pressure. The engine exhaust is routed through a conduit 19 to an expander 21 where the pressure of the exhaust vapor is decreased. The expander 21 is electrically coupled to the electrolyzer 30 via a power line 23. The expander 21 converts the potential energy stored within the engine exhaust vapor into electric power used to provide part of the power requirements of the electolyzer 30.

The exhaust vapor from the engine 10 flows through the expander 21 at a reduced pressure and is channeled by a conduit 16 to an air-cooled condenser 18. The exhaust from the engine 10 contains hydrogen, oxygen, water vapor and potential pollutants, such as NOx, at a temperature of about 1000°F. A temperature element or sensor 25 located in the conduit 16 upstream from the condenser 18 measures the temperature of the engine exhaust entering the condenser 18 and communicates the exhaust temperature value to a temperature controller 27 which operates a water valve 20 connected to the conduit 16 upstream of the temperature element 25. The valve 20 is connected by a water supply line 22 to a water reservoir 26. In response to the temperature of the engine exhaust, the controller 27 operates the valve 20 in a desired manner to spray water into the exhaust conduit 16, and thereby cool the engine exhaust vapor to the water saturation point prior to entering the condenser 18, where it is condensed into water. Cooling the engine exhaust reduces the backpressure on the engine 10 as the exhaust vapor passes through the condenser 18. A reduction in engine backpressure improves engine performance through increased horsepower availability. The condensed water exiting the condenser 18 is pumped by a pump 24 to the water reservoir 26. Any gases formed in the condenser 18 are first channeled through a catalytic converter 31 for removal of any potential pollutants and then vented to the atmosphere.

Referring still to Fig. 1, a water conduit 35 connects the water reservoir 26 to the electrolyzer 30. The electrolyzer 30 is provided with sensors for maintaining the water level in the electrolyzer 30 at an optimum level for efficient performance. The electrolyzer 30 generates hydrogen and oxygen by electrolysis. The electrolyzer 30 operates at a pressure of about 363 psig. The pressurized hydrogen generated by the electrolyzer 30 is passed through an expander 29 where the hydrogen pressured is lowered to the engine intake pressure and routed to the intake manifold of the engine 10 via conduit 33. The oxygen generated by the electrolyzer 30 is passed through an expander 43 and an air mixer 37 incorporated in a vent conduit 39 connected to the electrolyzer 30 and vented to the atmosphere. The expanders 29 and 43 are electrically coupled to the electrolyzer 30.

When the vehicle 11 is operating, electric power to operate the electrolyzer 30 for production of hydrogen and oxygen is provided by an electric circuit comprising the alternator 12, the battery 14 and the expanders operatively connected to the electrolyzer 30. When the vehicle 11 is not operating, hydrogen and oxygen is generated by the electrolyzer 30 by connecting the vehicle 11 to an external power source, such as a standard residential electrical outlet. The vehicle 11 is provided with an electrical outlet 36 for connection to the external power source. The outlet 36 is electrically coupled to the electrolyzer 30, hydrogen compressor 38 and water pump 40 housed in the vehicle 11, thereby forming a second electric circuit for operating the electrolyzer 30, compressor 38 and water pump 40 when the vehicle 11 is not operating.

Hydrogen produced by the electrolyzer 30 when the vehicle 11 is not operating and connected to an external power source is routed via conduit 41 to the compressor 38 and then to the hydrogen storage tank 42. The hydrogen is pressurized by the compressor 38 and stored in the storage tank 42 as pressurized vapor. The storage tank 42 is removable so that it may be replaced with a spare tank of hydrogen when the tank 42 becomes empty and an external electrical power source may not be readily available to recharge the tank 42.

Hydrogen conduit 48 connects the pressurized hydrogen storage tank 42 to the intake manifold of the engine 10. Hydrogen which exits the storage tank 42 at a high pressure is routed through the expander 50 where the pressure of the hydrogen is decreased to the required engine intake pressure. The expander 50 is electrically coupled to the electrolyzer 30 by a power line 52. The expander 50 converts the potential energy stored within the pressurized hydrogen into electric power used to power the electolyzer 30.

Periodically, the water reservoir 26 will require replenishment. The vehicle 11 is provided with a water pump 40 and a water port 44 in fluid communication with the water reservoir 26 via a water line 46. The port 44 provides access for adding water to the reservoir 26 as is required. Tap water may be used to fill the reservoir 26 as needed. However, distilled water may also be used if desired. Electrolyte for aiding the electrolysis process may also be added through the port 44. The water pump 40 is powered by an external power source connected to the electrical outlet 36.

The fuel system of the present invention may be retrofit into an existing vehicle or incorporated in a new vehicle design. While the use of hydrogen fuel for an internal combustion engine is known and understood in the art, the hydrogen fuel system of the present invention utilizes expanders to recover power from pressurized hydrogen and oxygen to supplement the electric power available to operate the electrolzyer and recycles the engine exhaust to produce more hydrogen and oxygen for fuel and thereby extend the driving range of the vehicle. In the operation of a vehicle 11 equipped with the fuel system of the present invention illustrated in Fig. 1, exhaust vapor from the internal combustion engine 10 is cooled as it is routed to a condenser 18 where the exhaust vapor is condensed into water and routed to the water reservoir 26. Water from the water reservoir 26 is supplied to the electrolyzer 30 where, through the action of electrolysis, hydrogen and oxygen gases are generated. The hydrogen generated by the electrolyzer 30 is routed to the engine 10 for powering the vehicle 11. The oxygen generated by the electrolyzer 30 is safely vented to the atmosphere. The fuel system of the present invention generates no pollutant emissions.

Referring now to Fig. 2, an alternate embodiment of the fuel system of the present invention is shown. The embodiment of Fig. 2 is substantially the same as the embodiment of Fig. 1 described hereinabove, however, in the embodiment of Fig. 2 the exhaust from the internal combustion engine 10 is vented to the atmosphere rather than being recycled. Hydrogen to power the engine 10 is provided by the electrolysis of water in the electrolyzer 30 and the hydrogen stored in storage tank 42.

In another embodiment of the invention shown in Fig. 3, the fuel system of the invention is similar to that described in Fig. 1 with the exception that hydrogen and oxygen comprise the fuel to power the engine 10. As illustrated in Fig. 3, the exhaust vapors from the engine 10 are cooled and recycled as described hereinabove. Oxygen generated by the electrolyzer 30, however, is routed via a conduit 60 and expander 61 to the intake manifold of the engine 10. When the vehicle 11 is off but connected to an external power source, oxygen generated by the electrolyzer 30 is routed to a compressor 62 where it is pressurized and stored in an oxygen storage tank 64. In an alternate embodiment illustrated in Fig. 4, the engine exhaust is not recycled, but is instead vented to the atmosphere through a vent conduit 66.

Referring again to Fig. 3, an oxygen conduit 68 connects the compressed oxygen storage tank 64 to the intake manifold of the engine 10. Oxygen which exits the storage tank 64 at a high pressure is routed through an expander 70 where the pressure of the oxygen is decreased to the required engine pressure. The expander 70 is electrically coupled to the electrolyzer 30 by a power line 72. The expander 70 converts the potential energy stored within the pressurized oxygen into electrical power which is used to power the electolyzer 30.

Referring now to Fig. 5, another alternate embodiment of the fuel system of the present invention is shown. The embodiment of Fig. 5 is substantially the same as the embodiment of Fig. 3 described hereinabove with the exception that oxygen generated by the electrolyzer 30 and not routed to the engine 10 via conduit 60, is routed through an expander 74 where the pressure is lowered to ambient pressure. The oxygen is then passed through an air mixer 76 and the resulting mixture of air and oxygen is routed to the compressor 62 where it is pressurized and stored in storage tank 64.

Referring still to Fig. 5, one or more expanders are housed in an expander housing 78. The input manifold of the housing 78 includes two connectors for air and/or oxygen and two connectors for hydrogen for illustrative purposes. It is understood that the housing 78 may include a greater or fewer number of input connectors to match the number of expanders housed within the expander housing 78. The output side of the housing 78 is provided with an outlet port for connection to a hydrogen conduit 81 and a second outlet port for connection to an oxygen conduit 83which are in fluid communication with the intake manifold of the engine 10. The housing 78 is internally configured to accept and route multiple input conduits to the hydrogen and oxygen outlet ports. In the alternate embodiment of Fig. 6, the exhaust vapor from the engine 10 is vented to the atmosphere.

Referring now to Fig. 7 another alternate embodiment of the fuel system of the present invention is shown. The embodiment of Fig. 7 is substantially the same as the embodiment of Fig. 5 described hereinabove with the exception that the oxygen conduit 60 includes a valve 80 incorporated therein for controlling the supply of oxygen from the electrolyzer 30 to the engine 10. The valve 80 is operatively coupled to an engine control unit (not shown in the drawings) for regulating oxygen flow to the engine 10. In addition, oxygen generated by the electrolyzer 30 and not routed to the engine 10 is routed through the expander 74 and air mixer 76 where it is vented to the atmosphere. The compressor 62 draws air through a port 82 open to the atmosphere. The air is pressurized and stored in the storage tank 64. When the vehicle 11 is operating, the compressed air in storage tank 64 is passed through an expander 84 and routed to the intake manifold of the engine 10 as described hereinabove relating to Fig. 1. In the alternate embodiment of Fig. 8, the exhaust vapor from the engine 10 is vented to the atmosphere.

In another mode of operation, compressed hydrogen and air may be supplied to the vehicle 11 from an external source, such as a refueling site or the like. In the schematic diagram of Fig. 9 the fuel system of the present invention is substantially the same as the embodiments previously described herein with the exception that compressed air and hydrogen are supplied to the vehicle 11 from an external source. Compressed air is stored in the vehicle 11 in the air storage tank 64. A compressed air supply line 90 provides a conduit and a connection for replenishing the air in storage tank 64 from an external source of compressed air.

The temperature of air stored in the tank 64 is at about 60°F to about 140°F. Energy derived from the compressed air may be maximized by heating the air prior to use as fuel to power the engine 10. The air is heated by routing it through heaters 92, which are in fluid communication with the circulating engine coolant, providing heat exchange with the air and raising its temperature to about 200°F. Excess air from the storage tank 64 is vented to atmosphere through a regulating vent valve 94.

Compressed hydrogen is stored in the hydrogen storage tank 42 in the vehicle 11. A compressed hydrogen supply line 96 provides a conduit and a connection for replenishing the hydrogen in the storage tank 42 from an external source of compressed hydrogen. A valve 98 is operatively coupled to an engine control unit (not shown in the drawings) for regulating hydrogen flow to the engine 10 from the storage tank 42. The low temperature hydrogen is routed through a heater 110, which is in fluid communication with the circulating engine coolant, providing heat exchange with the hydrogen and raising its temperature to the required temperature for use as fuel to power the internal combustion engine 10.

The electrolyzer 30 generates hydrogen and oxygen as described in greater detail above. The oxygen generated by the electrolyzer 30 is vented to the atmosphere through a vent valve 102 and a vent line 104. Ambient air is introduced into the vent line 104 via a port 106 for mixing with the oxygen prior to venting the air/oxygen mixture to the atmosphere. The production of hydrogen by the electrolyzer 30 varies depending on the amount of electricity available from the expanders 21 and 84 and by the horsepower requirements of the vehicle 11. When the vehicle 11 is moving at a low speed, less hydrogen fuel is required and excess hydrogen from the electrolyzer 30 is available. The excess hydrogen is stored in a pressurized tank 108 and available for use as the horsepower requirements of the vehicle 11 increase. When the horsepower requirements of the vehicle 11 exceed the capacity of hydrogen production of the electrolyzer 30, the hydrogen requirement of the vehicle 11 is supplemented with the hydrogen stored in the storage tank 42 by opening the valve 98 and thereby increasing the hydrogen supply to the engine 10.

While preferred and alternate embodiments of the invention have been shown and described, other and further embodiments of the invention may be devised without departing from the basic scope thereof, and the scope thereof is determined by the claims that follow.

CLAIMS:

1. A fuel system for an internal combustion engine, comprising:

(a) an oxygen storage tank containing pressurized oxygen operatively connected to said engine;

(b) a hydrogen storage tank containing pressurized hydrogen operatively connected to said engine;

(c) an electrolyzer for generating hydrogen and oxygen;

(d) a water reservoir in fluid communication with said electrolyzer;

(e) electric circuit means for providing electric power to said electrolyzer;

(f) conduit means for routing pressurized hydrogen and oxygen to said engine; and

(g) wherein said conduit means includes expanders disposed therein adapted to lower the pressure of said pressurized hydrogen and oxygen to the intake pressure of said engine.

2. The fuel system of claim 1, including an engine exhaust conduit for recycling engine exhaust to said electrolyzer to generate hydrogen and oxygen by electrolysis.

3. The fuel system of claim 2, wherein said engine exhaust is passed through a condenser and condensed into water.

4. The fuel system of claim 3, including means for injecting water into said engine exhaust conduit for cooling exhaust vapor from said engine.

5. The fuel system of claim 2, including a catalytic converter disposed in said engine exhaust conduit for filtering pollutants from exhaust vapor generated by said engine.

6. The fuel system of claim 1, wherein said conduit means includes a first conduit for routing hydrogen from said hydrogen storage tank to said engine and a second conduit for routing hydrogen from said electrolyzer to said engine.

7. The fuel system of claim 6, including a first compressor disposed in said first conduit operatively connected to said hydrogen storage tank.

8. The fuel system of claim 1, including an engine exhaust conduit for venting exhaust vapor generated by said engine into the atmosphere.

9. The fuel system of claim 1, wherein oxygen produced by said electrolyzer is routed through an expander and an air mixer prior to venting into the atmosphere.

10. The fuel system of claim 1, wherein said electric circuit means includes a first electric circuit electrically coupling said expanders with said electrolyzer.

11. The fuel system of claim 10, wherein said electric circuit means includes a second electric circuit electrically coupling said electrolyzer to an external power source.

12. The fuel system of claim 10, wherein said first electric circuit includes at least two expanders electrically coupled to said electrolyzer.

13. The fuel system of claim 11, including an electrical receptacle for connecting said second electric circuit to an external power source.

14. The fuel system of claim 1, wherein said water reservoir includes a fill port for adding water to said water reservoir.

15. The fuel system of claim 1, wherein said oxygen storage tank contains a pressurized oxygen/air mixture.

16. The fuel system of claim 15, including a first oxygen/air conduit for routing said oxygen/air mixture from said storage tank to said engine and a second oxygen/air conduit for routing oxygen from said electrolyzer to said engine.

17. The fuel system of claim 16, including an oxygen/air compressor disposed in said first oxygen/air conduit operatively connected to said oxygen/air storage tank.

18. The fuel system of claim 16, including an air mixer disposed in said first oxygen/air conduit.

19. The fuel system of claim 15, including an expander housing for housing said expanders and wherein said expander housing includes multiple inlet ports in selective fluid communication with a hydrogen outlet port and an oxygen/air outlet port.

20. The fuel system of claim 6 wherein said conduit means includes a third conduit for routing oxygen from said oxygen storage tank to said engine.

21. The fuel system of claim 1, including means for connecting said hydrogen storage tank and said oxygen storage tank to external hydrogen and oxygen sources for recharging said hydrogen and oxygen storage tanks.

22. A method of generating hydrogen for an internal combustion engine, said method comprising the steps of:

(a) providing an electrolyzer operatively connected to said engine;

(b) providing a water reservoir in fluid communication with said electrolyzer;

(c) connecting said electrolyzer to a power source and applying an electric current for generating hydrogen and oxygen;

(d) storing pressurized hydrogen in a first storage container in fluid communication with said engine;

(e) storing pressurized oxygen in a second storage container in fluid communication with said engine; and

(f) conveying pressurized hydrogen and oxygen to an intake manifold of said engine for powering said engine.

23. The method of claim 22 including the step of recycling exhaust vapor generated by said engine to produce hydrogen and oxygen by electrolysis.

24. The method of claim 23 including the step of condensing said exhaust vapor into water and routing the water to said electrolyzer.

25. The method of claim 22 including the step of pressurizing and storing an oxygen/air mixture in said second storage container.

26. The method of claim 22 including the step of providing conduit means for conveying pressurized hydrogen to said engine.

27. The method of claim 26 including the step of disposing expanders within said conduit means and channeling pressurized hydrogen through said expanders to reduce the pressure of said hydrogen to the intake pressure of said engine.

28. The method of claim 26 wherein said power source includes a first electric circuit coupling an expander disposed in said conduit means to said electrolyzer.

29. The method of claim 28 wherein said power source includes a second electric circuit coupling said electrolyzer to an external power source.

30. The method of claim 22 including the step of recharging said hydrogen and oxygen storage tanks from external compressed hydrogen and oxygen sources.

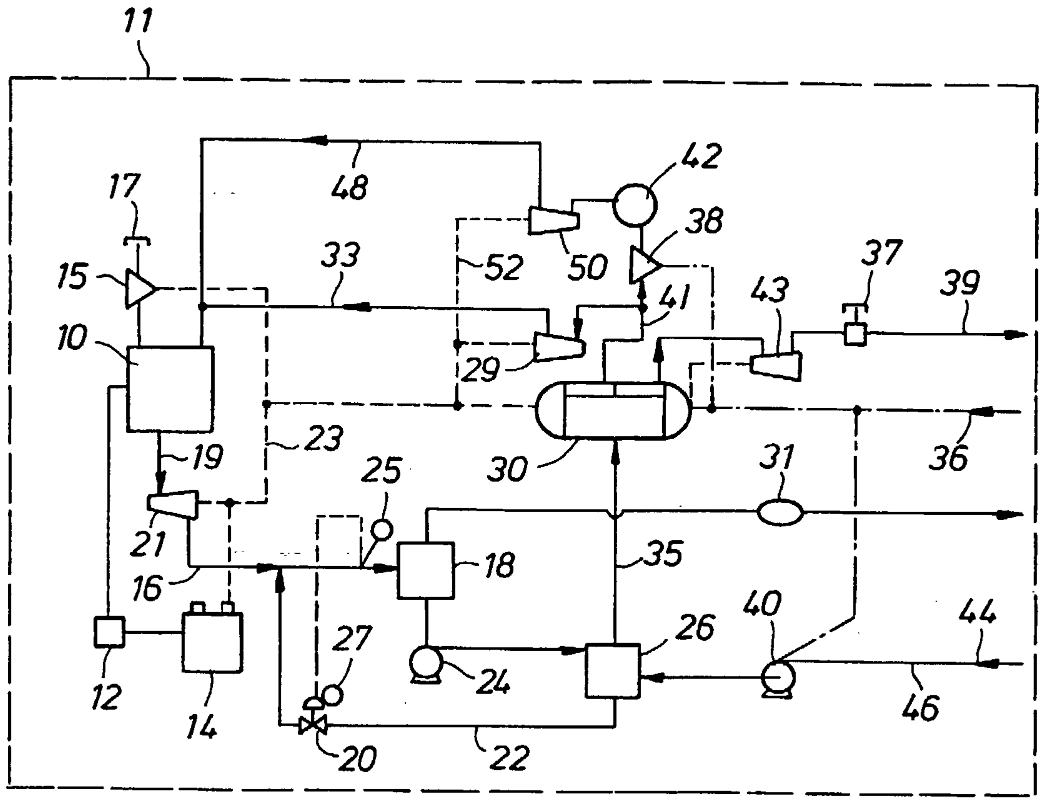
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FIG.1

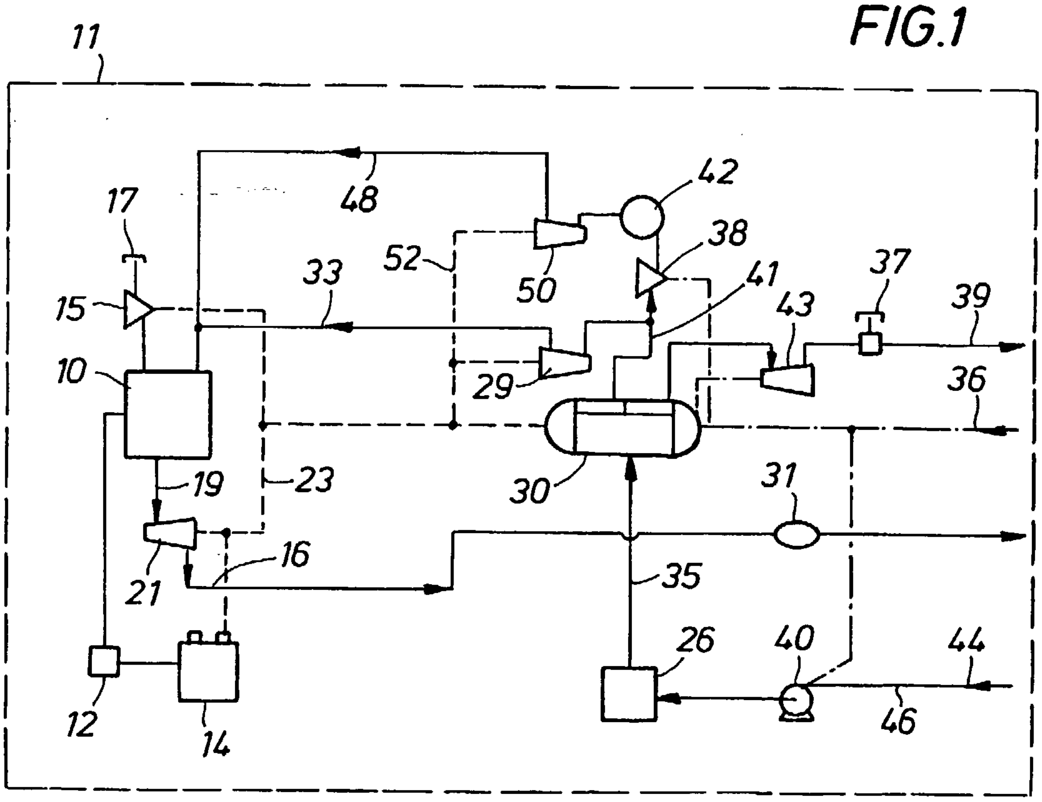
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FIG.2

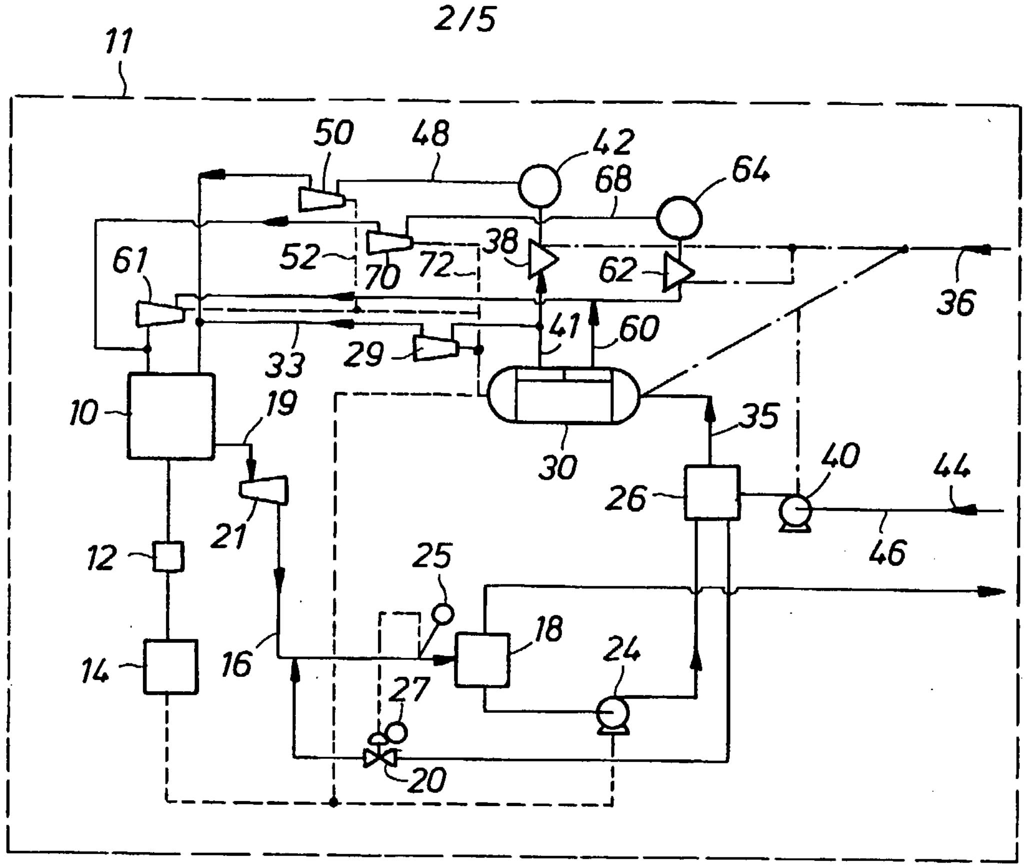
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FIG. 3

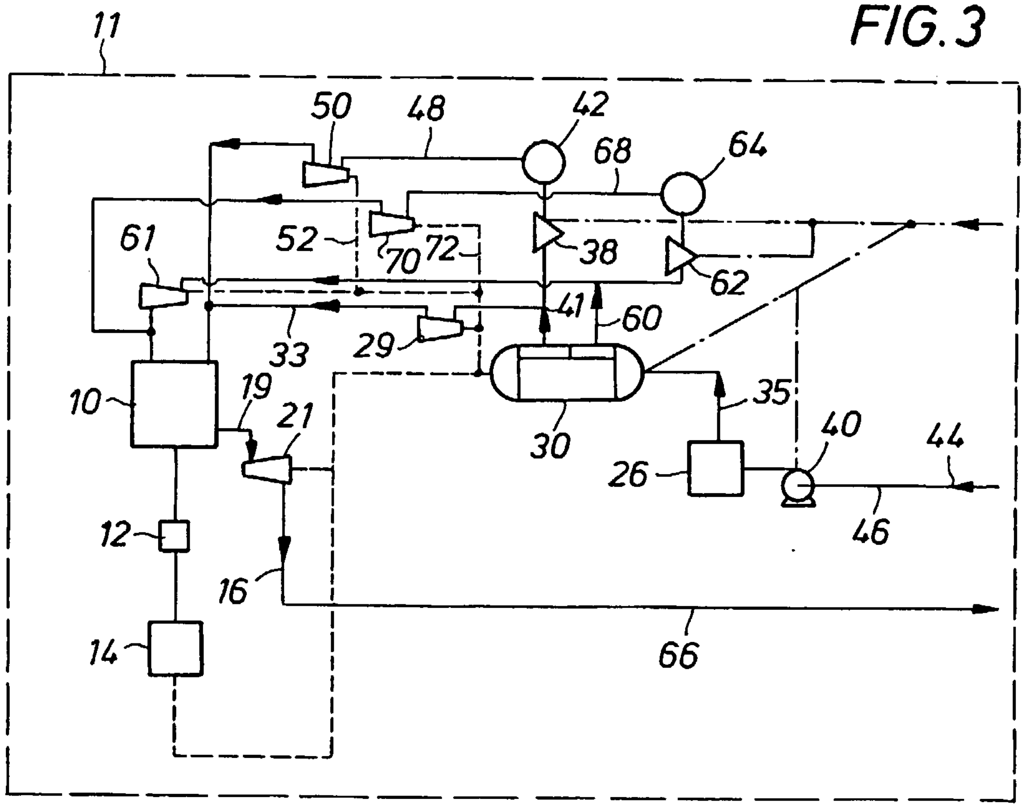
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FIG. 4

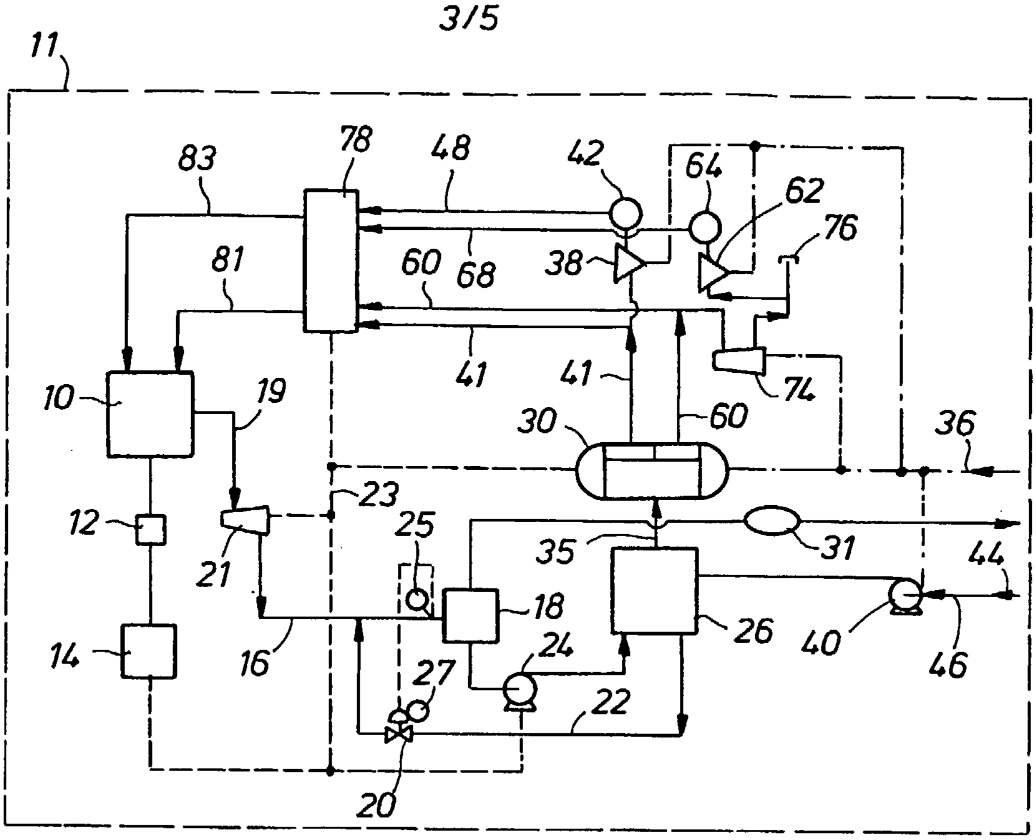
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FIG.5

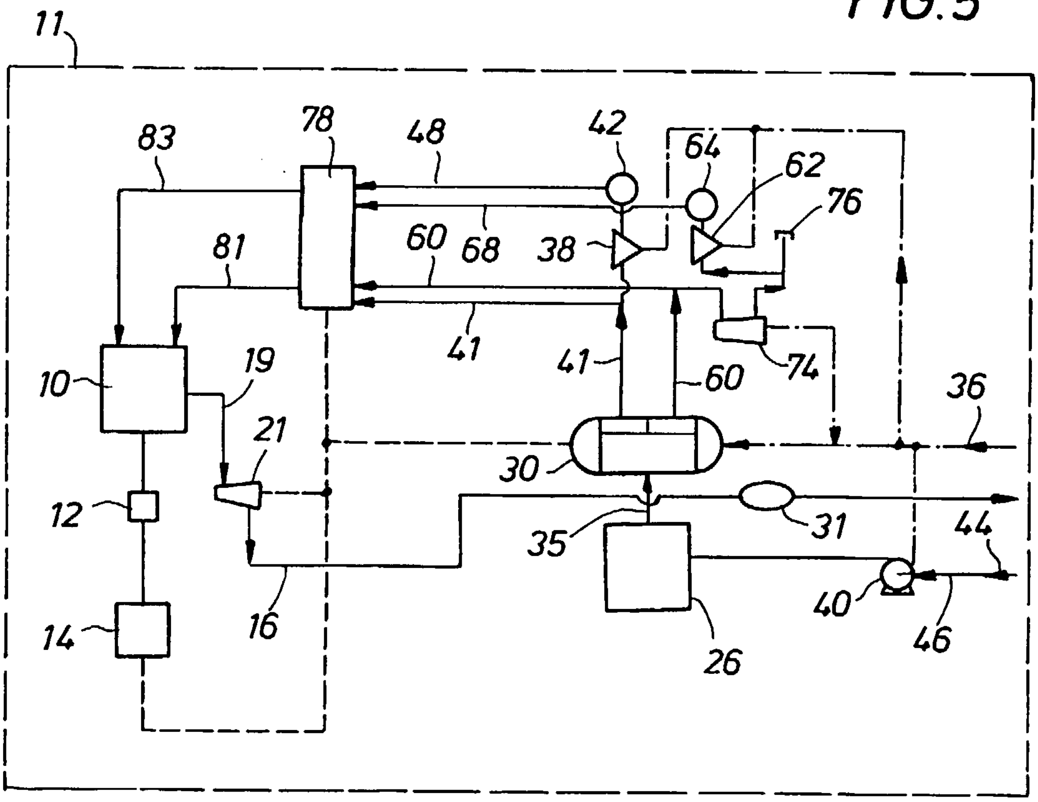
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FIG.6

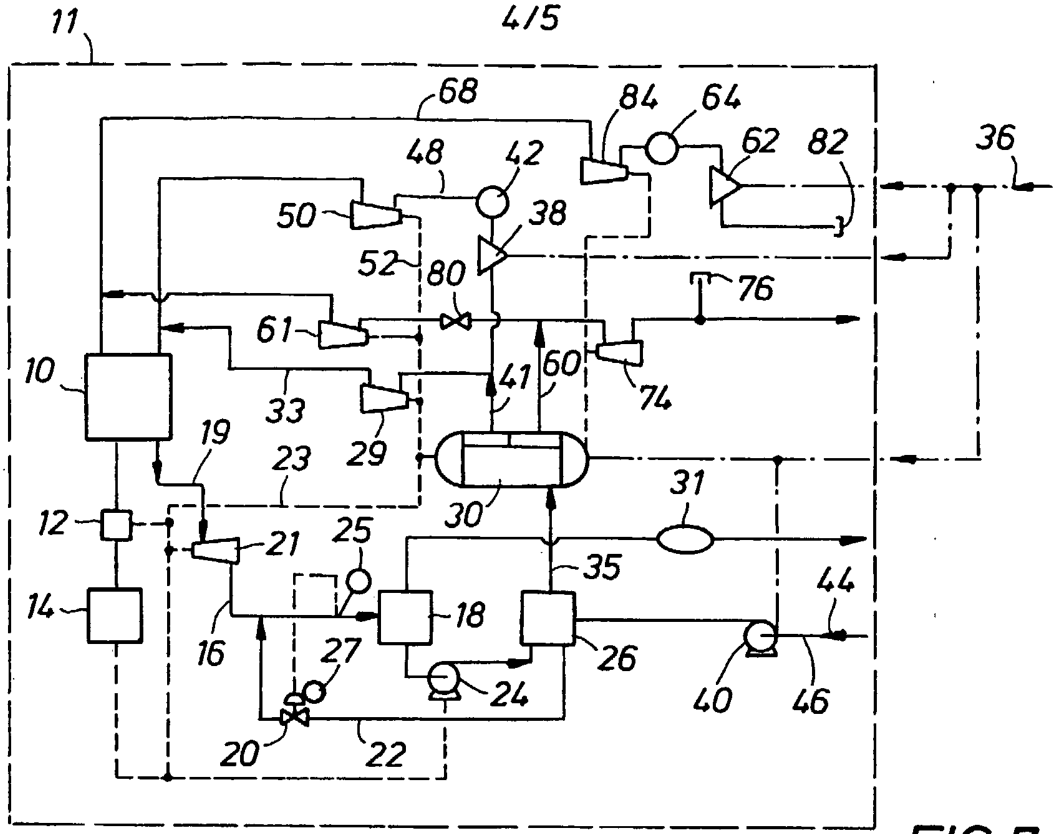
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FIG.7

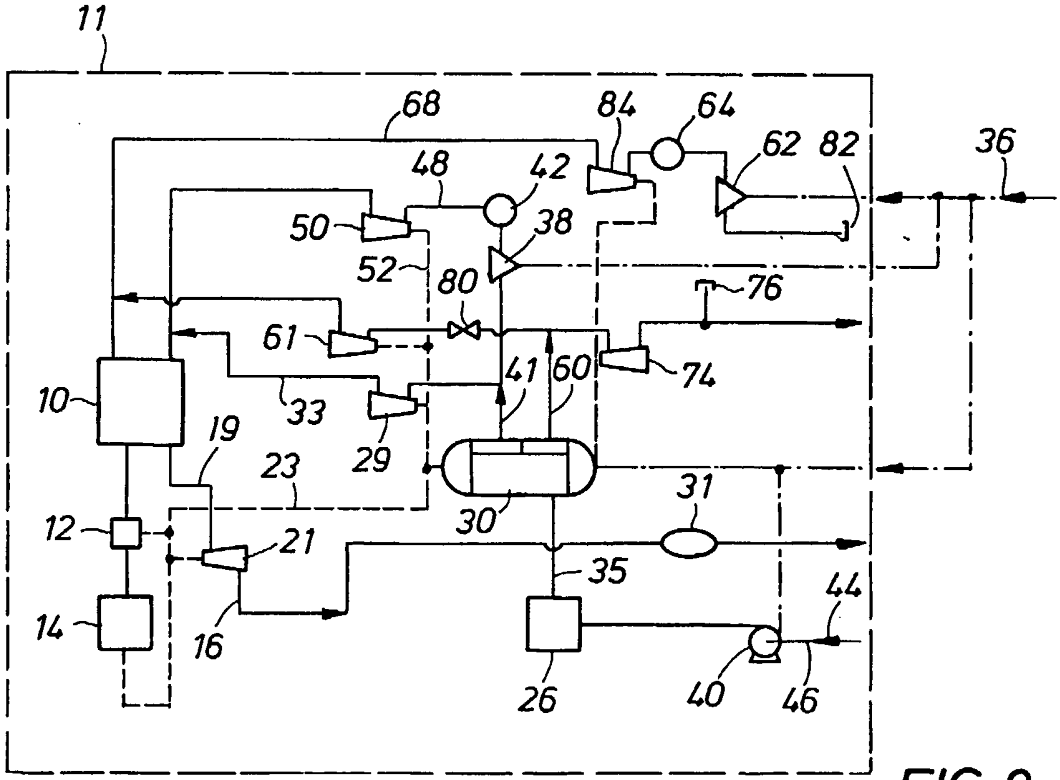
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FIG.8

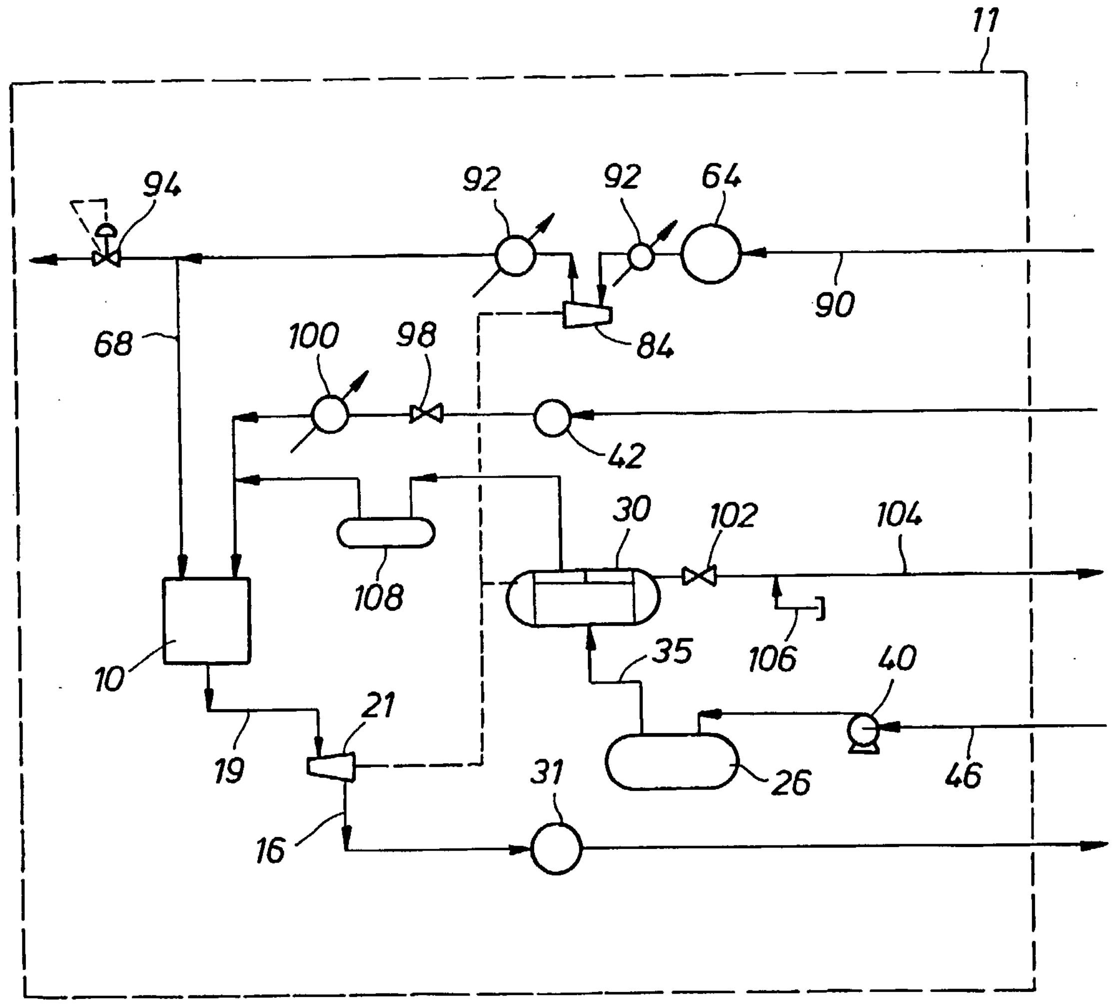
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FIG.9