

Application Serial No. 590,000
Filed: August 20, 1973
Contractor: Caltech/JPL

NASA Case No. 10-15574
Contract NAS7-100

S P E C I F I C A T I O N

TO ALL WHOM IT MAY CONCERN:

BE IT KNOWN THAT WE, JOHN HOUSEMAN, JACK H. RUPE
and RAYMOND KUSHIDA, all citizens of the United States
of America, residing at Pasadena, Sunland and Los Angeles
5 respectively, all in the County of Los Angeles, State of
California, have invented a new and useful

HYDROGEN RICH GAS GENERATOR

of which the following is a specification:

ABSTRACT OF THE DISCLOSURE

10 A process and apparatus is described for producing
a hydrogen rich gas from liquid hydrocarbons and water by
means of the steam reforming process using a partial
oxidation approach.

ORIGIN OF THE INVENTION

15 The invention described herein was made in the
performance of work under a NASA contract and is subject
to the provisions of Section 305 of the National Aeronautics
and Space Act of 1958, Public Law 85-568 (72 Stat. 435;
42 USC 2457).

AWARDS ABSTRACT

NASA Case No. NPO-13342 -/

Inventors: John Houseman,
Jack H. Rupe and
Raymond O. Kushida

~~Case No. 13342~~
~~Case No. 13342~~

Contractor: California Institute
of Technology/Jet Propulsion Lab
Pasadena, CA.

Contract NAS7-100

HYDROGEN RICH GAS GENERATOR

The object of this invention is to provide a compact, instant starting, low cost, and portable hydrogen rich gas generator to be used for providing hydrogen rich gas for mixing with the fuel used in internal combustion engines whereby their pollutant emissions are minimized.

Figure 1 shows, by way of example, the proposed placement of the hydrogen generator 20, the air, water and fuel pumps, respectively 36, 34, 28, required for its operation, and a water supply 30, under the hood of an automobile.

Figure 2 shows one embodiment of the invention consisting of a container having outer and inner walls 40, 42 with insulation 44 therebetween. A third wall 46, spaced from the inner wall 42 defines an air passage for conducting air injected into the passage near one end of the container so that it passes around the combustion region to be preheated. The air is directed to the other end of the chamber where it is directed by baffles around a plurality of pipes 50 to cool the hydrogen rich gas passing through these pipes from the combustion chamber to the auto engine. The heated air is then emitted into an ignition area 60, in the chamber where it is mixed with a hydrocarbon fuel. The mixture is ignited by a means such as a hot wire plug 64 to form hot gases. A water spray is emitted through tubes 66, 68 into the hot gases to produce steam, when a predetermined temperature of the hot combustion gases is sensed by a sensor 82. At that time, more hydrocarbon fuel is injected into the hot combustion gas and steam to be reformed into a hydrogen rich gas. This is collected by the pipes 50.

Figure 3 shows a control system for starting up and for shutting down the hydrogen rich gas generator. Upon turning on, an ignition key 83 turns on fuel pump 28, opens an ignition valve 94, and a small quantity of fuel is injected onto a hot wire device 76 in the chamber. A temperature sensor 80 senses when the heat produced is sufficient to ignite the injected air and fuel mixture. When this temperature is sensed a valve 100 is opened permitting the injection of fuel so that it is mixed with the air. When temperature sensor 82 senses a high enough combustion gas temperature, it opens a reformer valve 108 to permit injection of hydrocarbon fuel into the chamber and starts a water pump 38 to pump water as a spray into the chamber.

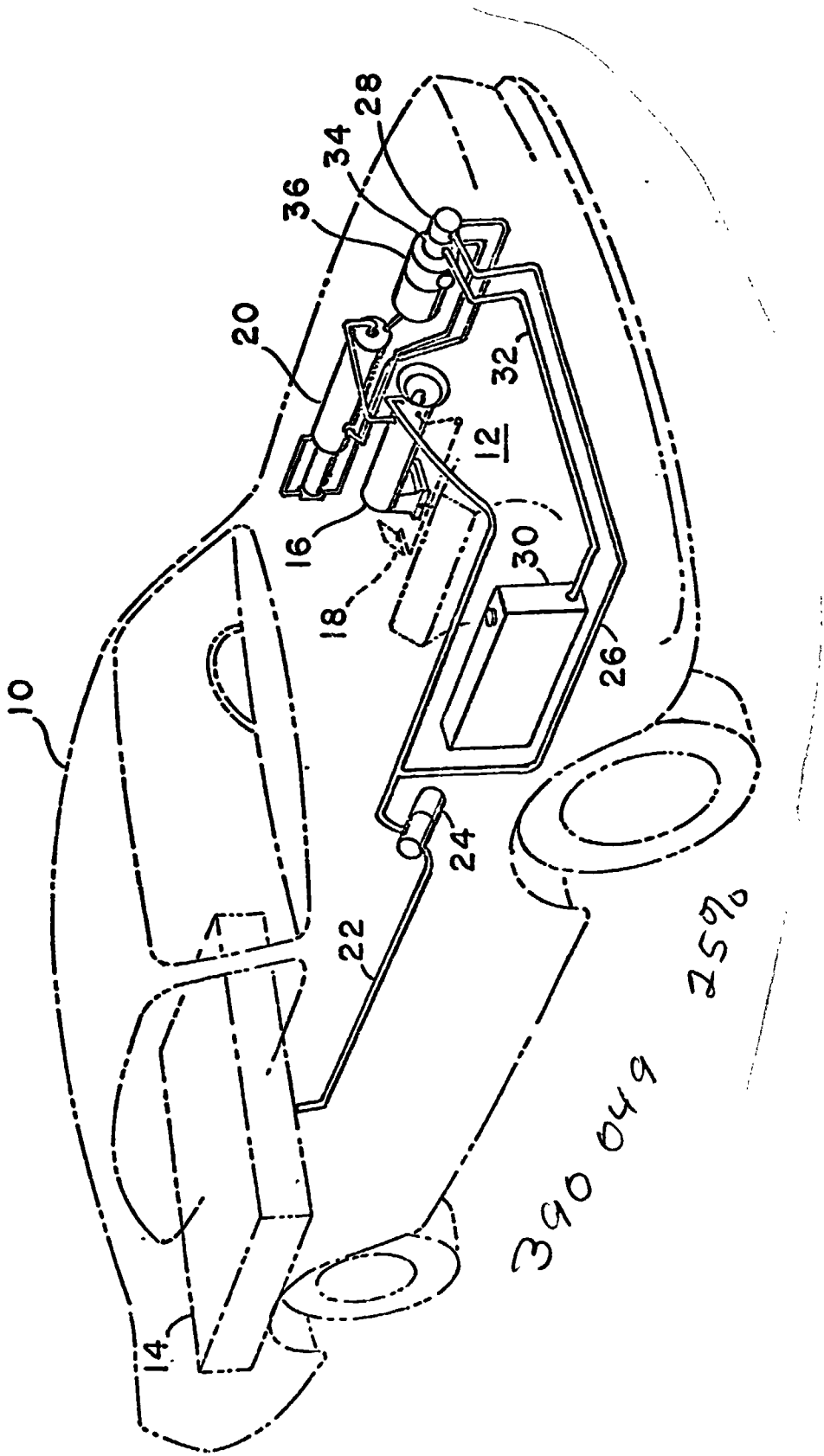
Application Serial No. 390,049
Filed: August 20, 1973

When the ignition key is turned off a counter 114 is started up. Upon its first count, it closes the reformer valve 108 cutting off injection of fuel into the steam reforming region of the chamber. On the second count, the water pump 38 is shut down. On the third count, the main fuel valve 100 is turned off. On the fourth count, the fuel pump 28 and the air compressor 36 are turned off.

Figure 4 shows another hydrogen rich gas generator arrangement. Here, air is preheated as before by passing through a passageway including baffled gas collection pipes and a spacing between walls 118 and 122. The preheated air is mixed with fuel sprayed into the chamber by a nozzle 130. An igniter 132 ignites the mixture to form an ignited hydrocarbon air mixture. This moves down the chamber where water is sprayed by nozzles 134, 136 to form steam. Further downstream, fuel is sprayed by nozzles 133, 140 to form a hydrogen rich gas. This is carried away through pipes 126.

Figure 5 shows still another embodiment of the invention. A pneumatic atomizer injects a preheated air and fuel mixture into a chamber 143 which connects with an air swirler 164 into a combustion chamber 150. The air swirler causes a vortex which is ignited by plug 166. The hot combustion gases which are formed have an air, water and fuel mixture sprayed into them by a pneumatic atomizer 168 whereby a hydrogen rich gas is formed. This is emitted through a tube 172 at one end of the chamber 150.

The novelty resides in the physical arrangement of the generator for generating the hot combustion gas by igniting a mixture of preheated air and fuel, injecting water into this gas to form steam and injecting fuel into this steam to form a hydrogen rich gas.



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FIG. 1

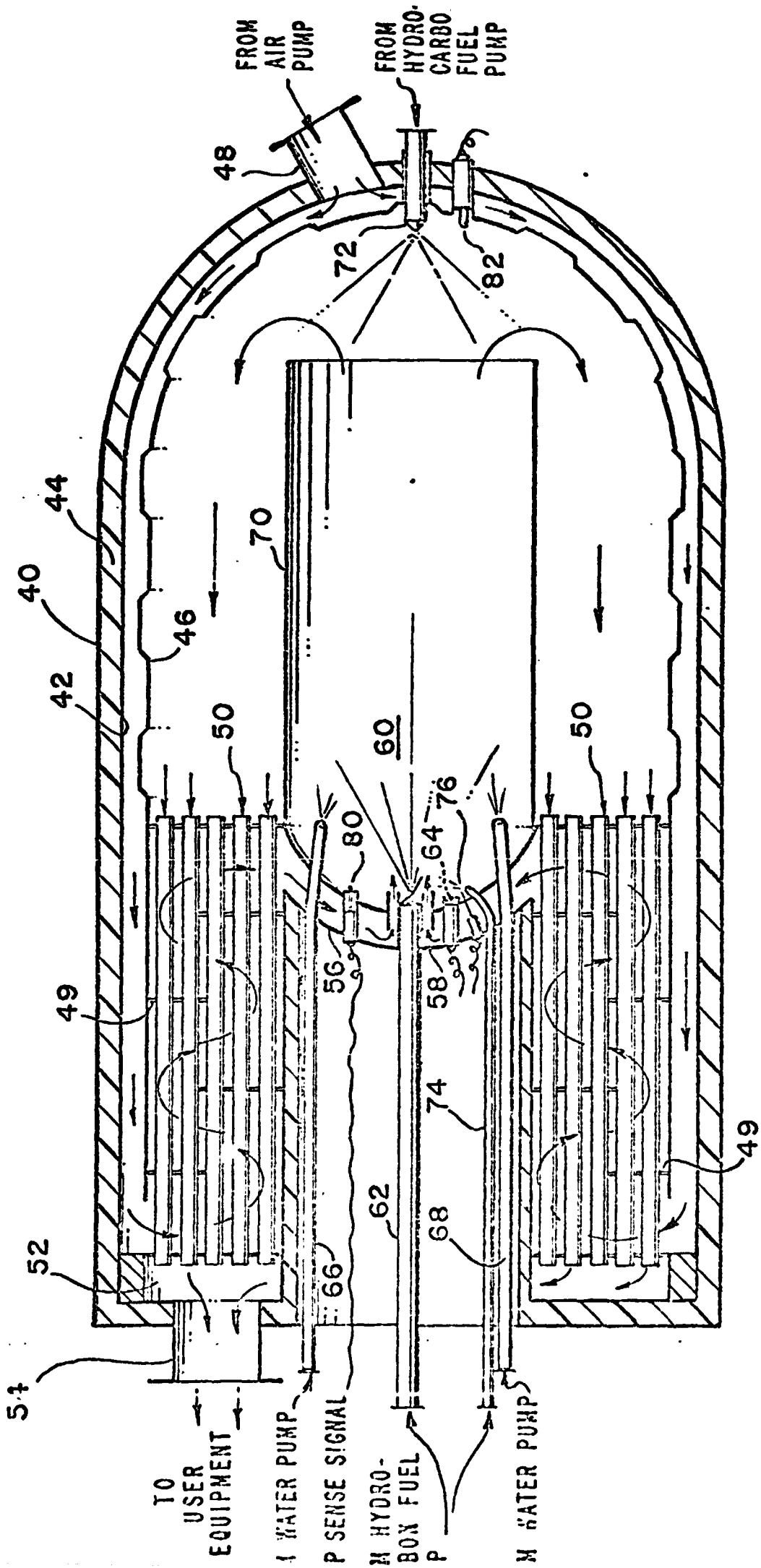
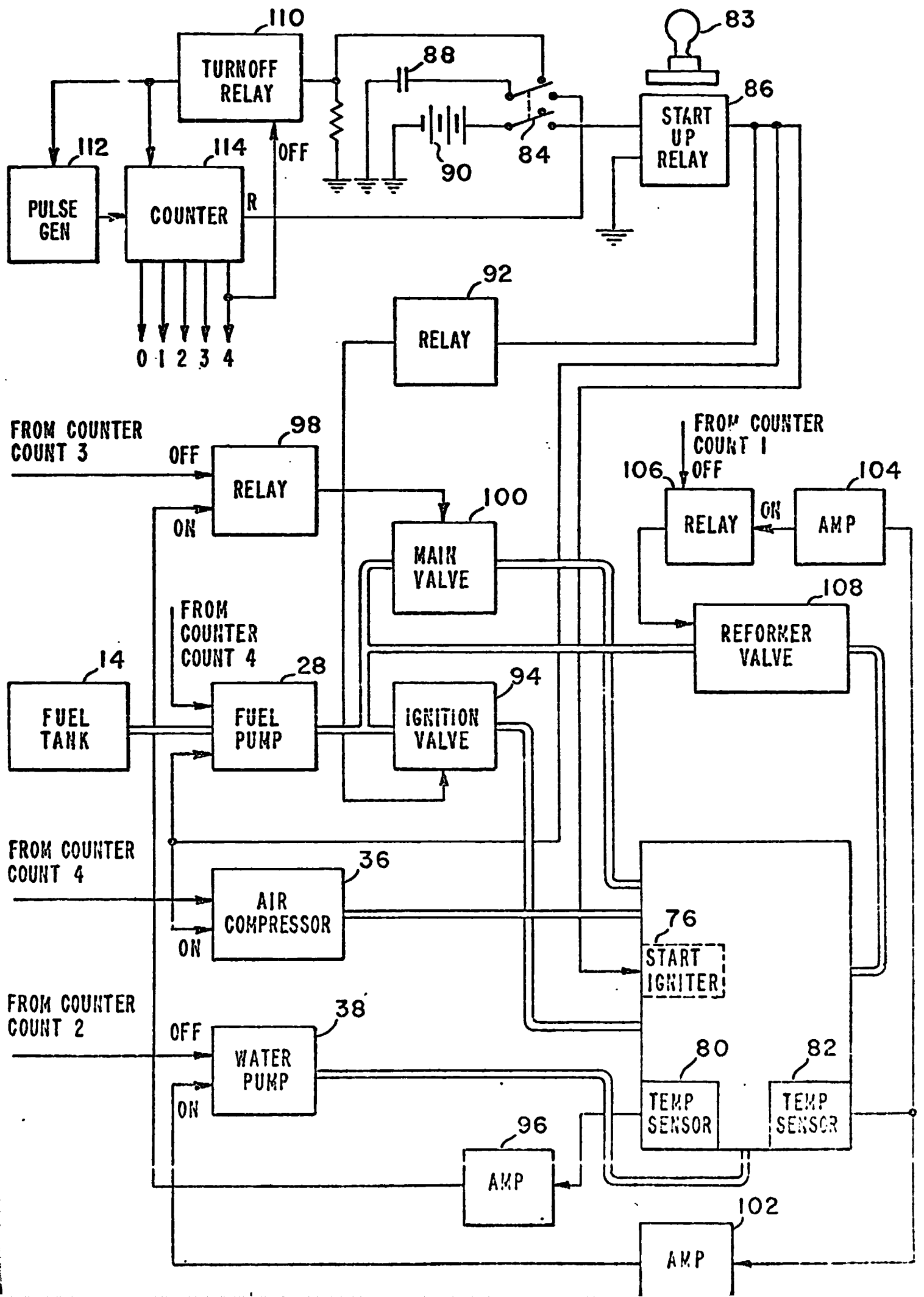


FIG. 2



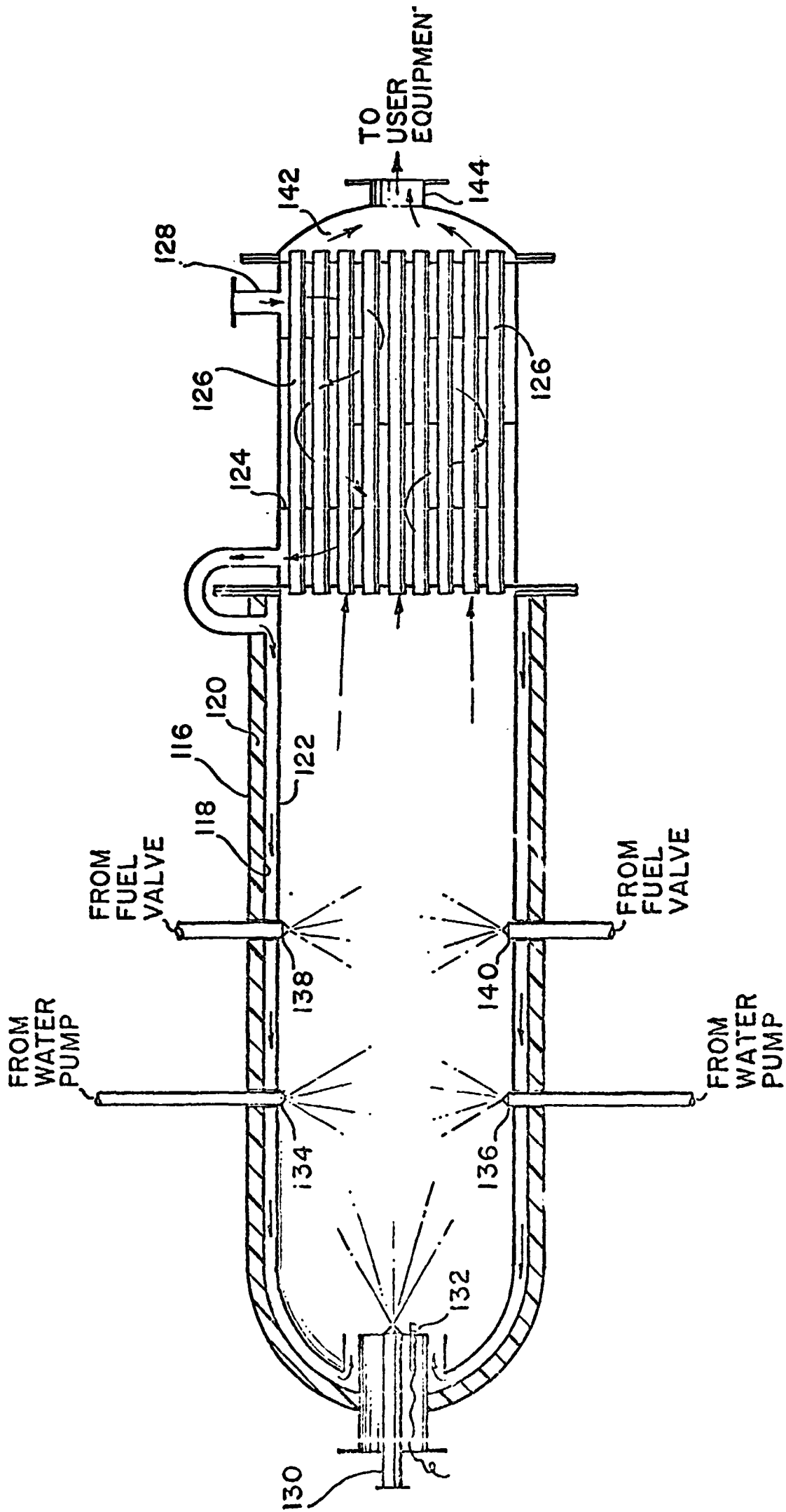


FIG. 4

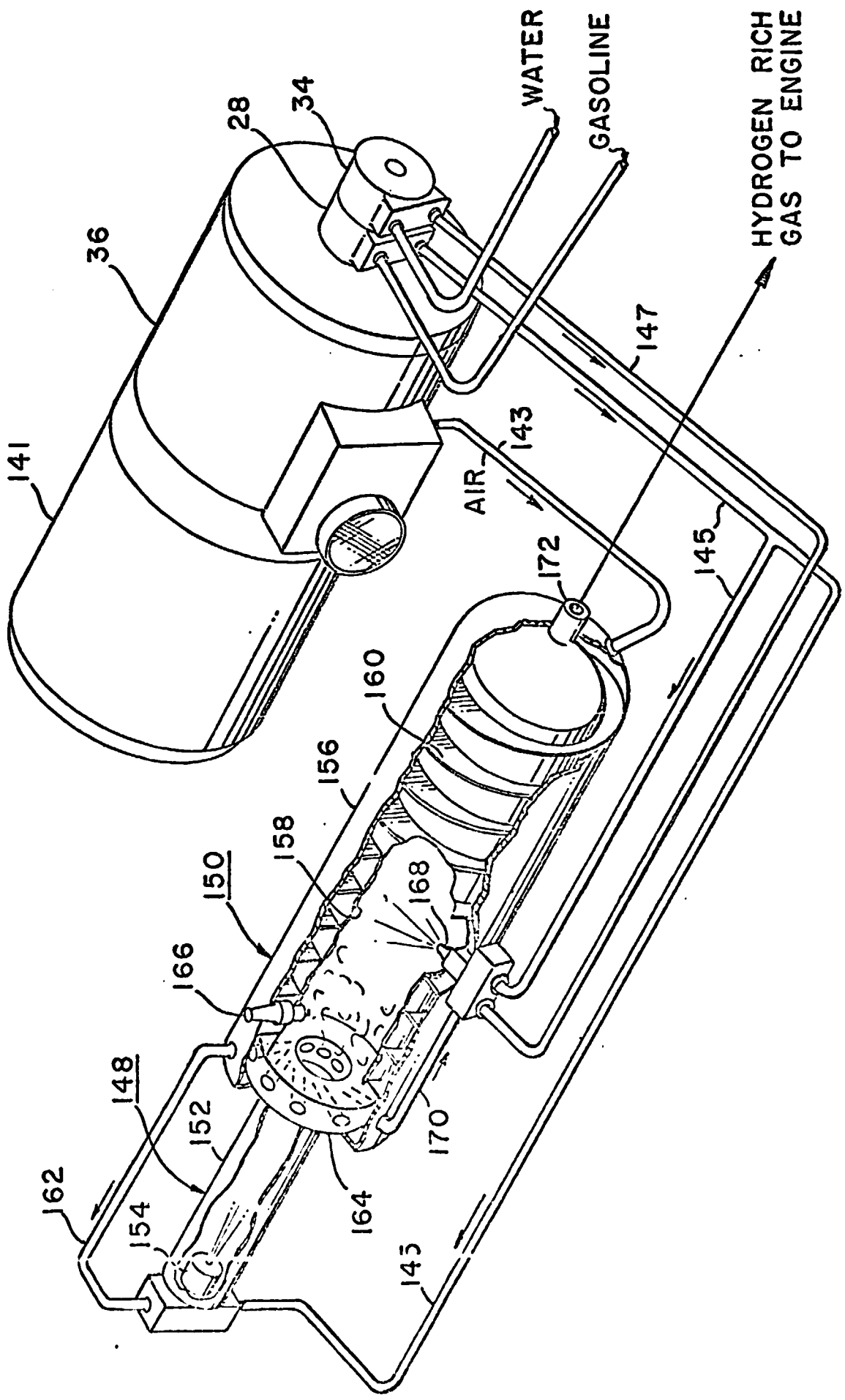


FIG. 5

HYDROGEN RICH
GAS TO ENGINE

BACKGROUND OF THE INVENTION

1. Field of the Invention:

This invention relates to hydrogen generators, and more particularly to improvements therein.

5 2. Description of the Prior Art:

Because of the considerable amount of air pollution caused by operation of the automobile engine, a considerable amount of research has been undertaken to see if the internal combustion engine can be made pollutant free. One approach, which appears to be very promising, is to use a fuel consisting of a mixture of a hydrogen rich gas with the hydrocarbon fuel, such as gasoline, presently being used, and air, in proportions so that, the mixture, at most, is on the very lean side and yet is still flammable. The problem still exists, however, of providing a hydrogen generator that is sufficiently compact to be conveniently carried within a passenger automobile. The hydrogen generator must also be able to start generating hydrogen fast enough, when engine start up occurs, to provide quick, pollution free auto engine start up. Other requirements for a hydrogen generator of the type indicated are that it must have a long, trouble free lifetime and, that it be safe and economical to operate.

OBJECTS AND SUMMARY OF THE INVENTION

An object of this invention is the provision of a novel and compact generator of a hydrogen rich gas.

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Yet another object of this invention is the provision of a novel fast starting generator of hydrogen rich gas.

5 Still another object of this invention is the provision of a hydrogen rich gas generator that is safe and economical to operate.

10 These and other objects of the invention may be achieved in a system wherein hydrogen rich gas is generated in a cylindrically shaped chamber by injecting air and hydrocarbon fuel at one end of said chamber, igniting the mixture of said air and hydrocarbon fuel to provide very hot combustion gases, by partial oxidation of the hydrocarbon. These gases move away from said ignition region to another region where water is injected to be turned into steam by 15 the hot combustion gases. Either simultaneously with the injection of water or subsequently thereto, more hydrocarbon fuel is injected. The steam which is formed mixes with the hot gases present to yield a uniform hot gas whereby a steam reforming reaction with the hydrocarbon fuel takes place to 20 produce a hydrogen rich gas.

The novel features of the invention are set forth with particularity in the appended claims. The invention will best be understood from the following description when read in conjunction with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 is a schematic drawing of an automobile, illustrating placement of this invention and associated components therein.

5 Figure 2 is a cross-sectional view of a hydrogen generator in accordance with this invention.

Figure 3 is a schematic illustration of a control system for a hydrogen generator in accordance with this invention.

10 Figure 4 is another embodiment of a hydrogen generator in accordance with this invention.

Figure 5 is yet another embodiment of a hydrogen generator in accordance with this invention.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

15 Figure 1 is the same as the Figure 1 shown in an application for patent by J. Rupe entitled, "System For Minimizing Internal Combustion Engine Pollution Emission", (Attorney's Docket No. 73/259) which is assigned to a common assignee. Figure 1 is shown to provide an appreciation
20 of this invention. Figure 1 shows an illustration of an automobile 10, having an engine 12, and a tank 14, in which

the hydrocarbon fuel is kept. The engine is equipped with
an induction tube 16, wherein there is located means for
mixing air, hydrogen rich gas and hydrocarbon fuel in
proportions which minimize the pollutant emission of the
5 engine. A suitable arrangement for an induction tube
including apparatus for mixing and controlling the mixture
proportions is shown and described in an application for
patent entitled, "System For Minimizing Internal Combustion
Engine Pollution Emission" by Jack H. Rupe Serial No. -----,
10 filed-----, (Attorney's Docket No. 73/259, which is assigned
to a common assignee.

There is also provided an air throttle 18 which
is controlled from the foot pedal, by the operator, and
which determines the amount of air permitted to flow to the
15 engine. Also, provided in accordance with this invention,
is a hydrogen gas generator. The hydrocarbon fuel is fed
into the mixing means in the induction tube through a pipe,
22, in which there is a fuel pump 24. Another pipe 26
branches from the pipe 22 to couple to a pump 28, which is
20 used to supply hydrocarbon fuel to the hydrogen gas generator
20. A water supply 30 is provided. A pipe 32 couples the
water supply to a pump 34 whereby water is provided to the
hydrogen generator. An air pump 36, is also employed for
applying air under pressure to the hydrogen generator.

25 Figure 2 is a sectional view of a hydrogen
generator in accordance with this invention. A bell-shaped

wall 40 encloses the hydrogen generator. There is an inner wall 42, spaced from the outer bell-shaped wall 40, and therebetween, there is placed thermal insulation material 44. Spaced from the inner wall 42, to define an air passageway therebetween, is another wall 46.

Air, from compressor 36 under pressure, is fed to an inlet 48, which directs the air through an opening in the walls into the passageway between the walls 42 and 46. The wall 46 surrounds the hot region of the hydrogen generator and therefore, serves to preheat the air flowing through the passageway. The air is further preheated in passing between a set of baffles 49 which control the air flow around tubes 50. The tubes 50 conduct the product gas from the reactor region of the hydrogen generator to an accumulator space 52, and thence to an exit flange 54.

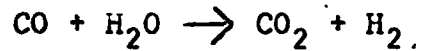
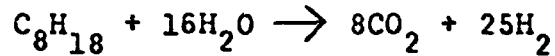
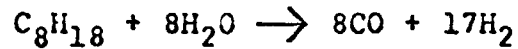
After passing through the heat exchanger presented by baffles 49 and the tubes 50, the heated air is conducted by a passageway 56, 58, into a partial oxidation region 60.

A tube 62, terminates in a nozzle through which a spray of liquid hydrocarbon is emitted into the partial oxidation region 60. There, it mixes with air entering from the passageway 56, 58, to provide a fuel rich mixture. The entrance passageways placement and the velocity of the air and the fuel are such as to create a vortex so that

excellent mixing takes place. The mixture is ignited
by a hot wire or spark igniter 64. The relative quantities
of air and fuel provided are such that only partial
oxidation of the hydrocarbon takes place but sufficient
5 air is provided so that carbon formation is avoided.
Combustion thus takes place under fuel rich conditions,
so that very little nitric oxide is produced. In view
of the manner of introduction of the fuel and air, a
vortex-type flame is provided with a high degree of
10 turbulence, which aids in mixing the air and the fuel and
which promotes flame stabilization.

Water spray tubes 66, 68, are provided to inject
water into the hot combustion gases produced by the burning
of the hydrocarbon fuel. The water spray is vaporized by
15 the gases to produce steam, which then mixes with the hot
partial oxidation gases to yield a uniform hot gas at the
end of the combustion zone which is defined by the walls
70. These walls are in the form of an open cylinder.

A second spray of liquid hydrocarbon is introduced
20 into the region at the end of the combustion zone by a spray
nozzle 72. The hydrocarbon droplets introduced by the
second spray nozzle vaporize rapidly and a steam reforming
reaction then takes place within the reactor space formed
between the walls 70 and 46. As an example, the reaction
25 which occurs is in accordance with the following formulas:



The first reaction represents the major one,
5 the last two reactions are of lesser importance. The
spray nozzle 72 must be carefully selected to provide the
correct cone angle and spray penetration to insure a
uniform mixture of hot gas and vaporized hydrocarbon in
the reactor annulus for optimum reaction without soot
10 formation.

Should it be desired to speed up the steam
reforming action, a catalyst can be placed in the reaction
space. This will be particularly effective when the fuel
contains no materials like lead or sulfur that would poison
15 the catalyst.

The resulting hot product gas flows through the
tubes 50 and is partially cooled since these tubes constitute
a heat exchanger whereby the incoming air takes on the heat
of the hot product gas. The tubes 50 terminate in the
20 collecting annulus space 52 and then thereafter are discharged
through the flange 54. The product gas will still be super-
heated with respect to water upon leaving the reactor. If
it is desired, the product gas may be further cooled down
to condense out the water for recirculation back to the water

feed tank. Also if desired, the air stream may be further preheated by using it to cool the cylinder block of the engine or by heat exchange with exhaust gases from the engine.

For start-up purposes, a tube 74 connected to the gas pump 28 is used to spray a small quantity of hydrocarbon fuel onto a hot wire device 76. Specifically, the tube 74 terminates in a nozzle which is adjacent a hot wire 76 which is surrounded by a wire mesh wick (not shown). A small amount of fuel is deposited on this wire mesh wick when it is desired to start the hydrogen generator. Fuel is then ignited and when a temperature sensor 80, which may be any of the well known temperature sensing devices, such as a thermistor, a photocell, or a bi-metallic device, indicates a high enough temperature is reached, then the main supply of hydrocarbon fuel from pipe 62 is enabled to take place.

After the starting flame has been created by the hot wire device 76 and the primary hydrocarbon fuel supply has commenced, and the emission from the spray nozzle 74 has been ignited, a second temperature sensor 82 comes into use. This temperature sensor is provided to indicate when the main flame, due to the burning of the hydrocarbon supplied through the nozzle 62 has heated up the combustion chamber walls to a sufficient degree so that the gas temperature at the sensor 82 reaches a set value. When this temperature sensor provides an output signal indicative of

this fact, when the water nozzles 66, 68, can commence the supply of water.

Figure 3 is a schematic drawing of a control arrangement for the hydrogen generator shown in Fig. 2.

5 Upon turning the ignition key 83 for the vehicle, a double pole double throw switch 84, (shown in the open position), is operated. This energizes a start up relay 86, and charges a capacitor 88 from a power source 90. The start up relay enables current to flow to activate the hot wire
10 igniter 76, and also enables the start up of the fuel pump 28, which draws fuel from the tank 14. Also, enabled to be started at this time is the air compressor 36. The start up relay 86 also enables a relay 92 to be operated. This relay energizes ignition fuel valve 94 for a short time
15 whereby a small quantity of hydrocarbon fuel is applied to the wick surrounding the hot wire igniter 76.

The temperature sensor 80 provides an output signal when it senses that a flame is present, which output signal is amplified by an amplifier 96. The output of
20 amplifier 96 energizes a relay 98, which enables the main hydrocarbon fuel solenoid valve 100 to be opened.

Thereafter, when temperature sensor 82 senses that the main flame has heated up the chamber to a sufficient degree, its output is applied to an amplifier 102, whose
25 output enables the water pump 38 to be turned on. Another

amplifier 104, also amplifies the output of the temperature sensor 82 and turns a relay 106 on. Relay 106 after a short delay enables a valve 108 to be turned on, which enables hydrocarbon fuel to flow through the nozzle 72 into the reforming region.

The turn on sequence enables a mixture of partial oxidation combustion gas and steam to be established first before the reformer-hydrocarbon stream is started. In addition, the reactor wall surface 70, as a result is thoroughly heated up before the major reformer-hydrocarbon stream is introduced. By this procedure, soot formation is avoided. The whole starting sequence occurs within a few seconds.

When it is desired to shut down, the start-up sequence is essentially repeated in reverse. When the ignition key 83 is turned off, the double pole double throw switch 84 is operated to the position shown. Capacitor 88 enables a turn off relay 110 to be operated over as long an interval as is required for turn off. This relay enables a pulse generator 112 to start generating pulses. These pulses are applied to a counter 114, which in response to them commences to count up. On the occurrence of the first count, relay 106 is enabled to be de-energized and the reformer valve 108 is closed. However, a hot stream of gas will still flow through the whole reactor to promote gassification of any tars or soot that may be deposited.

On the second count, the water pump 38 is turned off. On the third count, the relay 98 is deactivated whereupon the main fuel valve 100 is turned off. If desired, the turn off may be made to proceed in two steps, that is, when the relay 98 receives a turn-off signal, instead of turning off the main valve 100 completely, it may turn it down only partially for a few seconds so that a small air-rich flame will be present in the combustor space within the hydrogen reactor. Air-rich hot combustion gases will then sweep through the whole unit for a few seconds to insure combustion of any deposits of tar or soot with the available excess oxygen.

The main valve 100 is then turned off completely. Upon the fourth count, the fuel pump is turned off, as well as the air compressor, relay 110 is turned off resulting in the pulse generator being turned off. It should be noted that upon actuation of the ignition start key, the counter 114 is reset.

Figure 4 shows another embodiment of a hydrogen generator in accordance with this invention which has a different ratio of length to diameter, but basically operates along the same principles. Namely first, creating a partial oxidation flame region, which is used to vaporize water into steam, which is then used to reform a hydrocarbon. As before, the reactor vessel has an outer wall 116, and an inner wall 118, spaced therefrom, between which there is a

thermal insulating material, 120. A third wall 122 is spaced from the inner wall 118 to provide a passageway through which air can pass after it is pre-heated by passing through a heat exchanger provided by an arrangement of baffles 124 and tubes 126. Air is pumped into the shell-side of the heat exchanger through a flange 128. The air is further pre-heated by passing through the annulus formed between spaced walls 118, 122. The air is emitted into the reaction chamber on both sides of a nozzle 130, through which the hydrocarbon fuel is injected as a spray. An igniter 132 is used to ignite the air-hydrocarbon mixture to provide a partial oxidation flame in the region into which the air and hydrocarbon fuel are emitted.

The partial oxidation flame established by the ignited hydrocarbon air mixture provides hot combustion gases into which water sprays are injected through nozzles respectively 134, 136. The water is vaporized into steam by the hot combustion gases. The hydrocarbon is injected into the resulting gas through nozzles respectively 138, 140. A reforming reaction then takes place in the region downstream of the nozzles 138 and 140 which results in the production of the hydrogen rich gas. This gas then passes through the tubes 126 of the heat exchanger to be cooled by the incoming air flow. A product gas accumulates in an end zone 142 and is discharged through the flange 144 from whence it passes to the engine fuel pneumatic atomizer.

Arrangements for starting and controlling this embodiment of the invention, in connection with an internal combustion engine, are the same as indicated in connection with Figure 3. Obviously, if a start up for the purpose of generating a hydrogen rich gas for an automobile engine is not required the start up and turn off procedure need not be so elaborate.

Figure 5 is a drawing, in section, illustrating another embodiment of a hydrogen rich gas generator. An electric motor 141 drives an air pump 36, a gasoline pump 28 and a water pump 34 to provide these fluids to the gas generator over the respective pipes 143, 145 and 147. The hydrogen rich gas generator includes two portions respectively 148 and 150 which include chambers which have the same axis and communicate at one end with each other.

The first portion has cylindrical walls 152 which enclose a first chamber. At one end of this chamber is a pneumatic atomizer 154, to which air, as the operating fluid, and the hydrocarbon fuel are supplied to atomize the fuel.

The second portion 150 of the hydrogen generator has outer cylindrical walls 156. These enclose inner cylindrical walls, 158, which are spaced therefrom and define

a second chamber, which is the burning chamber. Between
the first and second walls is a spiral wall 160, which
defines a spiral passage. Air is pumped into one end of
the spiral passage over the pipe 142, to be directed around
5 the inner wall's 158 and thus, is preheated by the inner
chamber walls which surround the burning chamber. Some of the
preheated air is directed over a pipe 162 to the pneumatic
atomizer 154.

The fuel-air mixture created in the first chamber
10 is passed into the second chamber through an air swirler 164.
This comprises a toroid with a plurality of passages which
are angularly directed from the outer periphery of the
toroid ring to the central opening. Preheated air from
the spiral passage passes through these angularly directed
15 openings and causes the air-fuel mixture passing through
the central opening of the air swirler 164 to be swirled
as it enters into the burning chamber. A spark plug 166 or
other suitable igniting means ignites this mixture and the
hot gases which are created pass further into the chamber
20 into which there is sprayed a mixture of gasoline and water
through a second pneumatic atomizer 168.

The gasoline and water are supplied to the
pneumatic atomizer over pipes 145 and 147. Preheated air
is also provided as the atomizer working fluid over a pipe
25 170.

The hot gases in the second chamber convert the water spray in the fuel-water mixture into steam. The fuel is vaporized and a steam reforming action takes place within the reactor space formed by the burner chamber.

5 Hydrogen rich gas passes out of the opening 172 to the equipment which is going to use it.

For start up, the vehicle ignition switch will also energize the motor 140 which causes delivery of air to the hydrogen generator. After a suitable delay interval

10 to allow air pressure to build up to a predetermined value, such as 5 psig, or when the pressure is sensed by a pressure sensitive switch, (not shown) the engine cranking system is activated, the engine and hydrogen generator ignition

15 systems are activated and a magnetic clutch that couples the water and fuel pumps, respectively 34, 28, to the motor drive are activated. This produces hydrogen substantially

instantaneously and the engine then bootstraps itself to the idle condition.

While the hydrogen generator embodiments of the invention have been described in connection with a spark

20 ignition internal engine, which uses a liquid hydrocarbon, called gasoline, this is not to be construed as a limitation on the invention since it will operate with other liquid hydrocarbons, such as diesel oil, or jet fuel to produce

25 a hydrogen rich gas. Also, the hydrogen generator may be used with other types of combustion engines such as diesel

or jet, or gas turbines in stationary or automotive applications. This invention, by reason of using a partial oxidation process for generating the energy required for the steam reforming reaction, eliminates
5 the complicated structure required previously wherein the energy for a steam reforming step is supplied from the combustion gases from a separate burner by heat transfer through a heat exchange surface to the high temperature steam reformer gas.

10 There has therefore been described herein a novel and useful hydrogen rich gas generator.