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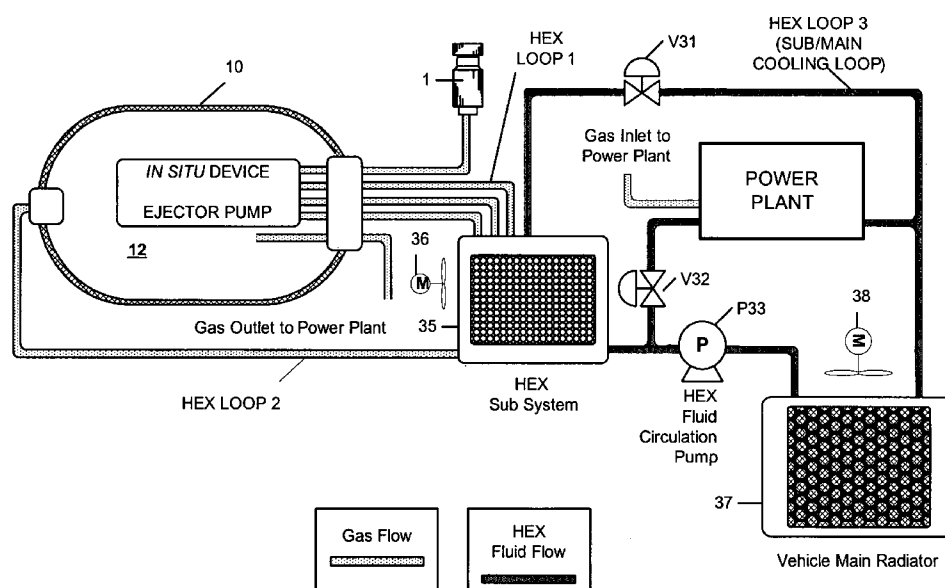
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(54) Title: THERMAL MANAGEMENT FOR HIGH PRESSURE GAS STORAGE TANKS

FIGURE 3B



(57) Abstract: Apparatus for the thermal management of high pressure gas storage tanks wherein the compression heat of refueling the tank is evacuated from the interior of the tank in which a gas circulates within the tank powered by a pump powered and as the gas traverses from the high pressure refuel depot to the storage tank, the circulating gas absorbs the refueling heat and carries the heat to a cooling system having a supplemental heat exchange device before the gas is introduced into the tank. The apparatus may be operated in reverse to transfer heat from a source to the tank interior to provide more complete exhaustion of the tank during vehicle operation.

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TITLE OF INVENTION

THERMAL MANAGEMENT FOR HIGH PRESSURE GAS STORAGE TANKS

TECHNICAL FIELD

The present invention relates to a system for cooling high pressure gas stored
5 in fuel tanks, typically, hydrogen gas and compressed natural gas introduced to the
tank at a refueling station. Onboard high pressure tank cooling is effected by direct
gas ejecting using a Venturi pump or another mechanical pump to circulate refill gas
to absorb heat within and to transfer absorbed heat to an environment external to the
tank.

10 In motor vehicles using hydrogen or using compressed natural gas (CNG) to
power vehicle engines, present practice is that fuel is stored in on board tanks
maintained at a maximum pressure in the range of about 5000 psi for hydrogen and
3600 psi for CNG. Higher pressures in the range of about 10,000 psi or more are
anticipated as the use of hydrogen (for fuel cells) and hydrogen and CNG (for internal
15 combustion engines) becomes more prevalent. I have developed *in situ* techniques
to manage thermal energy differences between high pressure gas in a tank and the
environment of the tank in a vehicle wherein a heat exchange device is fixed within
the tank (to absorb and radiate heat) and is operatively interconnected with an
external heat exchanger (correlatively to radiate and absorb heat) in the sequence of
20 the refill and exhaustion of the high pressure gas within the tank. In the specification
herein, high pressure hydrogen and high pressure CNG (compressed natural gas)
are both referred to as a "gas" or "high pressure gas." Both hydrogen and CNG are

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high pressure gases with which the invention is useful, typically, but not necessarily, in motor vehicle applications.

When the on board fuel tanks of a hydrogen powered vehicle are filled with hydrogen, the pressurized on board gas in the tanks may be characterized as having multiple forms of energy: 1) chemical energy associated with the hydrogen fuel itself (consumed in powering the vehicle), and 2) thermodynamic energy, namely, the mechanical, thermal and internal energy associated with the physics of high pressure refueling of a tank from sources of fuel at the high pressure gas refuel depot.

During a high pressure refueling process involving hydrogen and CNG fueled vehicles, gas within the interiors of the on board storage tanks become heated as a result of fuel gas compression when the tank pressure increases and other refueling parameters affect the refill. After refueling, the interior temperature of the gas within the tank and the pressure within the tank both decrease slowly as the fuel gas is consumed during vehicle operation. Conventionally, it is not possible to obtain a full refill tank pressure without temperature or pressure compensation during the course of refueling. The charge of fuel pressure input into and stored in the tank must be, at refill (because of the heating compression of the gas), initially in excess of the tank design pressure. Without pressure compensation (an initial overfill), vehicle mileage range is reduced because a full fill is not obtained. When higher optimum tank design pressures are encountered, this condition is exacerbated.

Slower flow rates, a pressure overfill and external pre-cooling have been proposed as solutions, however, the former undesirably extends the time of a refill, the latter two require substantial energy, thereby reducing the overall efficiency of a

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hydrogen / CNG economy. As tank pressures exceed 3600 psi (for CNG) and 5000 psi and approach or exceed 10,000 psi (for hydrogen), secondary treatment such as cooling becomes an important factor in the refueling process to achieve a full tank capacity fill. When a full fill is achieved, 1) overall vehicle range per each tank refill
5 thereby increases, 2) energy required for a refill (such as for precooling or a pressure overfill) is reduced, 3) time is saved, and 4) overall customer satisfaction increases.

DISCLOSURE OF INVENTION

Objects of the invention are to minimize tank heating, to increase the efficiency and refueling capacity of an on board fuel storage tank, and to increase the efficiency
10 and refueling capacity of an on board fuel storage tank in high pressure gas powered motor vehicles. It is a further object of the invention to provide a system that can remove the compression heat resulting from refueling an on board tank during high pressure refueling. An avoidance of secondary gas cooling pretreatment and/or pressure overfill, a speedier refueling time, increased refueling efficiency, and an
15 extension of overall vehicle range will result. Improved tank capacity per unit volume is achieved during refilling, particularly where nominal refill pressure is in the range of about 10,000 psi or greater for hydrogen and about 3,600 psi for CNG. It is also an object of the invention to utilize the cooling system in reverse, namely, to provide heat to the gas within the tank as the tank cools during operation, lowering the tank
20 pressure. When the tank gas is heated, a benefit results in that additional gas can be evacuated from the tank, further increasing the range of vehicle operation.

In accordance with the invention, effective reduction of fuel tank heating during the refueling process is provided by introducing the refueling gas into a Venturi (or

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ejector) pump system that sucks out the hot gas from within the tank and in a circuit introduces the hot gas into a heat exchanger where the gas is then cooled down. The cooled gas and the refueling gas are mixed in the ejector and then both gas streams are directed into the vehicle storage tank. Alternatively, a mechanical
5 circulation system may utilize the flow of gas in a circuit to absorb and dispose of excess heat associated with refueling.

The system herein provides onboard cooling; as a result, there is no need to change the refueling station equipment. The cost and weight of on board gas cooling equipment, important factors in the adoption of high pressure fueled vehicles, are
10 reduced. Cooling capacity is improved; continuous cooling is provided. Heat exchange efficiency approaches 100%. When there is an internal heat exchanger, the gas temperature in the heat exchanger is not perfectly equal to tank gas temperature, thus reducing internal heat exchanger efficiency to less than 100%. In the gas ejector system described herein, the gas flow cooling circuit, through an *in*
15 *situ* device or a Venturi pump, is interconnected with an external heat radiator or a vehicle sub cooling system such as an air conditioner, thereby collecting interior tank heat and radiating the absorbed heat into the ambient atmosphere or other system appropriate for the use, radiation, absorption, or disposal of the collected heat of high pressure refueling. Utilized in reverse, the cooling devices will heat the tank gas
20 while the vehicle is being operated and increase gas utilization in a refill.

The invention is described more fully in the following description of the preferred embodiment considered in view of the drawings. As is evident from the

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context of the particular drawing figures, the figures are generally shown in cross section format.

BRIEF DESCRIPTION OF DRAWINGS

Figure 1A shows an example of an ejector (Venturi) pump cooling system with
5 the pump at one end of a fuel storage tank wherein gas flows through an external radiator.

Figure 1B shows an embedded valve gas flow system utilized in the system of Figure 1A.

Figure 2A depicts an embodiment of the invention utilizing an ejector pump
10 gas flow system interconnected in circuits for gas flow from the refill depot through (1) an *in situ* heat exchange device (HEX), (2) a first external HEX and (3) a second HEX.

Figure 2B depicts an additional Venturi pump circulation system utilizing an *in situ* device and an external HEX.

Figure 2C depicts an embodiment of the invention otherwise shown in Figure
15 2A wherein a powered pump is utilized in place of the self powered ejector pump.

Figure 3A illustrates a system of the invention in which the gas flow circuits are thermally interconnected to a main or sub vehicle cooling system or radiator HEX for the disposition of the heat absorbed by the circulating gas.

Figure 3B shows in further detail the interconnection of the gas cooling circuit
20 loops to a vehicle subsystem cooler HEX or to the main vehicle power plant cooling system HEX.

Figure 3C shows a vehicle control system wherein temperature and pressure in gas flow components is monitored and regulated in the course of vehicle operation.

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Figure 3D shows an alternate configuration of HEX devices interconnected with a vehicle cooling system or sub system.

Figure 4A, Figure 4B, and Figure 4C respectively depict embodiments of the invention utilizing an ejector pump circulator and (1) an *in situ* tank HEX for heat transfer and (2) first HEX and (3) second HEX devices, particularly showing tank valve and pressure regulator configurations in the gas flow circuits during the states in which the tank is being refilled (Figure 4A), during driving (Figure 4B) and while the vehicle is parked (Figure 4C).

Figure 5A, Figure 5B, Figure 5C, Figure 5D, Figure 5E, Figure 5F, Figure 5G and Figure 5H respectively show (A) a heat transfer system utilizing a vehicle frame component, (B) a cross section through **5B** → ← **5B** in the frame element shown in Figure 5A, (C) a side view of an alternate flow conduit adapted to a frame element, (D) a heat pipe interconnected with a tank support frame and a tank *in situ* device, (E) a side view of a gas flow conduit embedded in a frame member, (F) a cross section view of the member shown in Figure 5E, (G) a gas flow conduit embedded in a frame member having a further melting / solidifying heat transfer media such as naphthalene therein, and (H) a cross section of a vehicle frame member having gas flow and coolant flow conduits embedded therein.

Figure 6A illustrates the interconnection of gas flow heat exchangers with gas flow loops and system and sub system HEX devices.

Figure 6B illustrates the vehicle control system interconnected with temperature and pressure monitors and the valve and pump systems.

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Figure 7A is a schematic of the main and sub vehicle cooling systems interconnected with a heater/cooler and the gas flow HEX systems.

Figure 7B illustrates, in the system of Figure 7A, the interconnections of gas flow heat exchangers with gas flow loops and system and sub system HEX devices.

5 Figure 7C illustrates vehicle control system interconnections of the system of Figure 7A.

Figure 8A shows the tank *in situ* HEX utilized in reverse conveying heat from "warm" devices in the vehicle to provide heat to the tank gas in a direct transfer to the *in situ* HEX within the tank. Figure 8B shows the connection if the *in situ* HEX within
10 the tank where heat is absorbed and then transferred to vehicle cooling systems, or a heat sink, where heat is radiated.

Figure 8C shows the tank *in situ* HEX utilized in reverse conveying heat from "warm" devices in the vehicle to the tank gas in an indirect transfer wherein a HEX associated with the heat sources is interposed between the *in situ* HEX and the heat
15 sources. Figure 8D shows vehicle cooling sources, or heat sinks, indirectly connected to the *in situ* device through a supplemental HEX.

BEST MODE FOR CARRYING OUT THE INVENTION

The invention increases the refueling energy efficiency of high pressure gas powered (Hydrogen and CNG) vehicles by withdrawing the heat of compression
20 resulting from tank refilling from the high pressure gas introduced into on board tanks and by eliminating the need for a slow fill, a pressure overfill and/or refueling station precooling of the gas. Overall, high pressure gas infrastructure energy requirements for motor vehicles are reduced, vehicle mileage range is increased when tank

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capacity is expanded, the need for short interval refills is eliminated, vehicle weight and cost are reduced, and consumer satisfaction is enhanced.

With reference to Figure 1A an example of a cooling system using an ejector pump fixed at one end cap or port assembly 11 comprised of mating elements 11a and 11b of a fuel storage tank 10 having interior gas storage volume 12 is shown. An ejector pump 3 is installed at the cap assembly providing a gas flow circuit 100 within the system from the refill depot receptacle 1. Fuel depot receptacle 1 is interconnected with a control for gas flow into the vehicle tank during refill and insures that the system is otherwise closed at all other times. The master gas flow conduit system in the vehicle from the refuel inlet through the ejector pump and heat exchanger to the tank is indicated by 100. At refill, gas flow from the refill depot, indicated by arrows →, enters the tank volume 12 through inlet 4. Gas is introduced into ejector pump 3 which sucks up the introduced hot gas from the tank interior through tank gas flow outlet 5. Ejector pump 3 is configured to provide gas flow from the inlet 3a whereby jet chamber 3d follows the nozzle 3c that leads from the inlet 3a. The pump throat 3e is disposed to introduce gas from the pump into the tank interior through gas flow conduit 4 in the tank. The suction inlet for gas flow to the pump is shown at 3b. The gas flow is interconnected to inlet 6 of external radiator or heat exchanger (HEX) 7 and passes through HEX outlet 8 returning to the ejector pump suction inlet 3b and flows to the tank interior 12 through tank inlet 4. A gas outlet for directing the flow of gas to the power plant while the vehicle is in operation is shown at valve V1 which leads to the power plant through pressure regulator PR1. Heat disposal from the heat exchanger is indicated by the arrows . The compression

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heat caused by a high pressure refill is thereby absorbed by the gas itself which circulates within the loop 100 and is radiated from the cooling / refueling circuit to an external environment through the HEX 7 such that a close to optimum refill of the tank is achieved without a slow fill, precooling or pressure overfill. In Figure 1B, control valves and regulators embedded in the end caps of the embodiment of Figure 1A are indicated as assemblies EV 1 and EV2. EV1 is shown in further detail as including a check, or one way flow, valve leading to gas flow inlet GF1 in the tank interior. Valve and regulator assembly EV2 includes two way switching valve V22 and pressure regulator PR30 leading to gas flow openings GF2 and GF 3 in the tank interior and opening GF4 at the tank exterior. Heat exchanger 7 is shown in the gas flow circuit receiving gas from the tank through GF4 and introducing cooled gas into the ejector pump suction inlet 3b through opening GF5.

In Figure 2A an end cap, tank port or boss assembly is adapted to each opposite end of the tank at 20 and 21 in a configuration wherein gas introduced from refill depot 1 circulates in a loop through *in situ* device 200 installed within the tank, through first external heat exchanger 201 into the ejector pump inlet 3a and circulates through the tank from ejector outlet 3e, then through second external heat exchanger 202 before being introduced to ejector pump suction inlet 3b and delivered into the tank. The ejector pump is indicated at 3. In Figure 2B, a port assembly is similarly adapted to each opposite end of the tank at 20 and 21 in a configuration wherein gas introduced from refill depot 1 circulates in a loop through *in situ* device 200, first external heat exchanger 201 and second external heat exchanger 202 before being introduced into the tank at the end of the circulation loop.

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In this example, the gas flow 210 is powered mechanically by turbine flow of the high pressure gas interconnected to a gas pump, by an electrically powered pump, or by a pump otherwise interconnected to the vehicle power plant mechanicals. In both Figure 2A and Figure 2B, gas flow is indicated by the arrows .

5 Figure 3A illustrates the disposition of the gas flow heat exchange loop passing through the *in situ* device through HEX LOOP 1 and HEX LOOP 2 providing the supplemental cooling system for gas passing through the tank and the circulation pump into gas flow conduits or circuits in the same external heat exchanger or radiator 35 where the heat may be dissipated in place. Radiator 35 may be further
10 cooled by a thermal interconnection with a main or sub vehicle cooling system through HEX circuit connections 36 and 37. Figure 3B shows the interconnection of HEX LOOP 1 and HEX LOOP 2 passing through radiator 35 that is in turn thermally interconnected with HEX LOOP 3, the vehicle's power plant main or subsystem cooling loop. Radiator 35 is thermally interconnected with cooling fan 36.
15 Valve/regulator V31 and valve/regulator V32 and pump P33 control the main vehicle thermal system which includes radiator 37 and fan 38. Operation of the system of Figure 3B is controlled by the monitoring of temperature and pressure in the various loops and systems interconnected or integrated with the main vehicle control system as shown in Figure 3C in accordance with design parameters. Figure 3D illustrates
20 an example wherein gas inflows from refill nozzle 1 directly into the tank volume 12 and is circulated in a gas HEX LOOP 11 through GF 1 and GF 4 at end caps 20 and 21 within the tank by pump 40. A second HEX LOOP 12 conveys a coolant media through *in situ* device 38 an external radiator 39 to provide additional heat exchange.

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HEX LOOP 11 and HEX LOOP 12 circulate through a radiator 35 that may be interconnected to a main or sub vehicle thermal management system through inlets/outlets 36 and 37. As described above, separate HEX devices may be utilized for each HEX loop.

5 Figure 4A, Figure 4B and Figure 4C illustrate, in a vehicle application, the respective modes: refilling, driving and parking. In each of Figure 4A, Figure 4B and Figure 4C, a valve/gas flow switching and pressure regulator system is embedded in each of the end port assemblies 20 and 21, designated as EV 20 and EV 21. *In situ* heat exchanger 200, and ejector pump 3 with its components, nozzle, throat and
10 outlet are evident from the drawing of Figure 1A. Refill inlet system 1 is similarly numerically designated as with equivalent elements shown in Figure 1A. The separate external heat exchangers HEX 1 and HEX 2 are indicated 201 and 202 with respective inlets/outlets in the gas flow circuit that are self evident in the drawings.

 Although depicted as conventional radiator elements in the foregoing drawings,
15 the heat exchangers utilized in the above examples may be supplemented or replaced by the vehicle sub frame cooling systems shown in Figure 5A, Figure 5B, Figure 5C, Figure 5D, Figure 5E and Figure 5F. Figure 5A shows a circulating gas flow cooling line circuit 603 disposed within a vehicle frame component 602 surrounding tank 601 for circulating the gas about the tank sub frame. Frame
20 cooling media, which will typically be air, is received in frame inlet 615 and exhausted through an outlet which may include a fan 635 or other active means for removing heat from the gas in line 603. In a closed cooling circuit, gas flows within a continuous circuit from the fuel tank circulating system through an inlet and outlet

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wherein "Gas Flow In" 610 is matched with a heat exchanger inlet connection 6 (Figure 1A); "Gas Flow Out" from the frame radiator 620 is matched with heat exchanger outlet connection 8 (Figure 1B) and the gas in the circulation loop returns to the tank gas circulation circuit. (Except as identifying flow in either direction, "in" and "out" designate the end connections of the circuit where the gas flow is connected to the HEX. Flow direction is not critical.) The heat from conduit line 603 is optionally radiated externally by air circulating in the frame driven by fan 635. In the absence of an air flow system, the frame body itself may be utilized as a heat sink for radiating or absorbing heat. The circulating gas flow circuit tube 603 may be formed as an extruded or molded interior conduit; however, it is preferable, whether the tube is within, upon, or otherwise a component of the sub frame assembly, that the gas circulation tube be a separate tube inserted within the frame assembly formed from a high conductivity high strength material such as a stainless steel alloy SUS, copper or aluminum. Figure 5B and Figure 5C respectively show examples of a cross sectional view and a side view of alternate configurations of gas flow tubes 603 in the frame 602. Figure 5D illustrates an example wherein a heat pipe 690 interconnected with an internal HEX device assembled in tank 601 conducts heat to a vehicle frame element 602 thereby utilized as a heat sink. Figure 5E and Figure 5F show an example, respectively, in longitudinal cross section and in a front view cross section, wherein the gas circulation pipe 603 is installed within a cavity 603a in the vehicle frame 602 interior and radiator fins 690 (Figure 5E) and 680 (Figure 5F) are respectively transverse to the frame section and longitudinally coextending with the frame section. Figure 5G illustrates a cross section of a sub frame assembly 700

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with gas flow conduit therein 603 including a melting / solidifying media 710 that changes in physical mode dependent upon temperature and heat absorbed, such as naphthalene, packed within the frame section as a component of the overall heat exchange system used in conjunction with the invention. In Figure 5H, supplemental
 5 cooling conduits 711 and 712 convey cooling fluid from a supplemental cooler to the frame element 602 sub system wherein the conduit 603 is installed.

With reference to Figure 6A, the cooling system management for a 70 MPa tank involves separate elements of heat transfer: 1) absorption of heat in the gas as the gas passes through an *in situ* a heat absorbing media 61 as the gas circulates
 10 from the refill nozzle through the tank to first cooling HEX loop 63; and 2) utilization of the heat absorbent properties of the gas itself as the gas is circulated by a pump or other device 62 through the tank to second cooling HEX loop 64. The first HEX loop 63 and second HEX loop 64 may be separately or jointly interconnected to a radiator or other heat absorber system in the vehicle 65, system HEX 1, which in turn may be
 15 interconnected with the main vehicle power plant system 66, system HEX 2. Various combinations and permutations of the foregoing thermal interconnections of the gas HEX loops and system HEX loops are possible. In Figure 6B, temperatures and pressures (1) in the tank, **PRESSURE**_{TANK} and **TEMPERATURE**_{TANK}; (2) in the first HEX loop, **PRESSURE**_{LOOP 1} and **TEMPERATURE**_{LOOP 1}; (3) in the second HEX loop,
 20 **PRESSURE**_{LOOP 2} and **TEMPERATURE**_{LOOP 2}; (4) in the subsystem, **PRESSURE**_{SUBSYSTEM} and **TEMPERATURE**_{SUBSYSTEM}; and in the main cooling system, **PRESSURE**_{MAIN} and **TEMPERATURE**_{MAIN} are monitored and the various control pumps **P**_{1-N} and valves **V**_{1-N} are controlled by the vehicle control system 67 depending upon various

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parameters sensed, and desired, such as vehicle mode, refilling, decompression, driving, and parking, ambient temperature, tank pressure, volumetric gas flow and the like.

In a further example, the vehicle air conditioner may be utilized as a cooling sub system wherein, for example, with reference to Figure 3A, the air conditioner cooling loop is thermally interconnected to conduits 36 and 37 in the HEX 35 that receives heat from an *in situ* device and a gas circulation pump system. Similarly, a heat mass already cooled by the air conditioner, such as a water reservoir, coolant or frame element can be utilized as a heat sink for indirect cooling of the gas interconnected in the manners shown in Figure 5A through Figure 5H. In another example adapted to the system of Figure 3D, utilizing an air conditioner cooler, the cooled air conditioning fluid itself can be circulated within an *in situ* device 41 such as either directly, or indirectly by a separate HEX (shown) cooled by the air conditioner fluid circulation from inlets/outlets 44 and 45. A hybrid ambient air plus air conditioning system may also be used, wherein ambient air heat exchanger 42 pre cools the circulating fluid before the fluid enters the A/C subsystem. Likewise, the vehicle body or sub frame can be utilized as a cooling mass, interconnected with the tank cooling circuit as is the A/C system discussed above. (See Figure 5A through Figure 5H.)

The heat exchanger may be in the form of a radiator and may include fins, pins, plates, wave shaped radiators, mesh, corrugation like elements, or other like devices having high thermal conductivity and high surface area per unit volume or weight, allowing for the maximum thermal efficiency with regard to heat absorbed and

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heat radiated. The heat sink and radiator are each operatively disposed with regard to a fluid conduit system for the transfer of captured heat. Entropic flow of energy is from hot (within the tank) to cool (the radiator outside). The fluid flow in the conduit system that is encompassed by the heat sink or radiator, in an example, is in a continuous fluid loop, from the hot tank interior where the gas captures heat – to the radiator where conduit fluid is cooled – returning to the tank interior to begin the heat absorption / heat radiation cycle anew.

A fan or blower may be operatively disposed with respect to the heat exchanger - operatively dependent on factors such as radiator capacity, rate of heat transfer to the heat sink and the radiator, temperature of heat transferred, fan or blower (cubic feet per minute (cfm)) capacity effective at the radiator, temperature of the ambient external environment, and the like. A control system for the fan and or pump may be configured to interrelate the foregoing factors and determine appropriate fan and or pump speed, on and off timing, and the like.

The system is adaptable to multiple tanks and may be suitably interoperatively interconnected with a vehicle control system that provides selectable or controllable inlet valves and selectable or controllable outlet valves for the tanks and the coolant system through a control means, logic circuit, or CPU on the vehicle. The vehicle control system also monitors pressure and/or temperature or other sensing means associated with the tanks or their inlet and outlet lines, the cooling fluid circulation lines, and the fluid pump and may be adapted to interface with the vehicle control CPU accordingly. Specific vehicle control configurations and parameters, and sensors, valve locations and systems in accordance with the principles of the

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invention are preferably based on overall vehicle design considerations. For example, pressure, temperature and other sensors and controls may be provided to monitor tank and/or line pressures and temperatures, to start, stop and adjust fluid flow, fan speed and duration, and other parameters associated with a proper operating
5 protocol of the ejector pump and vehicle tank or valve system for refilling and consumption of pressurized fuel in the course of vehicle operation. As an additional benefit, the HEX devices utilized may be operated in the inverse, for example, during driving, when decompression of the stored gas lowers the tank gas temperature. As shown in Figure 7A, a heater/cooler 75 may be an element of the HEX system and/or
10 power plant and air conditioner heat exhaust may be utilized in a direct or indirect heating loop to warm gas during vehicle operation to provide an added enhancement of vehicle range extension as the fuel in the tank will be more completely evacuated in comparison with a situation where residual gas is left cold and unwarmed.

Figure 8A shows heat from the power plant, from the air conditioner exhaust,
15 from a supplemental heater, and from a frame or sub frame member transferred to the *in situ* device 71 within the tank 10 through a direct connection, such as a heat pipe (Figure 5D) or a thermally conductive fluid circuit such as is shown in the drawings herein. In Figure 8B, a coolant system is interconnected with the *in situ* device 71. Figure 8C shows a configuration wherein heat is transferred indirectly to
20 gas within the tank through a supplemental HEX 80 interposed between the power plant, the air conditioner exhaust, a supplemental heater, or the frame or sub frame member and the *in situ* device 71 within the tank 10; and Figure 8D shows an inverse configuration wherein the *in situ* device is thermally connected through an

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intermediate HEX device 80 to vehicle cooling sources. Thus, the systems for heat transfer, whether heat absorption in the tank for cooling, heat radiation in the tank for warming, heat absorption from a source exterior to the tank for gas warming, or heat radiation from a source exterior to the tank for gas cooling are essentially
5 interchangeable in function and equivalent in structural purpose within design limits. A thermally absorbent heating – cooling media such as naphthalene is both a heater and a cooling device. Heat transfer may be accomplished by a gas or fluid flow conduit circuit of a heat pipe. Other heat transfer systems and devices are likewise adaptable for use with the invention.

10 With reference to the embodiments discussed above as examples, there is provided an apparatus wherein the compression heat of refueling of a high pressure storage tank is evacuated from the interior of the tank in which a gas circulating within the tank passes through an ejector pump powered by the mechanical energy of the refueling gas as the gas traverses from the high pressure refuel depot to the
15 storage tank and the circulating gas absorbs the refueling heat and carries the heat to a cooling system before the gas is introduced into the tank for storage and the obverse thermal management occurs wherein gas is heated for better tank evacuation while driving.

In all instances described herein, it is assumed that during the state of
20 refueling, the outlet valves for each tank are closed; and during the instance of consumption, the inlet valves for each tank are closed and the cooling fluid correspondingly circulated in a manner typically monitored and controlled by a vehicle operation system. The on board vehicle tank system may include a plurality

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of on board tanks that may have a filling sequence wherein all tanks are filled in parallel simultaneously or all tanks are filled separately in a series order essentially one at a time.

INDUSTRIAL APPLICABILITY

5 Motor vehicles using hydrogen or using compressed natural gas (CNG) as fuel to power vehicle engines are expected to require high pressure storage tanks for fuel gas in the range of in excess of 3600 psi or more for CNG and 10,000 psi or more for hydrogen. Because of the energy characteristics of a high pressure gas in the stages of compression during refill, and decompression during consumption (exhaustion of
10 the tank), it is not possible conventionally to obtain a full refill tank pressure without temperature or pressure compensation during the course of refueling. Various secondary treatments have been proposed.

The invention minimizes tank heating and increases the efficiency and refueling capacity of an on board fuel storage tank by providing a system that can
15 remove the compression heat resulting from refueling an on board tank during high pressure refueling. Utilizing an *in situ* heat exchanger and an external heat exchanger, the invention allows secondary gas cooling pretreatment and/or pressure overfill to be eliminated and achieves a speedier refueling time, increased refueling efficiency, and an extension of overall vehicle range. As a further advantage is
20 realized when the heat exchange system is utilized in reverse, gas within the tank is heated as the tank would otherwise cool during vehicle operation, lowering the tank pressure. When the tank gas is heated, additional gas can be evacuated from the

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tank, further increasing the range of vehicle operation and reducing the need for short interval refills.

In providing an onboard system, the invention does not require a change in refueling station equipment. Cost and weight of on board gas cooling equipment are
5 reduced; cooling capacity is improved; continuous cooling is provided; and heat exchange efficiency approaches 100%.

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CLAIMS

1. A storage tank system for a high pressure gas comprising a tank, a tank inlet and a tank outlet, an *in situ* heat exchange device installed within the tank, at least one heat exchange device exterior to the tank, a coolant/heating media, a dual
5 circulation flow path for the media, a first flow path interconnecting the *in situ* heat exchanger and the heat exchanger exterior to the tank, a second flow path interconnecting a gas flow circuit from the tank interior to a heat exchanger exterior to the tank, at least one pump, and an interconnection of the flow paths with at least one of the tank inlet and the tank outlet, wherein, upon the refill of the tank through
10 the tank inlet, 1) the refill gas comprises the media, 2) the media circulates in a section of the first flow path and the second flow path and absorbs the heat of compression resulting from the refueling of the tank, 3) the heat absorbed is conducted by the media to the exterior heat exchanger whereby the absorbed heat is exhausted from the tank to an environment external to the tank, and 4) the pump is
15 interposed in the flow path to provide motive power to circulate the media.
2. Apparatus in accordance with claim 1 wherein the pump is interconnected in a first gas flow path intermediate an outlet of the *in situ* heat exchanger and the external heat exchanger, the first flow path passing through the exterior heat
20 exchanger and exiting into the tank interior, and the second gas flow path is through the tank interior to a tank outlet to the external heat exchanger to a return inlet to the tank interior.

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3. Apparatus in accordance with claim 2 wherein the pump comprises a Venturi chamber pump.
4. Apparatus in accordance with claim 1 wherein the pump comprises a
5 mechanical pump.
5. Apparatus in accordance with claim 1 wherein the flow path comprises a circulation system that includes an auxiliary blower system thermally interconnected with an external heat exchanger for cooling the media in one or more flow paths
10 external to the tank.
6. Apparatus in accordance with claim 1 wherein the external heat exchanger is selected from at least one of a radiator, a heat sink and a vehicle coolant system.
- 15 7. Apparatus in accordance with claim 1 wherein the external heat exchanger includes one or more closed loop gas flow circuit passing through a radiator that is thermally interconnected with a vehicle power plant radiator system that includes a circulating coolant fluid.
- 20 8. Apparatus in accordance with claim 1 wherein the media is the fuel gas and the flow path includes a loop in a media circulation circuit within a heat absorber in the tank interior and heat absorbed by the absorber is transferred to an external

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radiator interconnected in the flow path where the heat is disposed of from the radiator and the media is recirculated to the tank interior.

9. Apparatus in accordance with claim 1 wherein the external heat exchange
5 device is a radiator comprising 1) a configuration of heat disposing elements on a vehicle frame assembly and 2) a fluid circulation loop within vehicle frame assembly proximate the heat disposing elements.

10. An on board vehicle tank system for fuel gas storage in accordance with any
10 one or more of claim 1, claim 2, claim 3, claim 4, claim 5, claim 6, claim 7, claim 8, or claim 9 including a plurality of on board tanks.

11. Apparatus in accord with claim 10 wherein the filling sequence for the plurality
of tanks is 1) all tanks are filled in parallel simultaneously, or 2) all tanks are filled
15 separately in a series order essentially one at a time.

12. Apparatus in accord with claim 3 operated in a refueling mode for the tank
wherein a pressure powered ejector pump in the flow path produces a Venturi jet
interposed between a high pressure refilling line at a gas depot and the tank and the
20 ejector pump has a suction inlet for gas flow and an outlet for gas flow to the tank
and the Venturi jet is powered by the pressure difference in the gas flow circuit
between the refilling line at the gas depot and the tank.

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13. A heating system for a high pressure gas storage tank comprising 1) a fluid flow path within an *in situ* heat exchange device within the tank, 2) a heat absorber external to the tank whereby heat is absorbed, and 3) a flow path interconnecting the *in situ* heat exchanger and the heat absorber such that heat flow occurs between the external heat absorber and the *in situ* device in the tank.
14. The heating system of claim 13 wherein the heat absorber acquires heat from at least one of a vehicle power plant, the vehicle air conditioner exhaust, a supplemental heater, and a vehicle frame or sub frame member and the heat is transferred to the *in situ* device within the tank through the connection of a fluid flow path through the at least one of a vehicle power plant, the vehicle air conditioner exhaust, a supplemental heater, and a vehicle frame or sub frame member to the *in situ* device.
15. The heating system of claim 14 wherein the connection is through a heat pipe.
16. The heating system of claim 14 wherein the connection is through a thermally conductive coolant/heating fluid circuit separate from the gas flow path of the vehicle.
17. The heating system of claim 13 wherein heat from at least one of the power plant, the air conditioner exhaust, a supplemental heater, and a vehicle frame or sub frame member is transferred to the *in situ* device within the tank through a HEX device interposed between the *in situ* device and the at least one of the power plant,

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the air conditioner exhaust, a supplemental heater, and a vehicle frame or sub frame member.

18. A storage tank system for a high pressure gas comprising a tank, a tank inlet
5 and a tank outlet, an *in situ* heat exchange device installed within the tank, at least
one heat exchange device exterior to the tank, a coolant/heating media, a dual
circulation flow path for the media, a first flow path interconnecting the *in situ* heat
exchanger and the heat exchanger exterior to the tank, a second flow path
interconnecting a gas flow circuit from the tank interior to a heat exchanger exterior to
10 the tank, at least one pump, and an interconnection of the flow paths with at least
one of the tank inlet and the tank outlet, wherein, upon the consumption of gas from
the tank, gas flows in circulation flow path through an external heat exchanger
wherein heat is absorbed and, in the circulation flow path, the gas flow is introduced
into one of the *in situ* heat exchanger or the tank interior such that the gas within the
15 tank is heated by the heat absorbed when the gas flows through the external heat
exchanger.

19. A vehicle storage tank system for a high pressure gas comprising a tank, a
tank inlet and a tank outlet, an *in situ* heat exchange device installed within the tank,
20 a heat exchange device exterior to the tank, a coolant/heating media, a circulation
flow path for the media interconnecting the *in situ* heat exchanger, the heat
exchanger exterior to the tank, and, depending upon the vehicle mode of operation,
the inlet of the tank from a refueling depot and an outlet of the tank to the vehicle

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power plant, wherein the media circulates in a section of the flow path from the *in situ* heat exchanger to the exterior heat exchanger and thermal energy is exchanged between the *in situ* heat exchanger and the exterior heat exchanger dependent upon whether the fuel in the tank is being refilled or consumed.

5

20. The tank system of claim 18 or 19 wherein the section of the flow path for the media interconnecting with the tank outlet to the power plant is closed and thermal energy is transferred from the heat absorbed by the *in situ* heat exchanger to the heat exchange device exterior to the tank when the tank is being refilled.

10

21. The tank system of claim 18 or 19 wherein the section of the flow path for the media interconnecting with the tank inlet with the refueling depot is closed and thermal energy is transferred from the heat exchange device exterior to the tank heat to the *in situ* heat exchanger when fuel in the tank is being consumed.

15

22. The tank system of claim 18 or 19 wherein, during a mode when the tank is being refilled, a pressure powered ejector pump is interposed in the media flow path and produces a Venturi jet interposed between a high pressure refilling line at a gas depot and the tank, the ejector pump has a suction inlet for gas flow and an outlet for
20 gas flow to the tank, and the Venturi jet is powered by the pressure difference in the gas flow path between the refilling line at the gas depot and the tank.

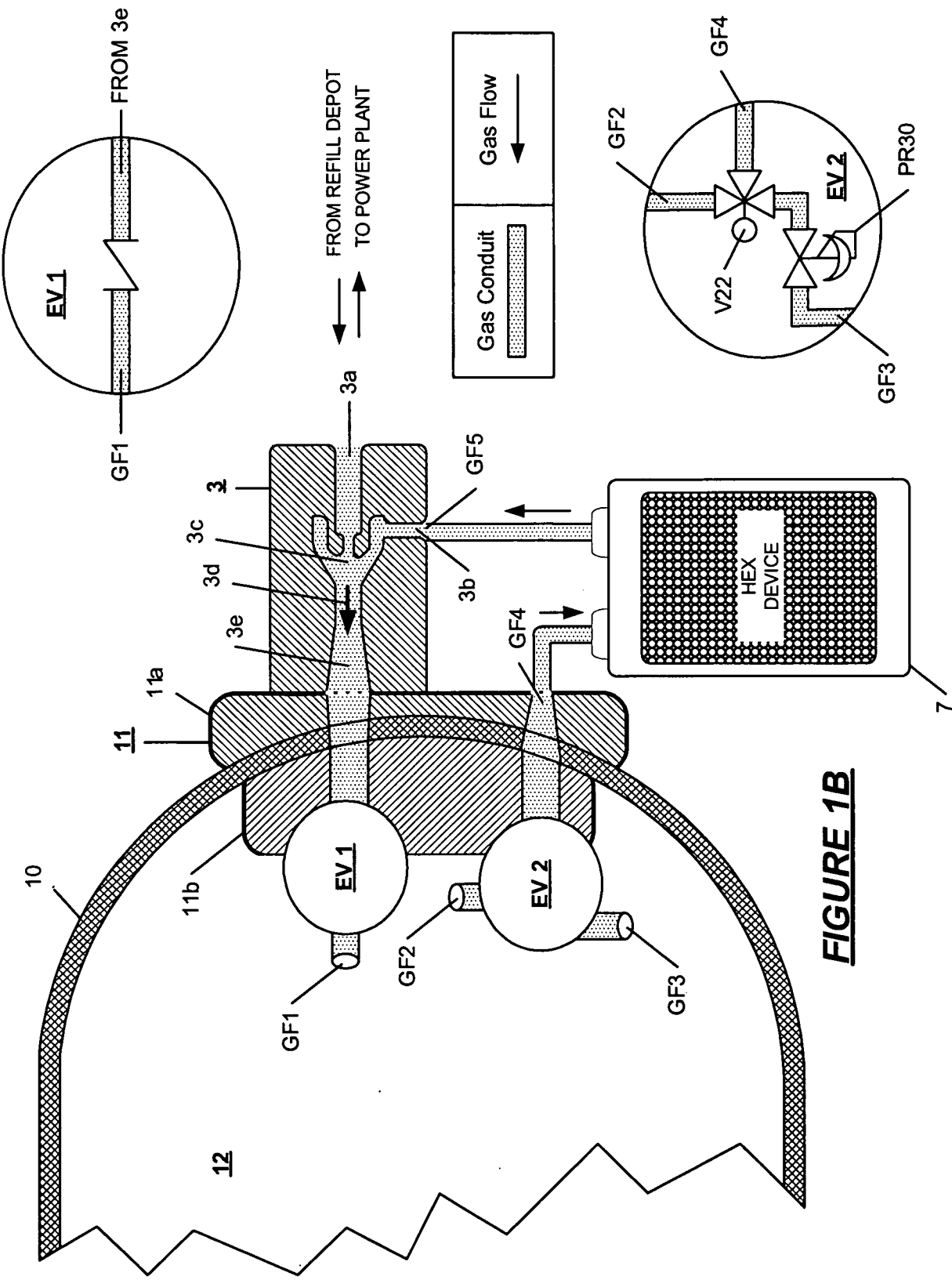


FIGURE 1B

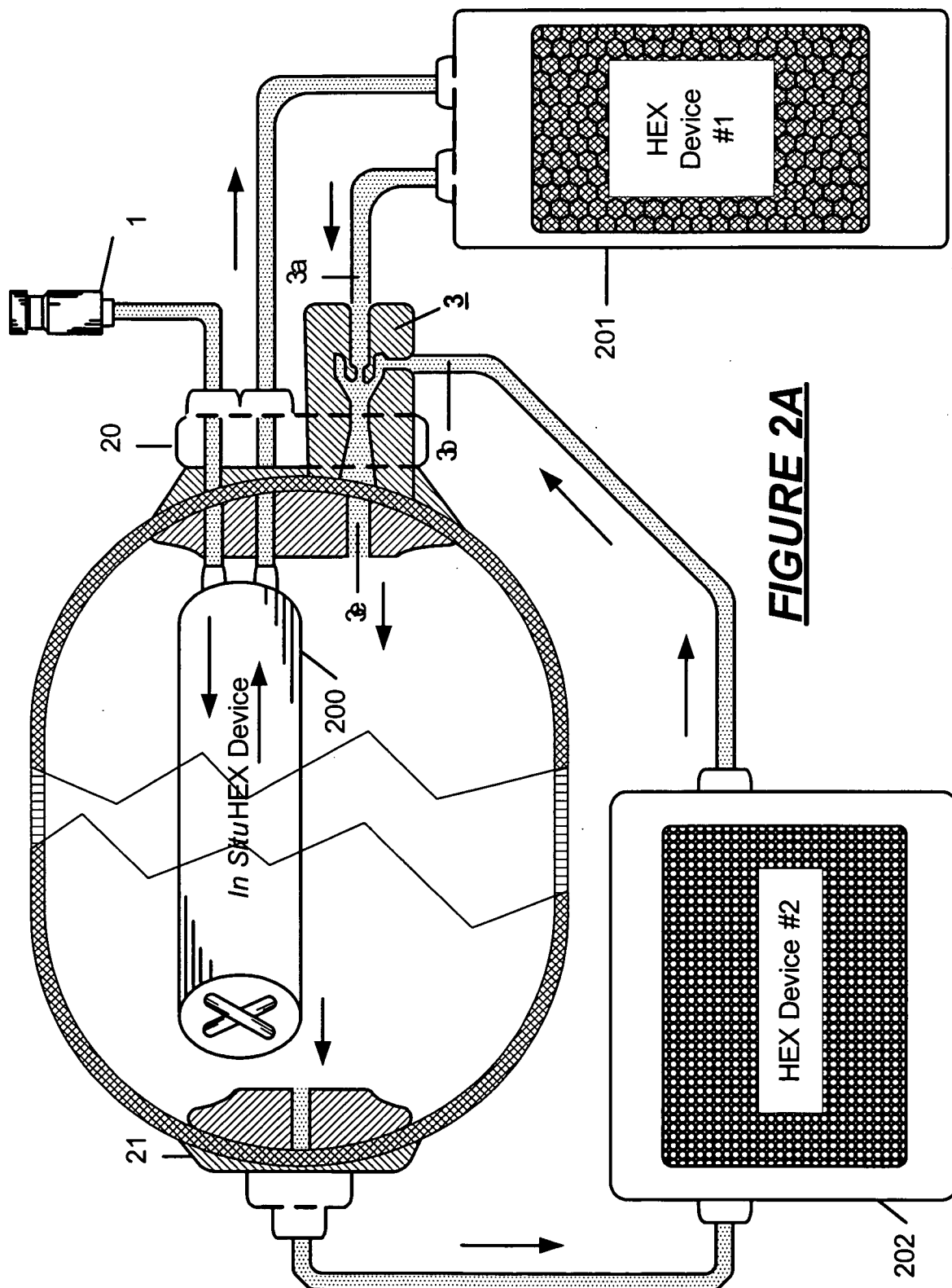


FIGURE 2A

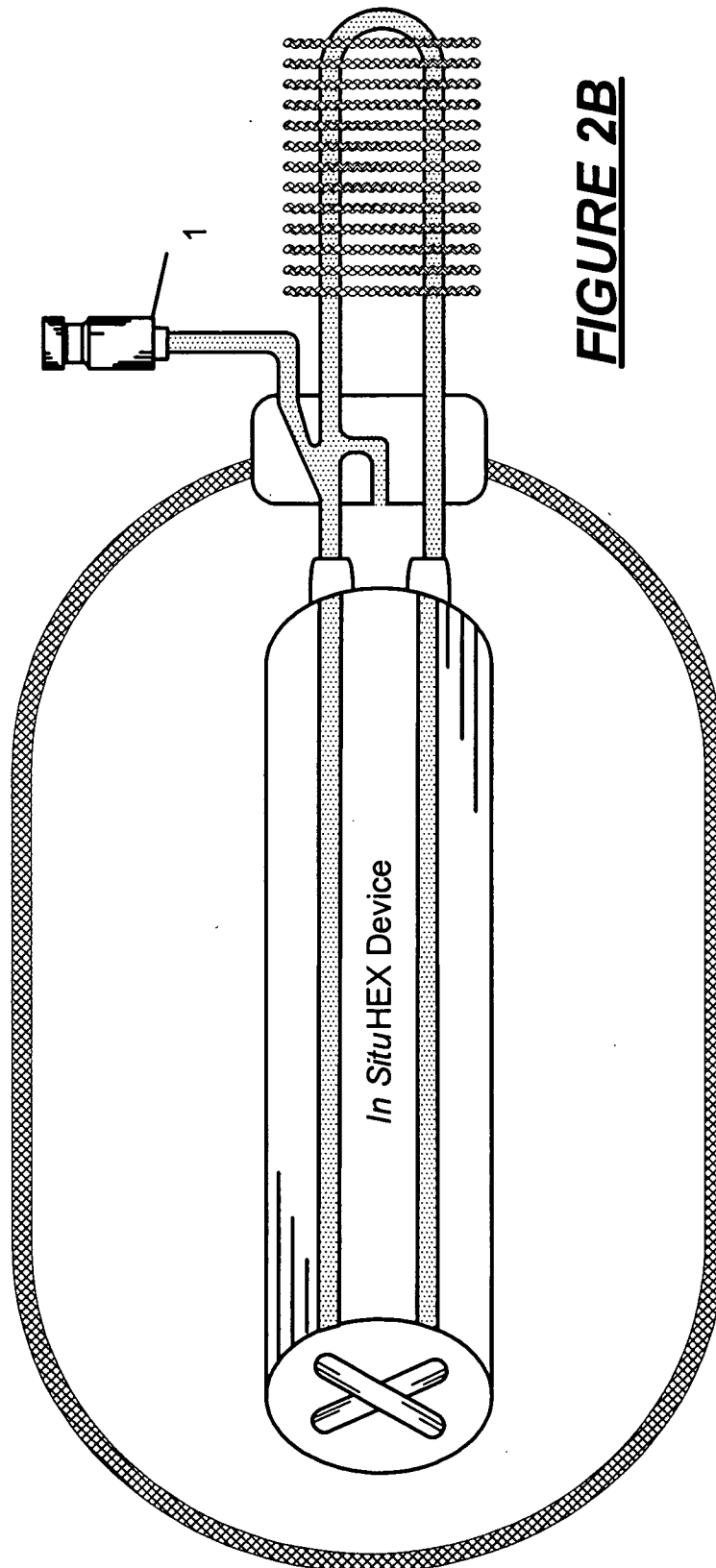


FIGURE 2B

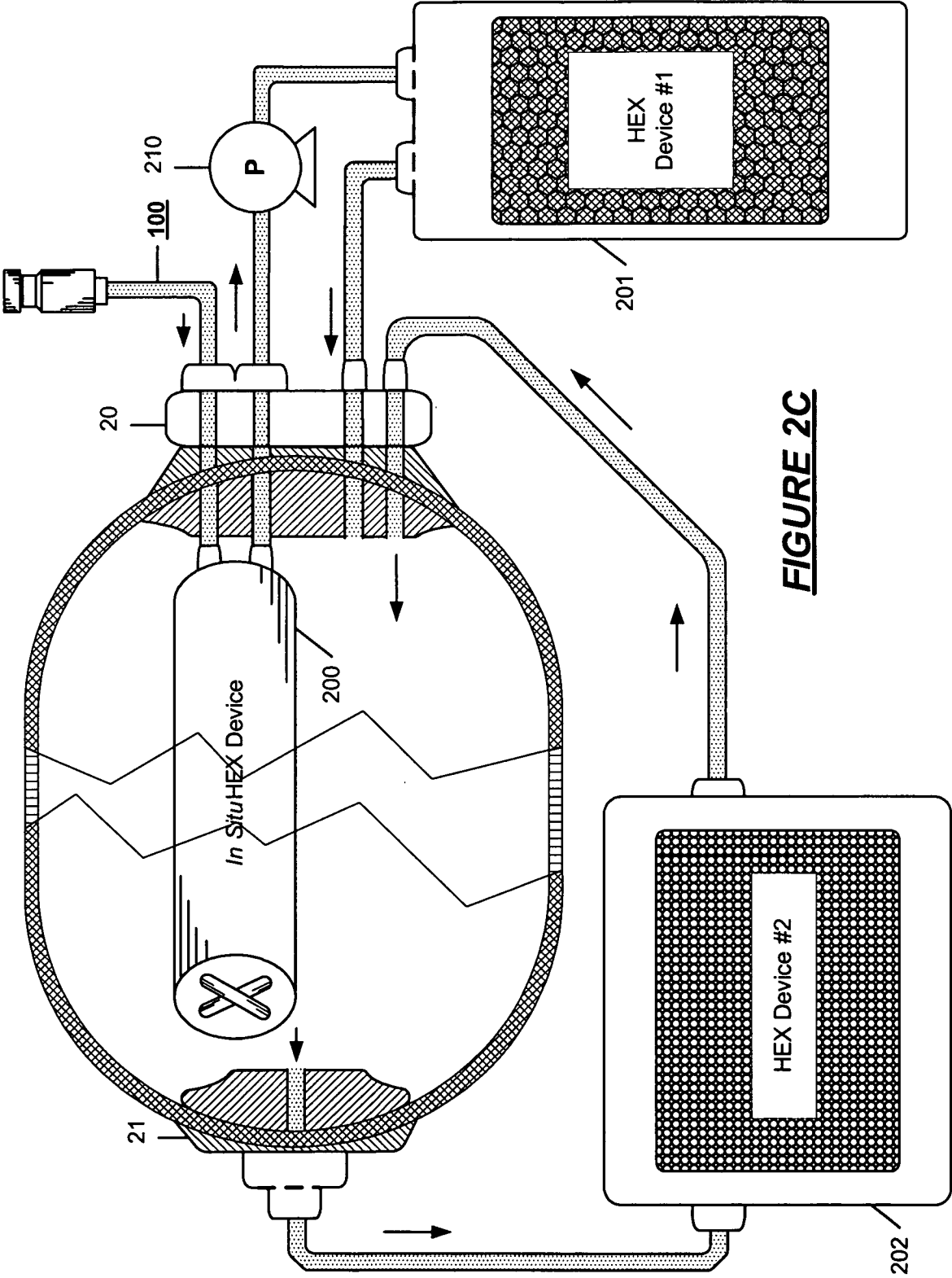


FIGURE 2C

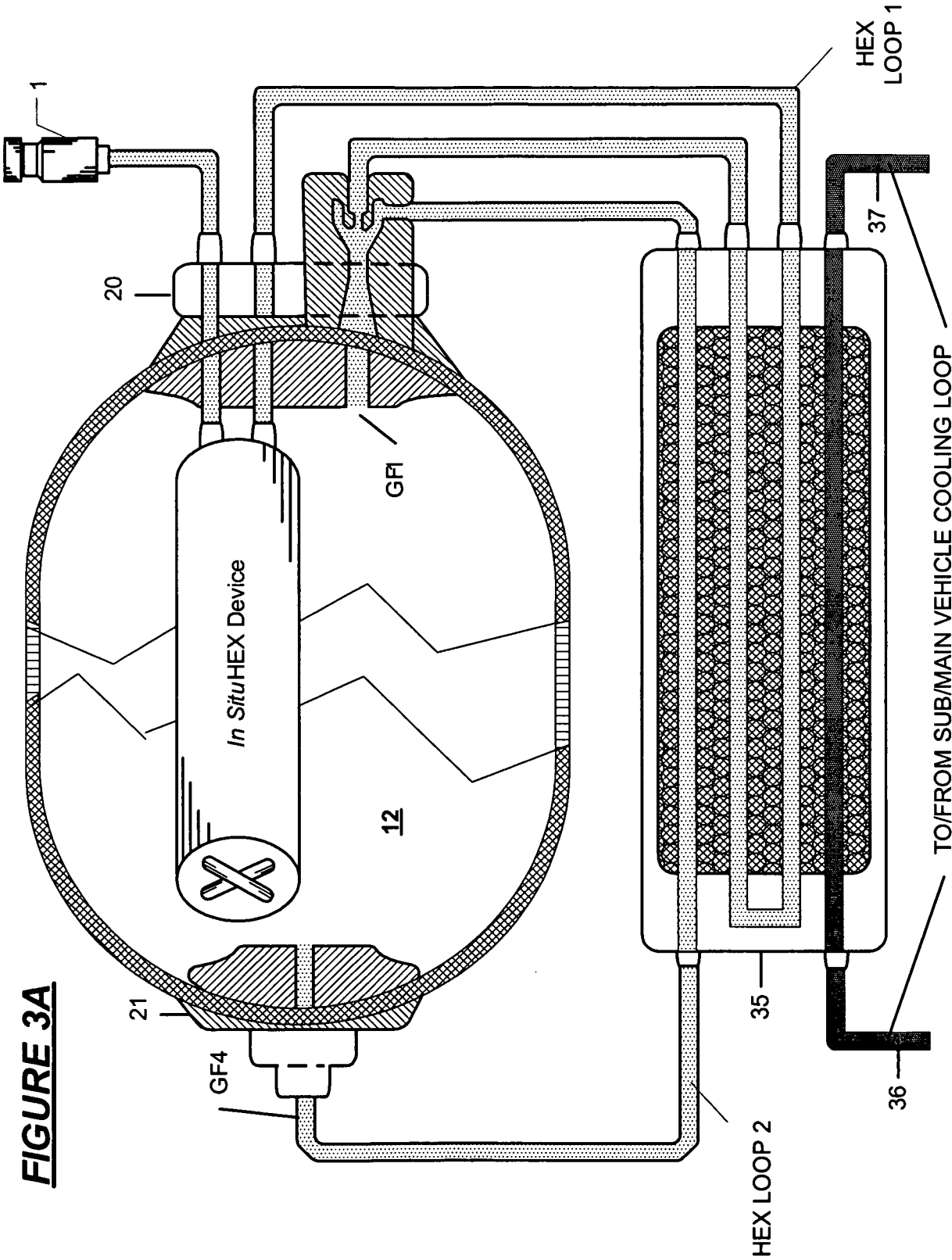


FIGURE 3B

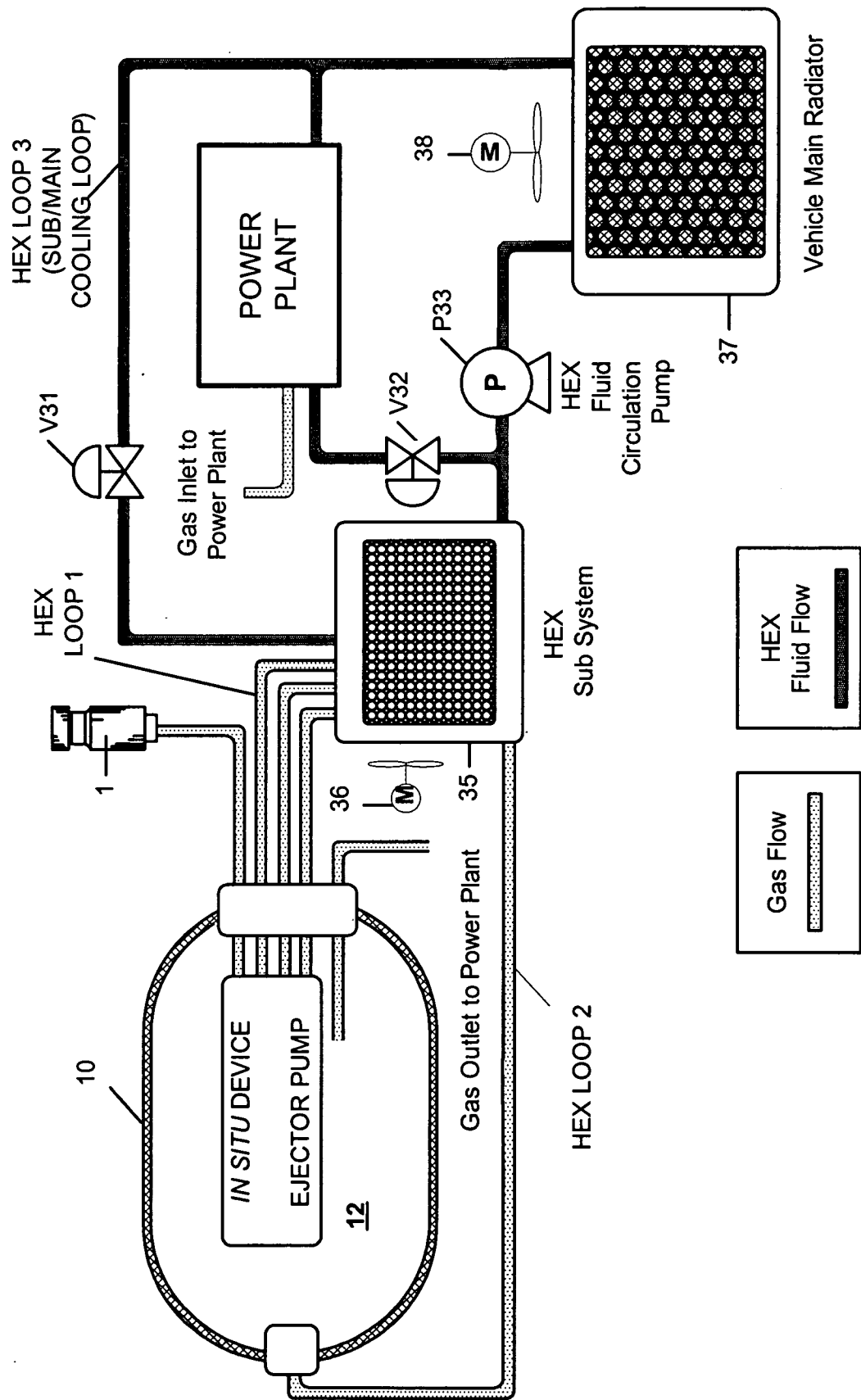
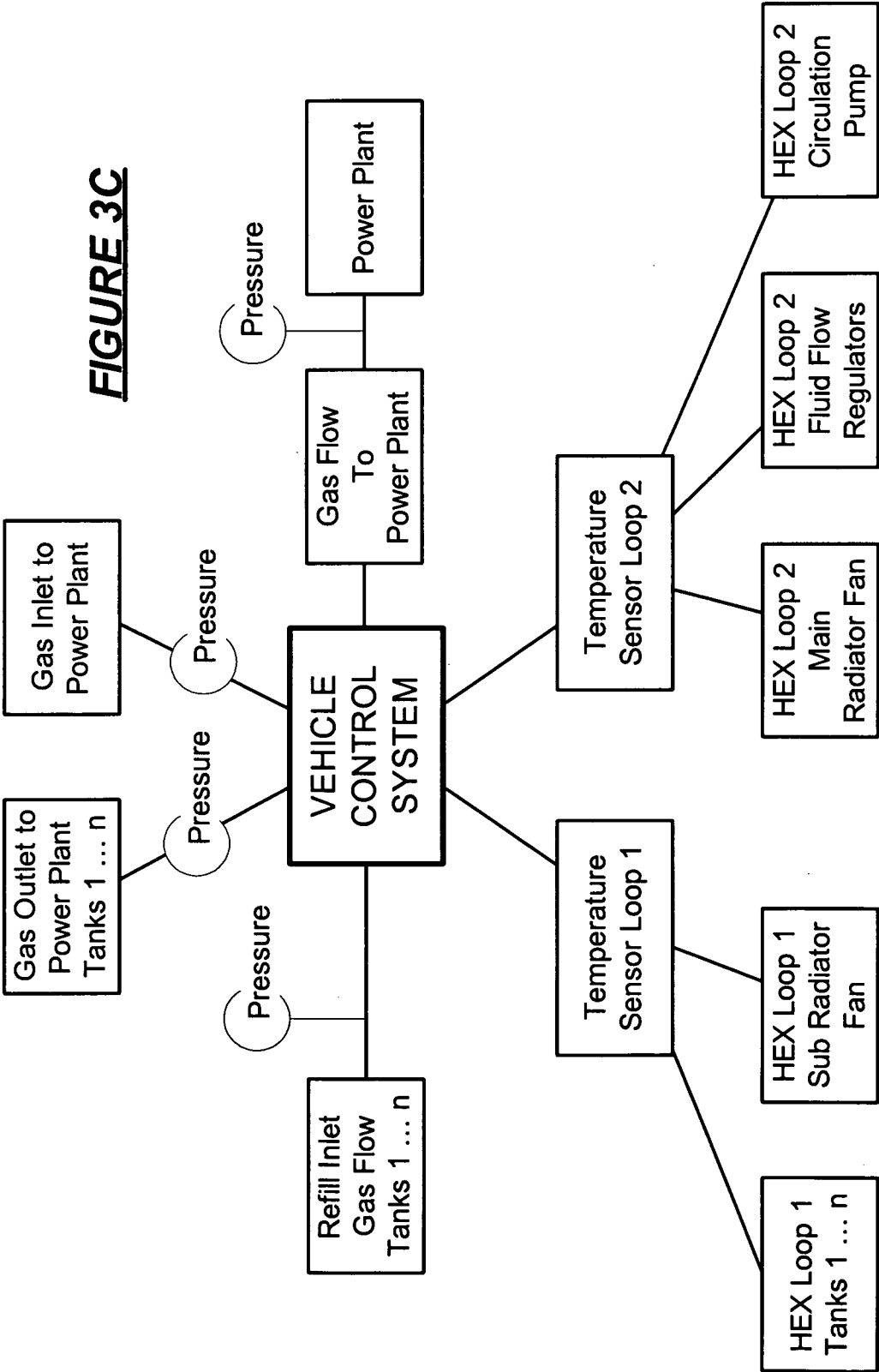
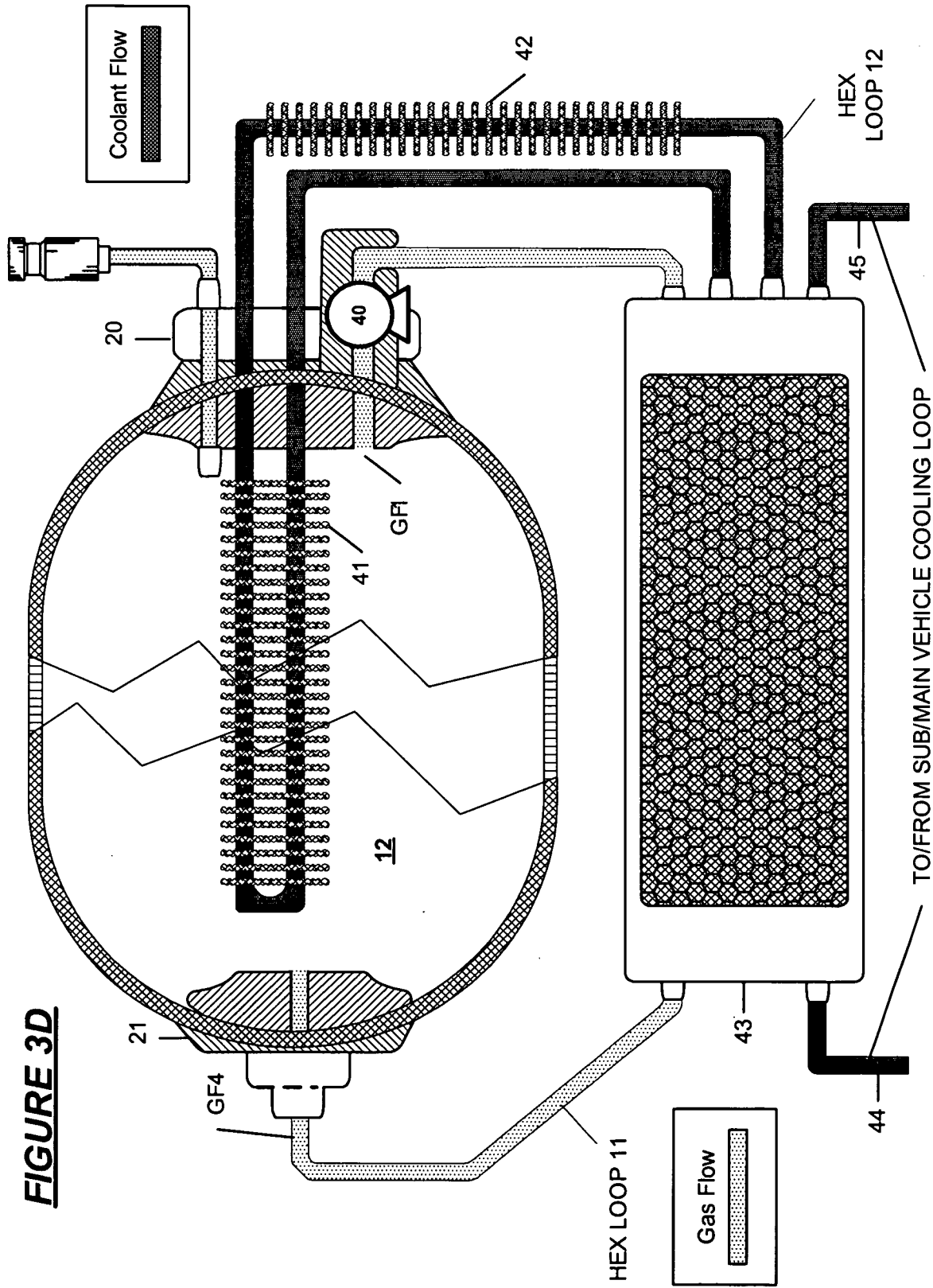
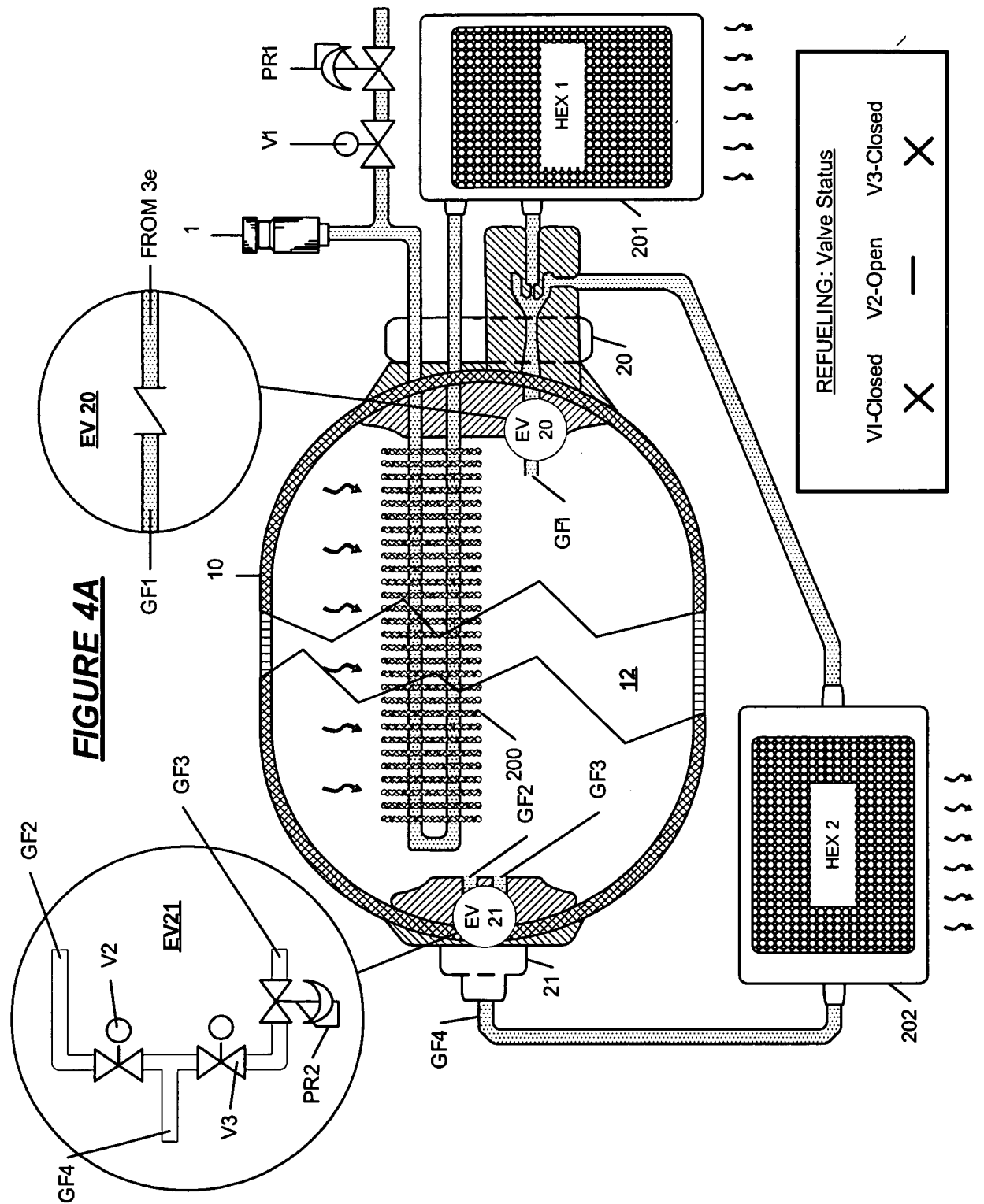
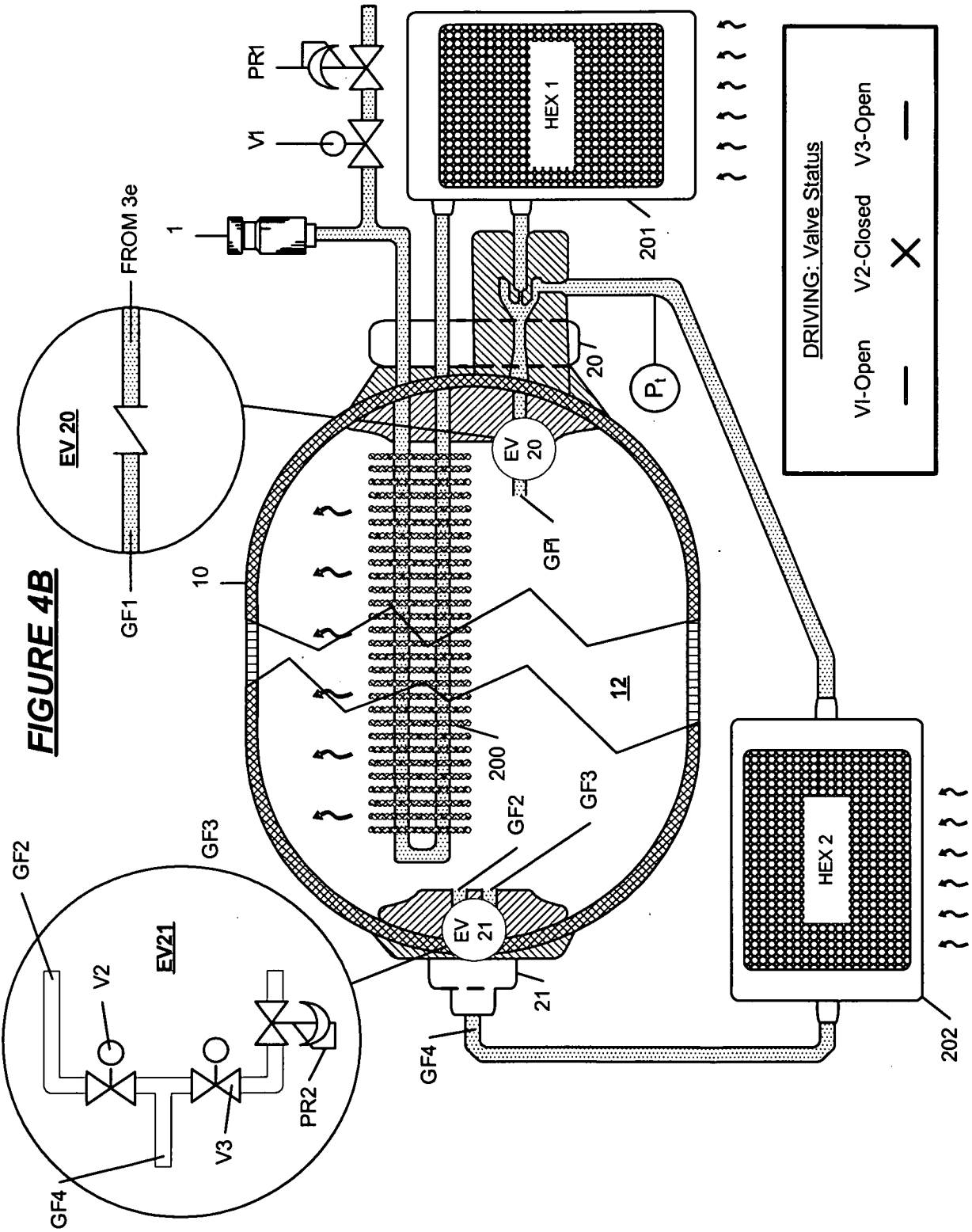


FIGURE 3C









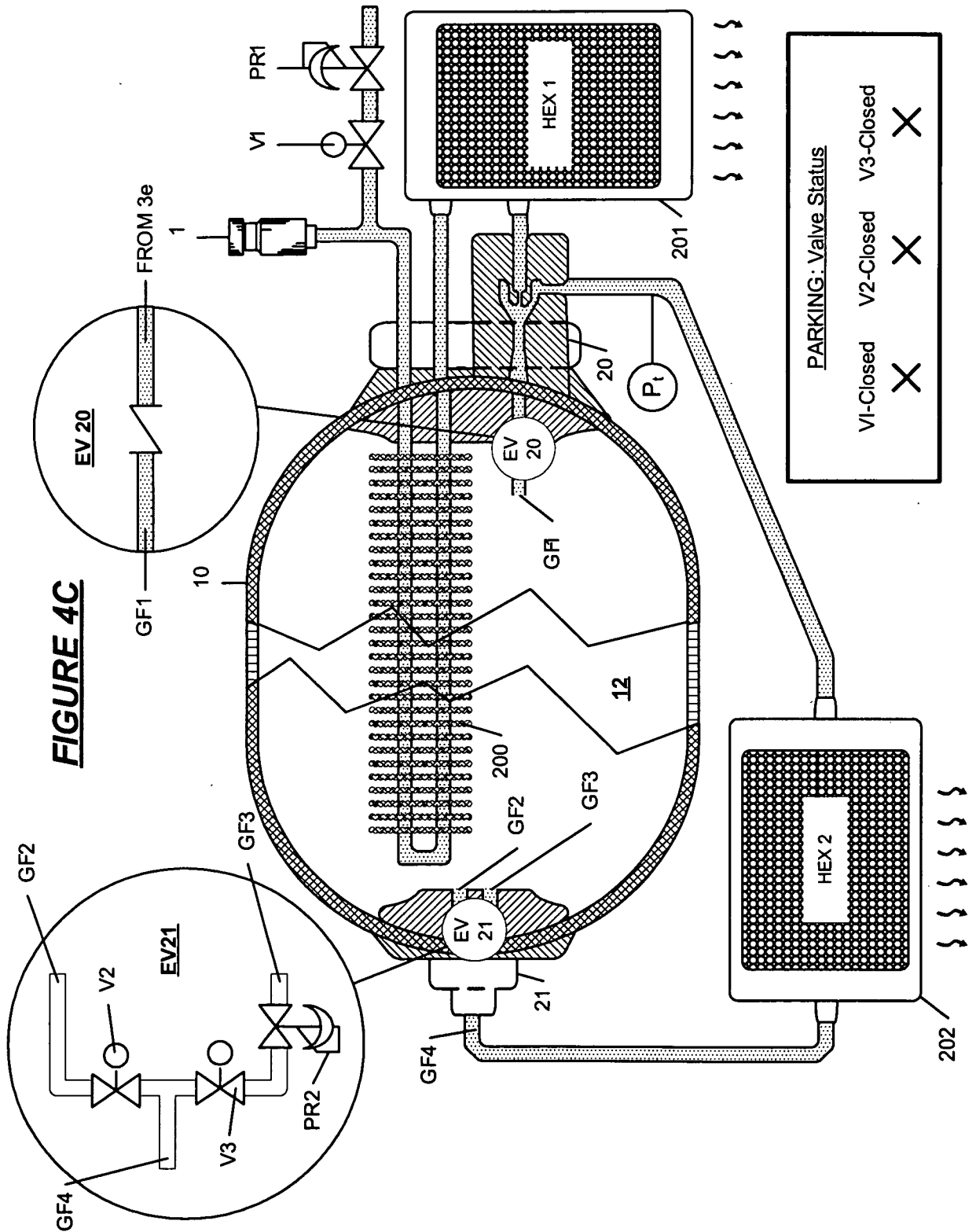


FIGURE 5B

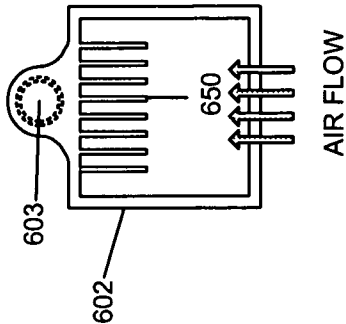


FIGURE 5D

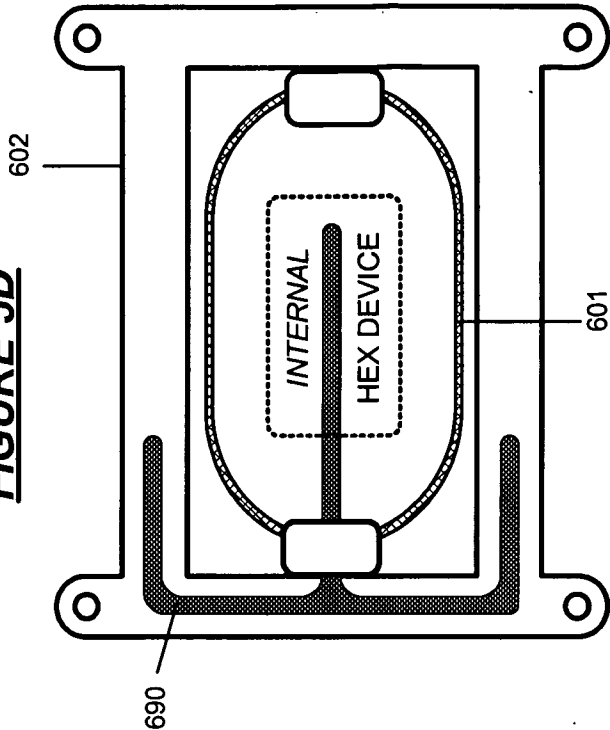


FIGURE 5A

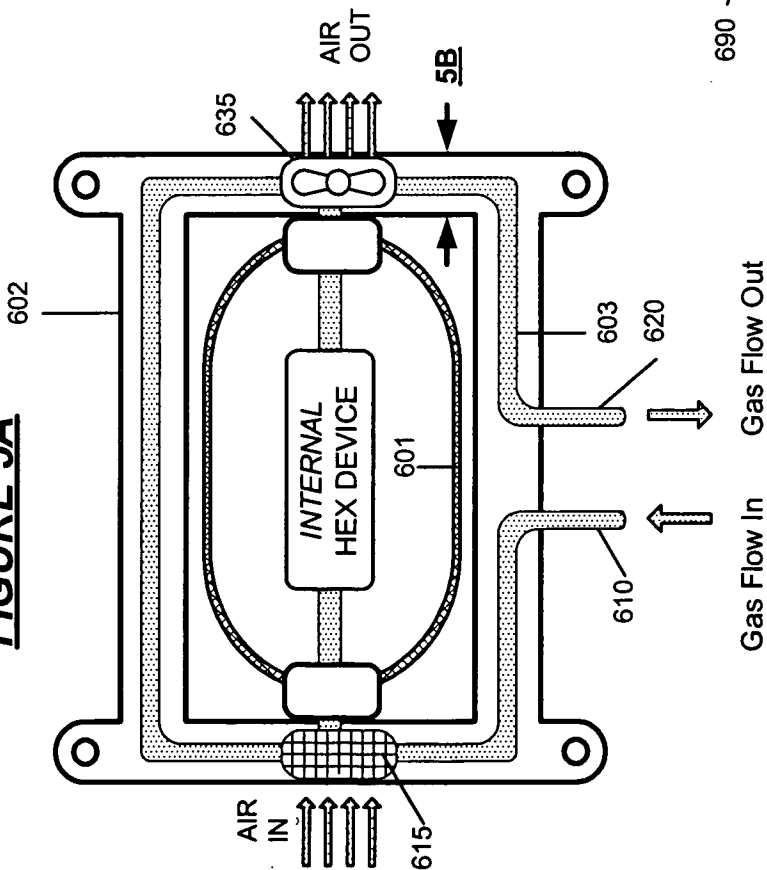


FIGURE 5C

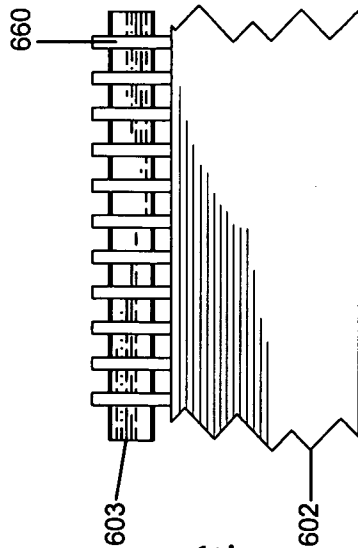


FIGURE 5E

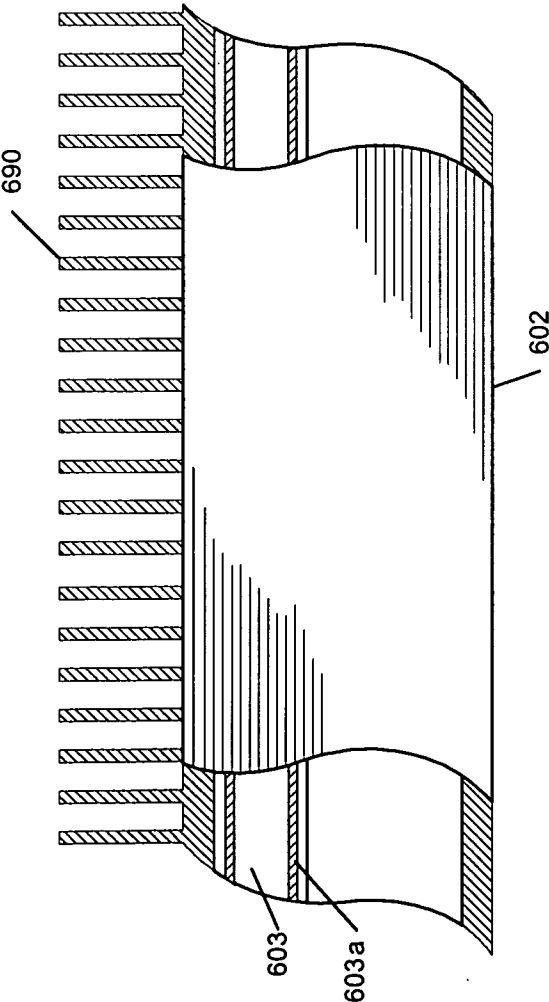


FIGURE 5F

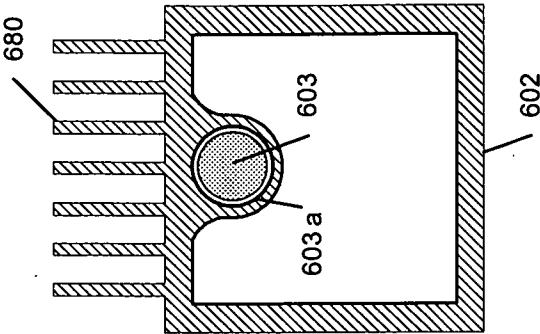


FIGURE 5G

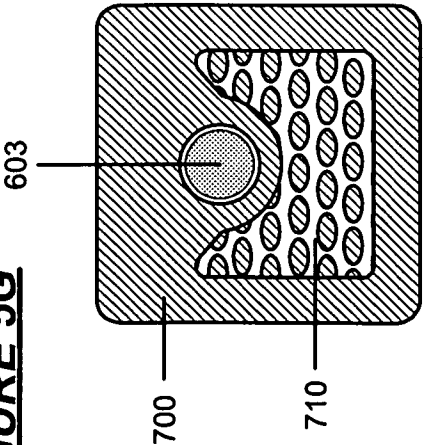
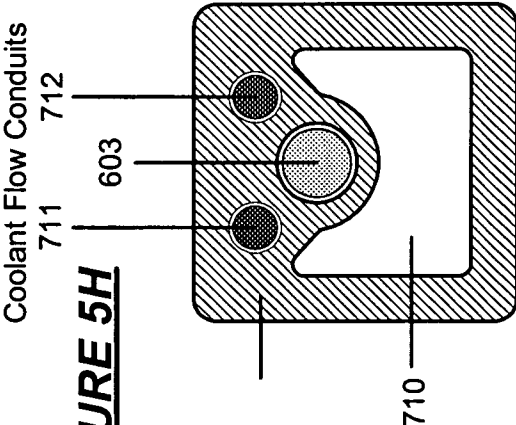


FIGURE 5H



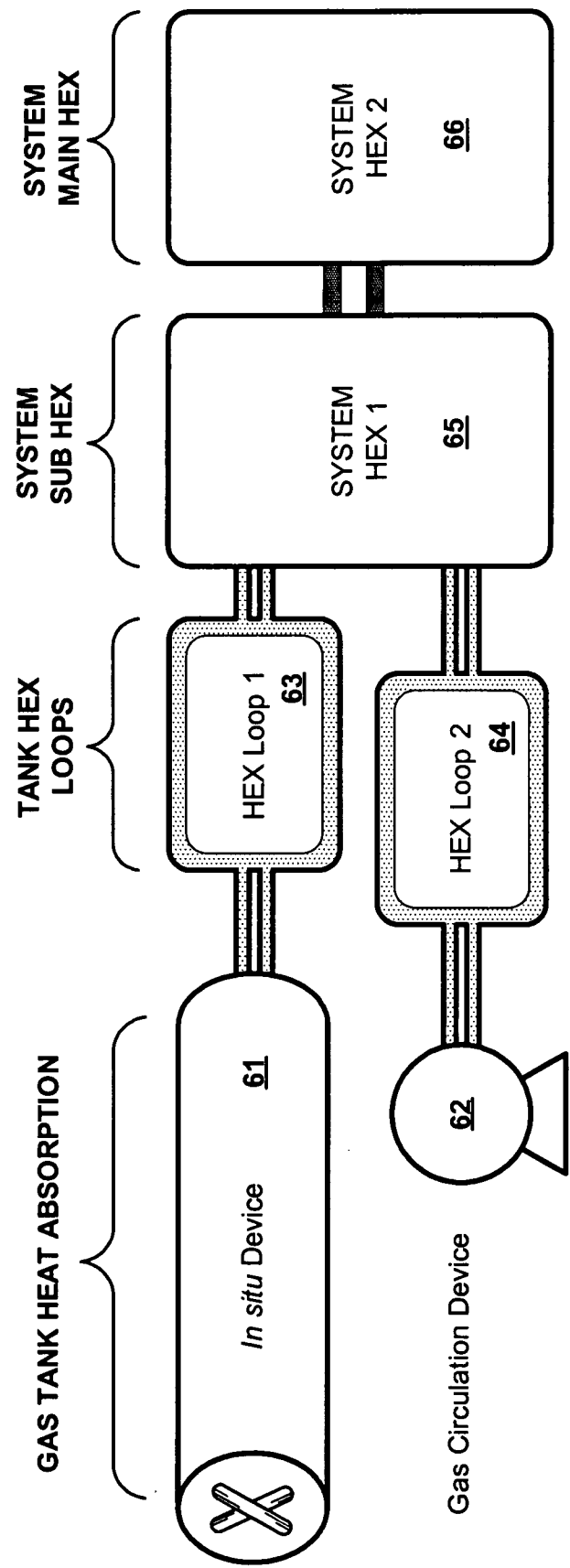


FIGURE 6A

FIGURE 6B

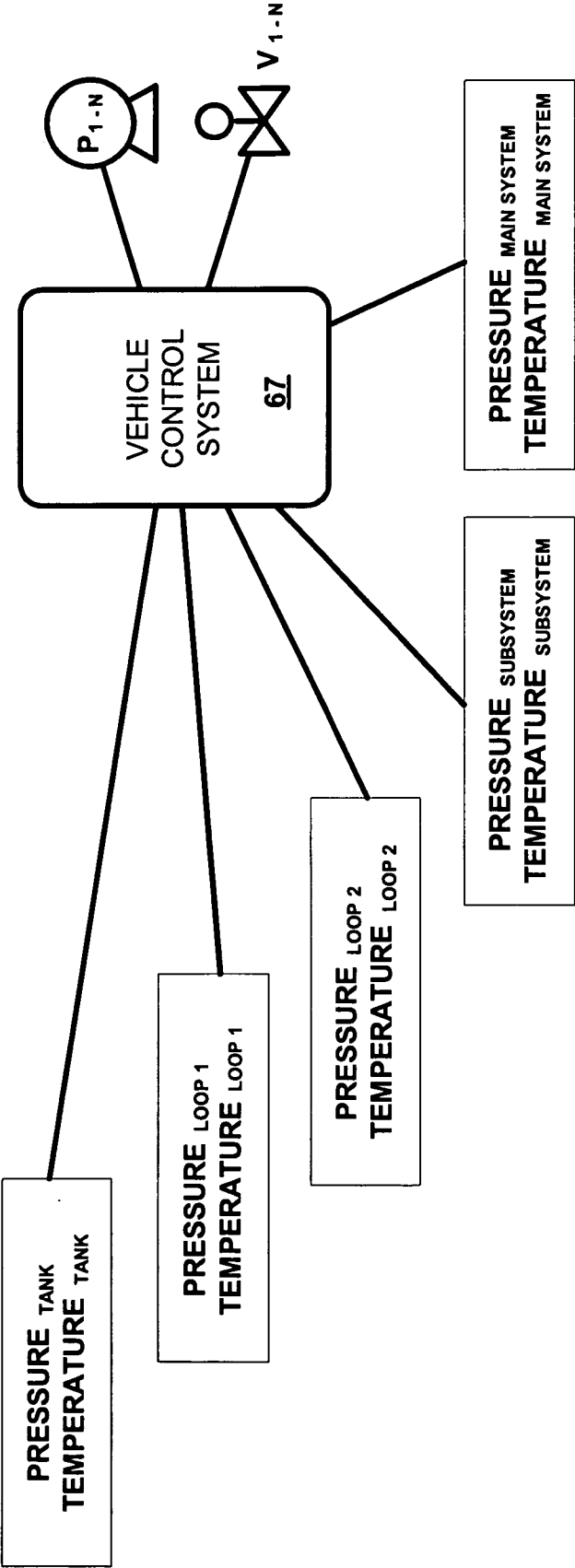
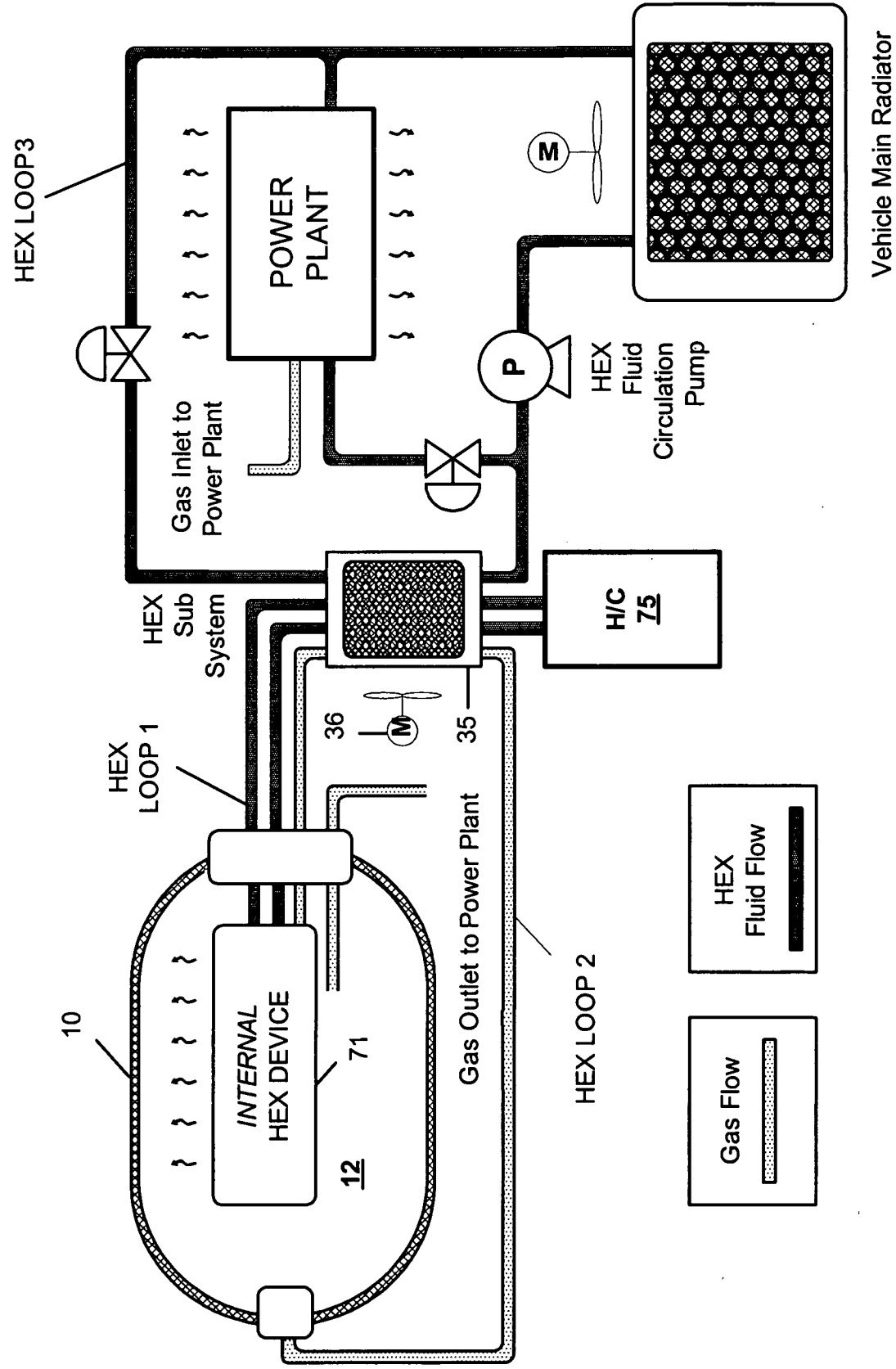


FIGURE 7A



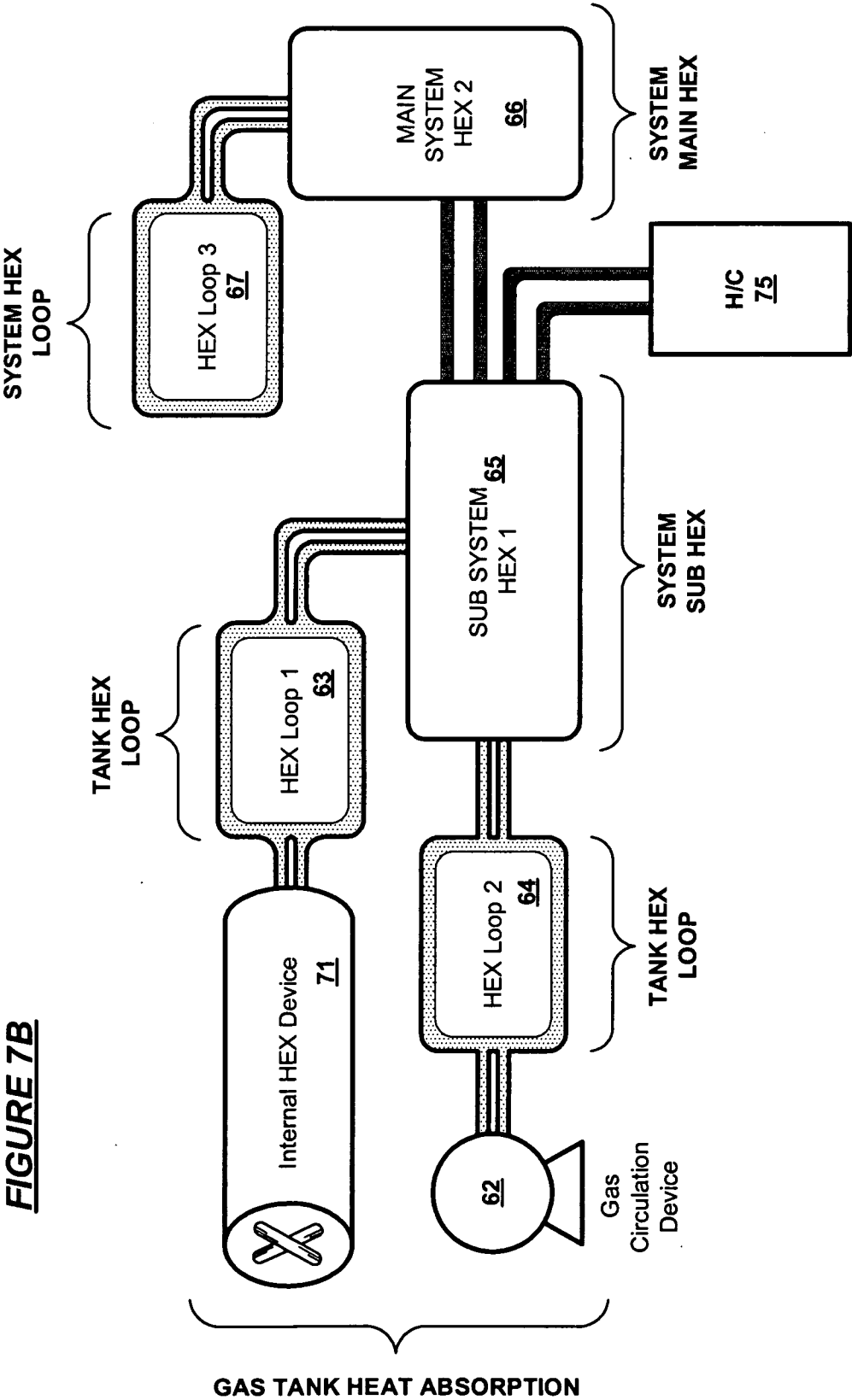
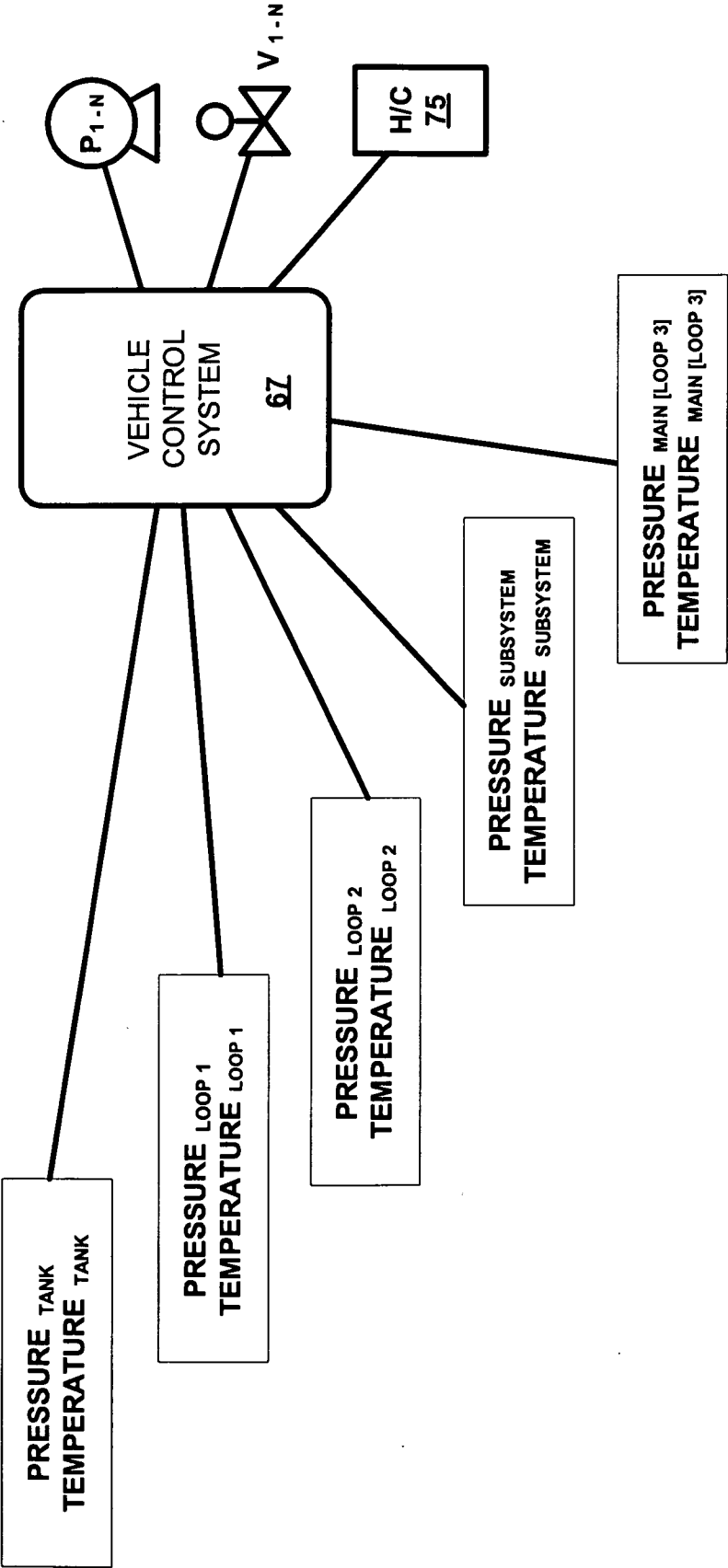


FIGURE 7C



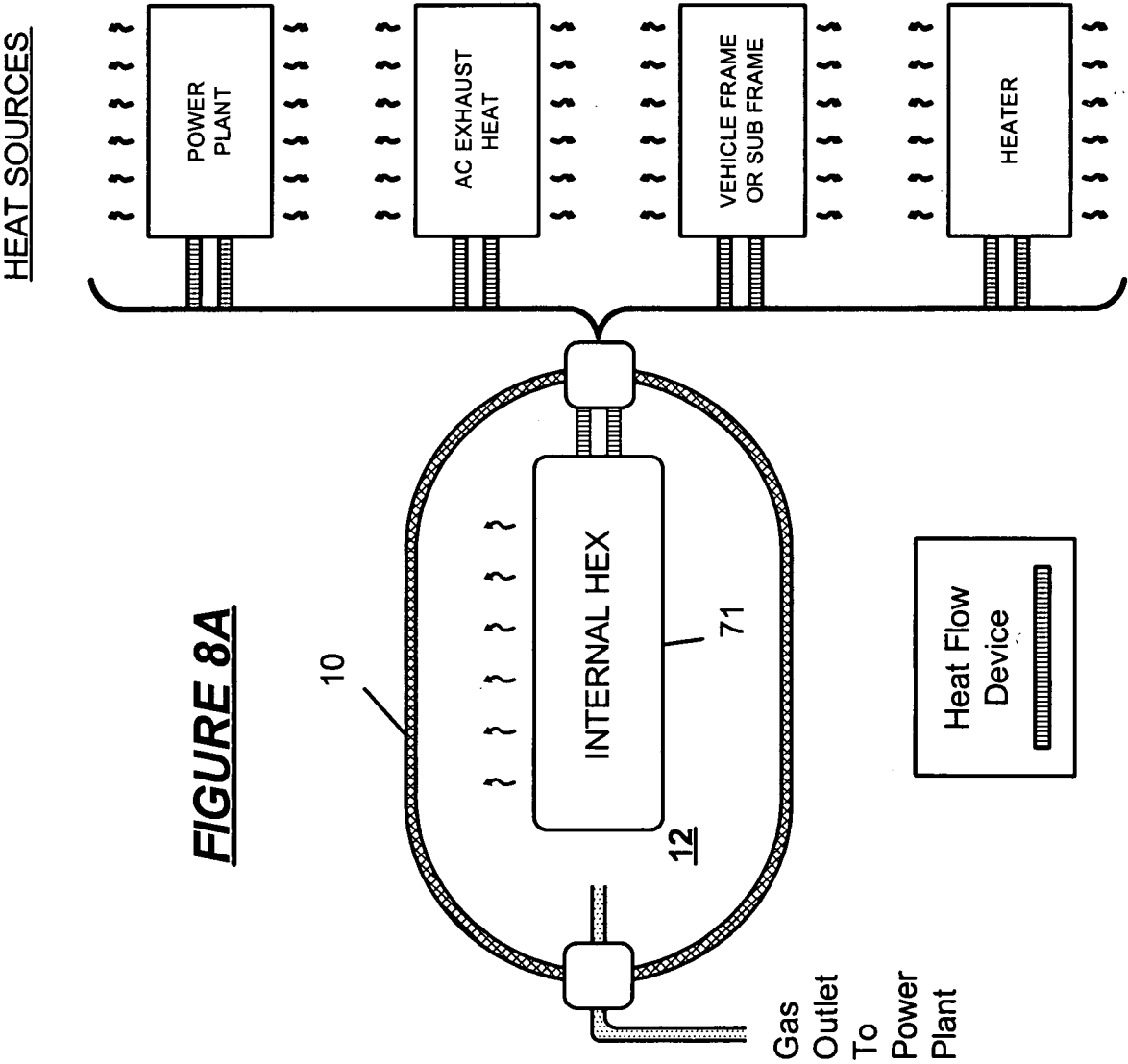


FIGURE 8A

