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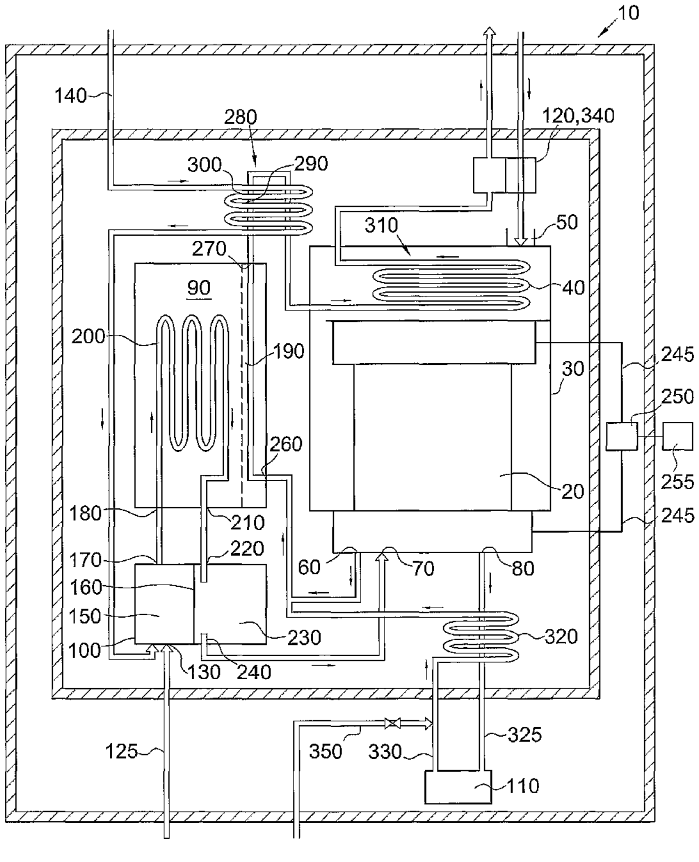

(57) Abstract: The present invention is concerned with improved fuel cell stack system assemblies comprising: (a) at least one fuel cell organised into at least one fuel cell stack defining an open oxidant inlet manifold; and (b) at least one enclosure housing: (i) said at least one fuel cell stack; (ii) a fuel cell stack oxidant-side inlet to said enclosure; (iii) a fuel cell stack oxidant-side outlet from said enclosure; (iv) a fuel inlet and outlet to said at least one fuel cell stack; and (v) at least one heat exchange surface of a heat exchanger, said at least one heat exchange surface having an in-use cool side on the interior of said enclosure and an in-use hot side external to said enclosure and in thermal communication with said fuel cell stack oxidant-side outlet; wherein said fuel cell stack system assembly defines an oxidant flow path: (A) from said fuel cell stack oxidant-side inlet; (B) across said at least one heat exchange surface; (C) across said at least one fuel cell stack; (D) to said fuel cell stack oxidant-side outlet.

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FUEL CELL STACK SYSTEM ASSEMBLY

The present invention is concerned with improved fuel cell stack assemblies.

It is known from US 6942942 to provide fuel cell stack system assemblies having a thermal enclosure within a structural enclosure. In particular, this is designed to ensure that the "hot" components of a solid oxide fuel cell system (such as the fuel cell stacks, fuel cell stack enclosures, fuel reformer, steam generator, tail gas combustor, heat exchangers and fuel/air manifolds) are contained within a thermally insulated "hot zone" and that other components (e.g. the air supply system and electronics control system) are contained within a "cool zone" surrounding or close to the "hot zone". Systems incorporating high temperature fuel cells are often constrained in their layout by the number of components that are required to be in the hot zone, the temperature of that hot zone, and the components that are not required in the hot zone, and the relationship between operation of the components in the hot zone and those in the cool zone.

Other prior art includes US 5340664, US 5366819, US 6033793, US 6326097, US 2004/0048123 and WO 97/24776. In particular, it is noted that the '664 and '776 publications describe effecting discrete temperature zones within fuel cell apparatus. However, it is noted in particular that there is no teaching, suggestion or motivation to provide discrete reformation and WGS (water gas shift) zones. Furthermore, there is no teaching, suggestion or motivation to use thermal energy from exhaust oxidant other than for reforming, nor to divert flow prior to the inlet oxidant heat exchanger.

The term "fuel cell stack assembly" as used herein means an at least one stack of fuel cells, together with end-plates and a compression system, fuel in/out and oxidant in/out connections, electrical and control/monitoring connections. Optionally, a fuel cell stack assembly can additionally comprise fuel cell stack insulation.

The term "fuel cell stack system assembly" as used herein means a fully functional fuel cell stack system, incorporating a fuel cell stack assembly, together with a reformer (if inlet fuel is to be reformed), an at least one heat exchanger, system control and electronics, and insulation. Optional additional components for a fuel cell stack system assembly include a tail-gas combustor.

In particular, for small fuel cell stack system assemblies (for example under 50kWe, or even under 5kWe in size), thermal losses become very significant and can impact upon operational efficiency, especially when the fuel cell stack assembly operates at part load. The use of a "hot box" to package the components susceptible to thermal loss can help mitigate this problem. In addition, making components as small as possible can help reduce the total surface area and thereby reduce the surface heat loss. In addition, the use of small components can also reduce the thermal mass of the fuel cell stack assembly and improve transient response (e.g. start-up, in-operation load changes and shut-down speed of the system).

It is also highly desirable to simplify construction and reduce the part count and cost of fuel cell stack assemblies, particularly of small fuel cell stack assemblies such as for domestic or small business enterprise fuel cell stack assemblies (such as micro combined heat and power (mCHP), and tri-generation products (TriGen)) and auxiliary power supply units (APUs) for e.g. vehicles.

According to the present invention there is provided a fuel cell stack assembly comprising:

- (a) at least one fuel cell organised into at least one fuel cell stack defining an open oxidant inlet manifold; and
- (b) at least one enclosure housing:
    - (i) said at least one fuel cell stack;
    - (ii) a fuel cell stack oxidant-side inlet to said enclosure;
    - (iii) a fuel cell stack oxidant-side outlet from said enclosure;
    - (iv) a fuel inlet and reacted fuel outlet to said at least one fuel cell stack; and

(v) at least one heat exchange surface of a heat exchanger, said at least one heat exchange surface having an in-use cool side on the interior of said enclosure and an in-use hot side external to said enclosure and in thermal communication with said fuel cell stack oxidant-side outlet;

wherein said fuel cell stack assembly defines an oxidant flow path:

(A) from said fuel cell stack oxidant-side inlet;
(B) across said at least one heat exchange surface;
(C) across said at least one fuel cell stack;
(D) to said fuel cell stack oxidant-side outlet.

Conventional high temperature fuel cell stack system assemblies comprise a discrete air pre-heater unit, which acts to effect a heat exchange between the inlet oxidant stream and the outlet oxidant stream. Once the inlet oxidant stream has passed through the heat exchanger, it is then passed to the separately housed fuel cell stack. The architecture of the fuel cell stack system assemblies of the present invention removes the need for the separate discrete air pre-heater unit, reducing the number of component parts of the system and thus reducing system size and surface area for heat loss, reducing the thermal mass of the fuel cell stack assembly and improving transient response, simplifying manufacture, and reducing cost.

In particular embodiments, the present invention results in an increased in-use thermal efficiency of the fuel cell stack assembly. Thus, for example, certain embodiments of the present invention have an in-use enhanced thermal efficiency when compared to equivalent prior art fuel cell stack assemblies. Such an increase in efficiency can be at least 0.5, 1, 1.5, 2, 2.5, 3, 3.5, 4, 4.5, 5, 10, 15 or 20 percent.

In particular, due to the operational conditions of air pre-heaters and fuel cell stacks, in order to place an air pre-heater in fluid communication with a separate fuel cell stack, it is usually necessary to bolt or weld a first fluid connector (e.g. a pipe) to an outlet from the air pre-heater, and to bolt or weld a fluid connector to an oxidant inlet of the fuel cell stack, and to then bolt or weld together the two fluid connectors. This is slow, cumbersome and costly, requiring the use of at least one additional fluid connector and at least two additional fluid connector joints as compared to the present invention.

Preferably, the at least one enclosure comprises a thermal enclosure, particularly a thermally insulated enclosure. By providing thermal insulation for the fuel cell stack assembly and other hot zone components, heat loss to the exterior of the enclosure can be reduced and thus system efficiency and efficacy enhanced.

Depending upon the conditions in which the fuel cell stack assembly is to be used, different oxidants may be used. In certain embodiments, the oxidant to be used is air and thus the fuel cell stack oxidant-side inlet and fuel cell stack oxidant-side outlet comprise an air inlet and an air outlet respectively.

Preferably, the heat source comprises a fuel cell stack oxidant-side outlet. Thus, in use a cool oxidant stream (e.g. an atmospheric air stream) enters the enclosure, passes over the heat exchange surface such that the oxidant stream is heated, passes across the at least one fuel cell stack to which it provides a source of oxidant and is further heated in the process, and then passes to the oxidant-side outlet which is in thermal communication with the heat exchange surface so as to exchange heat with the inlet cool oxidant.

In certain embodiments, the at least one heat exchange surface comprises an enclosure heat exchanger (i.e. a heat exchanger defining the heat exchange surface in the enclosure) which on a side external to the enclosure is preferably in fluid communication with the fuel cell stack oxidant-side outlet.

In particular embodiments having the heat exchange surface comprising a heat exchanger, the fuel cell stack assembly additionally comprises a reformer having a reformer heat exchanger in fluid communication with and positioned between said fuel cell stack oxidant-side outlet and said enclosure heat exchanger.

Thus, hot oxidant flow from the oxidant-side outlet can pass across a reformer heat exchanger in order to provide energy for the endothermic reformation of a fuel source (e.g. a hydrocarbon fuel such as, for example, natural gas) and, at a reduced temperature, can then pass to the enclosure heat exchanger where it provides heat energy to the inlet oxidant steam.

In certain embodiments, the fuel cell stack assembly is additionally provided with a burner in fluid communication with said fuel outlet and said fuel cell stack oxidant-side outlet. This allows the in-use partially-depleted hot oxidant stream to combine with the outlet reacted fuel steam and for any non-oxidised fuel to be burnt off to provide further heat energy which can be recovered and put to use e.g. as an additional heat source for any of the endothermic processes or steps taking place in the fuel cell stack assembly, or for heating the incoming oxidant, or heating the incoming fuel stream, or another internal or external heat load. Such an external heat load could be that, or providing central heating and/or hot water to a domestic application.

The present arrangement of the at least one heat exchange surface is particularly useful for closely integrating the fuel cell stack and heat transfer surfaces, benefiting operational transient response times and minimising system thermal losses, hence increasing system efficiency.

As mentioned above, the fuel cell stack assemblies of the present invention are particularly useful in small-scale applications and in certain embodiments the fuel cell stack assembly has a maximum power output of 0.5, 1, 2, 2.5, 5, 10, 15, 20, 25, 30, 35, 40, 45 or 50 kW. Particular applications include micro-CHP, small power generator, vehicle auxiliary power units (APUs), and uninterruptible power supplies (UPS) systems which can e.g. provide critical power back-up or base load requirements. Vehicle APUs include car, truck, boat, yacht, submersible, semi-submersible, and space vehicle APUs.

The fuel cell stack assemblies of the present invention are particularly applicable to solid oxide fuel cells (SOFCs), more particularly intermediate-temperature solid oxide fuel cells (IT-SOFCs) having an operating temperature of between 450 - 650°C.

In particular, the fuel cell stack system assemblies of the present invention may comprise a hot box enclosure defining a hot box volume and containing within it at least one partition defining first and second hot box volumes within said hot box enclosure, said first and second hot box volumes being thermally insulated from one another, the first volume containing the enclosure. The hot box volume can be thermally insulated from the exterior of the hot box. Each hot box volume can contain within it components having an in-use operational temperature different to the in-use operational temperature of the components in the other hot box volume(s). Thus, different components can be readily integrated into a fuel cell stack system assembly, in particular with a relatively small overall system volume. This can thus allow for system efficiency improvements and reduced system thermal mass and thus increased speeds of system heat-up and cool-down and thus overall system efficiency and efficacy.

In certain embodiments, the fuel cell stack assemblies additionally comprise a reformer, the reformer being contained within the second volume. In use, the first and second hot box volumes may have different operational temperatures.

Thus, for example, in the case of a fuel cell stack assembly incorporating IT-SOFCs and which is to be provided with a hydrocarbon fuel source, the first hot box volume contains the at least one fuel cell stack which has an operational temperature of about 400-650 °C, for example about 500-620 °C; the second hot box volume contains a reformer having an operational temperature of about 500-800 °C, more particularly 620-700 °C.

The first and second hot box volumes are thermally insulated from one-another so that in use, discrete operational temperatures can be achieved within them, and they are both contained within the hot box volume, thermally insulated from the exterior of the hot box. By creating separate temperature zones in this way, the components within the various high temperature zones can be grouped together in such a way that they operate at beneficial temperatures to one another within that hot box zone. Thus the hot box zones can be designed to operate at beneficial temperatures for the components in that temperature zone without unduly influencing the effective operating temperatures and thus the efficiency and efficacy of the individual components in that zone and those in different temperature zones other than by the designed for temperature exchange that occurs via the gas flows between the various components, and the designed for radiant and convective heat transfer between closely positioned components. In this way, the system and its components can be efficiently and effectively thermally integrated as a whole package by the use of more than three temperature zones (two or more hot zones and one cool zone)

The hot box enclosure can also be provided with a further partition which defines a third hot box volume thermally insulated from the first and second hot box volumes. In particular, this can be used to house a water gas shift (WGS) reactor. WGS reactors are particularly useful in increasing fuel cell operating efficiency where a fuel has to be reduced to yield a hydrogen-rich gas feed which is passed to the at least one fuel cell. Reduction in a reformer typically generates carbon monoxide as a by-product as well as hydrogen, and the WGS reactor contains a catalyst and is provided with a supply of fuel containing carbon monoxide, water and heat energy. In an exothermic reaction, the catalyst converts the carbon monoxide and water into carbon dioxide and hydrogen, which is then passed to the at least one fuel cell.

The operational temperature for a WGS reactor is typically different to those for the at least one fuel cell and the reformer, and thus the provision of a separate thermal zone for the WGS reactor allows the convenient and efficient operation of the WGS reactor, enhancing hydrogen volumes for the at least one fuel cell yielded from a fuel source, and enhancing overall power output. In particular, the WGS reactor can have an in-use operating temperature of about 250-500 °C, more specifically about 300-400 °C.

Thus, in certain embodiments, the fuel cell stack assembly additionally comprises a hot box enclosure defining a hot box volume and containing within it at least first and second partitions defining first, second and third hot box volumes within said hot box enclosure, said first, second and third hot box volumes being thermally insulated from one another, the first hot box volume containing the enclosure, the second hot box volume containing a reformer, and the third volume containing a WGS reactor. The hot box volume (and thus the first, second and third hot box volumes) are thermally insulated from the exterior of the hot box enclosure.

In particular embodiments, hot box enclosure is contained within a housing. In particular, the housing can define an in use "cool zone" which can contain component parts of the fuel cell stack system assembly which do not need to be or should not be kept within the hot box.

Component parts which are suitably kept within the "cool zone" include system control electronics, power electronics, pumps, fans, blowers, wiring loom, control valves, water delivery system, heat recovery heat exchanger, condenser, air filter, safety shut down equipment. The in-use operation temperature of the "cool zone" can be <80 °C. More preferably, the in-use operational temperature of the "cool zone" is <40 °C.

In such fuel cell stack system assemblies, the reformer can comprise a heat exchanger in fluid communication with and positioned between said fuel cell stack oxidant-side outlet and said enclosure heat exchanger, i.e. a fluid flow path may be defined from fuel cell stack oxidant-side outlet to a reformer heat exchanger inlet to a reformer heat exchanger outlet to the enclosure heat exchanger, from which the oxidant can be exhausted *via* an optional burner.

The fuel outlet from the at least one fuel cell stack can pass out of the hot box as an outbound fuel outlet to a condenser which is used to condense water from the fuel outlet and back into the hot box as a return fuel outlet in fluid communication with the fuel cell stack oxidant-side outlet.

This return fuel outlet can be in thermal communication with the outbound fuel outlet in order to retain heat. For example, this can be done by way of a heat exchanger such as a counter-current heat exchanger.

Thus, in use a hot fuel outlet stream has water condensed from it and is then combined with the fuel cell stack oxidant-side outlet stream and enters the reformer heat exchanger. Final exhaustion from the hot box can be *via* a burner which will burn off any remaining unreacted fuel and heat energy can be recovered from the burner for subsequent use.

Another embodiment is to have a hot fuel outlet stream pass into a burner where it is mixed with fuel cell stack oxidant-side outlet stream to burn off any unreacted fuel and recover the heat generated by having the burner as part of a heat exchanger to heat the fuel cell stack oxidant-side incoming air or heat the fuel cell fuel-side incoming fuel.

In other preferred embodiments, a hot fuel outlet stream passes into a burner where it is mixed with the fuel cell stack oxidant-side outlet stream, any unreacted fuel burnt off and the heat generated recovered by having the burner thermally coupled to a reformer unit.

Alternatively, the "burner" need not actually employ a flame to effect combustion of any unreacted fuel, which instead can be oxidised by a catalyst. For example, a catalyst can be integrated into the reformer unit so as to generate heat which can transfer directly across the reformer heat exchanger. Such a burner can be achieved by wash-coating one of the heat exchanger area surfaces with a suitable burner catalyst. Likewise such a burner can be achieved by coating a monolith or other high surface area unit, such as expanded metal, and placing the unit within a reformer or heat exchanger device.

The WGS reactor and the reformer require water (as steam) as a reactant and so the hot box can be provided with a water inlet. The WGS reactor can be provided with a first inlet, a first outlet, a second inlet, and a second outlet. The reformer can be provided with a reformer inlet and a reformer outlet. The fuel cell stack assembly also of course requires fuel and so can be provided with a fuel inlet. With such components, the fluid flow path to the fuel cell stack fuel inlet can be as follows: from the water inlet to a steam generator heat exchanger, and fuel inlet to the WGS first inlet, to the WGS first outlet to the reformer inlet to the reformer outlet to the WGS second inlet to the WGS second outlet to the fuel cell stack fuel inlet.

In such arrangements, fuel and steam inlets to the WGS first inlet will supply a relatively cool flow, which can pass across a first surface of a WGS heat exchanger. The reformer outlet in fluid communication with the WGS second inlet can pass fluid across a second surface of the WGS heat exchanger, thus cooling the in-use hot reformate generated by the reformer, and heating the relatively cool fuel and steam flows, enhancing reformer action. The WGS heat exchanger second surface can be at least partially coated with a WGS catalyst. In particular, in the in-use direction of flow from the WGS second inlet to the WGS second outlet, the WGS heat exchanger second surface can have first and second zones, the first zone not being provided with any catalyst, and the second zone being provided with catalyst. The first zone can for example comprise at least 10, 20, 30, 40, 50, 60 or 70% of the total flow path distance from the WGS second inlet to the WGS second outlet. Thus, in the first zone the reformate is simply cooled as it crosses the WGS heat exchanger second surface, and in the second zone the catalyst acts to catalyse the WGS reaction to yield hydrogen.

In an alternative embodiment, the aforementioned WGS heat exchanger may be featured as a discrete heat exchanger and a separate WGS stage (such as a catalyst coated monolith), the separate WGS stage being in fluid connection with the second heat exchanger outlet and the stack fuel inlet.

In order to further enhance the thermal efficiency of the fuel cell stack system assembly, the water inlet can be in thermal communication with the fuel cell stack oxidant-side outlet. More particularly, in embodiments where a fluid flow path is defined from the fuel cell stack oxidant-side outlet to a reformer heat exchanger inlet to a reformer heat exchanger outlet to the enclosure heat exchanger, the water inlet can be in thermal communication with the flow path between the reformer heat exchanger outlet and the enclosure heat exchanger. The water inlet can be provided in the form of a pipe, and can comprise expansion bellows in thermal communication with the flow path between the reformer heat exchanger outlet and the enclosure heat exchanger. Alternatives to expansion bellows will be readily apparent to a person of ordinary skill in the art, and include e.g. coiled pipe arrangements, and heat exchange fin arrangements. This allows a significant heat transfer area from which steam for the reformer can be generated, especially when expansion bellows are employed. A secondary benefit would be that the bellows would be cooled by evaporating the water, lowering the temperature of the bellow material (generally of steel construction). This will improve strength during operation and allow for thinner and lower cost materials to be used.

In order to assist with start-up of the fuel cell stack system assembly and further improve transition responsiveness, an auxiliary fuel inlet can be provided such that fuel can be burnt or otherwise oxidised to release heat energy directly into the fuel cell stack system assembly, particularly into the reformer and to the at least one heat exchange surface. An ignition source can of course be provided. Thus, for example, an auxiliary fuel feed can be provided into a return fuel outlet and oxidised by combusting over an oxidation catalyst coating in the reformer.

In certain embodiments, the heat source for the at least one heat exchange surface is an enclosure heat exchanger which is in fluid communication with the fuel cell stack oxidant-side outlet. Where an auxiliary fuel inlet is provided, the "hot" side of the enclosure heat exchanger can be provided with a catalyst across which the fuel cell stack oxidant-side outlet flow and auxiliary fuel inlet flow pass, and the auxiliary fuel is oxidised, thus heating the at least one heat exchange surface and heating inlet oxidant. Alternatively, catalyst can be provided on the first (hot) side of the enclosure heat exchanger. Suitable catalysts will be readily apparent to one of ordinary skill in the art and include precious metal based oxidation catalysts such as platinum or palladium based systems. There are also non-precious metal based catalysts which have been tested, such as nickel or copper based systems.

This can provide notable benefits - in particular this avoids the need found in prior art fuel cell stack assemblies for a separate heat exchanger or start-up burner for start-up heating. In particular, avoiding the use of a start-up burner avoids the risk of combustion products passing through the at least one fuel cell and reducing fuel cell stack life. In addition, it allows for the design and layout of a more compact system, reducing system weight and size, reducing cost and, due to the reduced number of components in the system, reducing thermal mass and so improving system start-up and dynamic response time.

In preferred embodiments, the fuel cell stack assembly additionally comprises an air pre-heater burner in which an additional fuel supply provides fuel that is oxidised to generate heat, which is transferred via a heat exchange surface to additionally heat the fuel cell stack inlet oxidant. Such an operation is preferably configured to occur at fuel cell system start-up when additional heat is required to heat up the fuel cell stack from ambient temperature to close to fuel cell stack operating temperature. Such oxidation and resulting heat transfer preferably continues until such time as the fuel cell stack temperature reaches a level where the electrochemical reaction occurring in the fuel cell active layers provides sufficient heat that the fuel cell stack is thermally self-sufficient. Once the fuel cell stack has attained the correct temperature then the additional fuel supply to the pre-heater burner is shut-off. In another embodiment for rapid fuel cell stack heating at start-up, in-use fuel is mixed into the inlet oxidant stream and is oxidised prior to entry into the fuel cell stack in order to effect direct heating of the inlet oxidant, thus avoiding the need to use a heat exchanger element. However, this method requires that the oxidant side of the fuel cell stack is tolerant to combusted products.

The invention will be further apparent from the following description with reference to the several figures of the accompanying drawings which show, by way of example only, fuel cell stack system assemblies. Of the Figures:

Figure 1	shows a plan view of the component parts of a fuel cell stack assembly;
Figure 1A	shows an embodiment with an additional fuel supply 126 to the burner 120 for start-up operation;
Figure 2	shows a plan view of the various thermal zones of a fuel cell stack assembly;
Figure 2A	shows plan view of an alternative embodiment of a fuel cell stack assembly according to the present invention;
Figure 3	shows an alternative embodiment of the fuel cell stack system assembly of Figures 1 and 2, with a rearranged enclosure 30;
Figure 3A	shows a further embodimetn in which the fuel cell stack system of Figure 3 is additionally provided with burner 121 thermally close to/adjacent reformer 90;
Figure 4	shows a further alternative embodiment of the fuel cell stack system assembly of Figures 1 and 2, with a rearranged burner 120A;

Figure 5	shows a further alternative embodiment of the fuel cell stack system assembly of Figures 1 and 2, with an alternative arrangement of the burner 120B; and
Figure 6	shows a still further alternative embodiment of the fuel stack system assembly of Figures 1 and 2, including an alternative gas flow path.

Teachings of fuel cell and fuel cell stack assemblies are well known to one of ordinary skill in the art, and in particular include US 6794075, WO 02/35628, WO 03/075382, WO 2004/089848, WO 2005/078843, WO 2006/079800, and WO 2006/106334, which are incorporated herein by reference in their entirety.

Fuel cell stack assembly 10 comprises a plurality of IT-SOFC fuel cells (not shown) arranged into a fuel cell stack 20 which defines an open oxidant inlet manifold such that oxidant surrounding the fuel cell stack 20 is able to cross the oxidant side of the fuel cells and provide oxygen for the oxidation of fuel. Thermal enclosure 30 contains within it fuel cell stack 20 together with heat exchange surface 40 and defines a fuel cell stack oxidant-side inlet 50 to enclosure 30, a fuel cell stack oxidant-side outlet 60 from enclosure 30, and a fuel inlet 70 and fuel outlet 80 to fuel cell stack 20.

Thus, an oxidant flow path is defined from fuel cell stack oxidant-side inlet 50 across heat exchange surface 40, across fuel cell stack 20 to fuel cell stack oxidant-side outlet 60. In passing across the fuel cell stack and to the fuel cell stack oxidant-side outlet, the oxidant passes around the outside of the fuel cell stack 20 and then enters into the fuel cell stack 20 and exits it via internal ducting to fuel cell stack oxidant-side outlet 60.

In use, air is used as the oxidant source for the fuel cells, and so fuel cell stack oxidant-side inlet 50 is an air inlet, and fuel cell stack oxidant-side outlet 60 is an air outlet.

Fuel cell stack assembly 10 also comprises a reformer 90, a water gas shift (WGS) reactor 100, condenser 110, and burner 120.

In use, hydrocarbon fuel first passes from fuel inlet 125 to the first inlet 130 of WGS reactor 100 where it mixes with water supplied from water inlet 140, and the mixture passes along first WGS passageway 150 across heat exchanger 160 which warms the mixture, and out of first WGS outlet 170, and the warmed water and hydrocarbon fuel mixture then passes to reformer inlet 180 and is heated as it passes across a first side of reformer heat exchanger 190 and is reformed as it passes across reformer catalyst surface 200 to primarily yield hydrogen, carbon monoxide and carbon dioxide. The reformed fuel and water mixture then exits reformer 90 *via* reformer outlet 210 and passes into WGS second inlet 220, and along WGS second passageway 230 across heat exchanger 160 which cools the reformed mixture (in turn heating the mixture in WGS first passageway 150). The first half of the WGS second passageway 230 proximal the WGS second inlet 220 allows the hot reformed mixture to cool by transferring heat across the heat exchanger 160. The second half of the WGS second passageway 160 proximal the WGS second outlet (i.e. distal the WGS second inlet 220) is coated on its inner wall (i.e. the surface in contact with the reformed mixture) with WGS catalyst, allowing water in the mixture to react with any carbon monoxide to generate carbon dioxide and hydrogen.

The reformed fuel mixture then passes from the WGS second outlet 240 to the fuel cell stack 20 fuel inlet 70.

Simultaneously, air enters enclosure 30 *via* fuel cell stack oxidant-side inlet 50, passes across heat exchange surface 40 and is heated (the equivalent of this in prior art devices is a discrete air pre-heater which is provided separately), and then passes across fuel cell stack 20 to which it provides a source of oxygen. As the hydrogen passes over the fuel side of the fuel cells and the oxygen passes over the oxidant side of the fuel cells, the hydrogen is oxidised to yield water on the fuel-side of the fuel cell, heat energy, and an electrical current is generated which passes via insulated conducting elements 245 to a power electronics system 250 located in the cool zone, where the power electronics are connected to a electrical load 255.

The hot oxidant-depleted air then exits the fuel cells and fuel cell stack 20 *via* fuel cell stack oxidant-side outlet 60 and passes to reformer heat exchanger inlet 260.

Simultaneously, hot fuel-side gases from fuel cell stack 20 comprising hydrogen, carbon dioxide, water, and any un-reformed hydrocarbon fuel, exits fuel cell stack 20 and enclosure 30 *via* fuel outlet 80, cross a first side of counter-current heat exchanger 320 and is cooled, and passes *via* outbound fuel outlet 325 to condenser 110 which acts to cool the fuel-side gases and condense out water. The remaining gas-phase fuel-side gases are then returned *via* return fuel outlet 330 and pass over a second side of counter-current heat exchanger 320 and are heated by the hot fuel-side gases on the other side. The hot fuel-side gases are then combined with the hot oxidant-depleted air at reformer heat exchange inlet 260.

The mixed hot fuel and oxidant gases then pass across a second side of reformer heat exchanger 190 and are cooled as they pass heat energy to the fuel and water mixture on the first side of reformer heat exchanger 190. The mixed hot fuel and oxidant gases then exit reformer heat exchanger 190 *via* reformer heat exchanger outlet 270, and pass through expansion bellows 280 on a first side 290 thereof.

Expansion bellows 280 has a large surface area and acts as a heat exchanger and steam generator. On the other (second) side 300 of expansion bellows 280, water from water inlet 140 passes and is warmed to create steam before going to the WGS first inlet 130. This further cools the mixed hot fuel and oxidant gases, which still have a temperature above ambient atmospheric temperature.

The mixed hot fuel and oxidant gases then pass to a first (hot) side of enclosure heat exchanger 310 which has a second (cool) side comprising heat exchange surface 40. As the still-hot mixed fuel and oxidant gases cross the first side of enclosure heat exchanger 310 and the inlet air crosses heat exchange surface 40, the inlet air is heated prior to its passage to fuel cell stack 20.

Finally, the mixed fuel and oxidant gases are exhausted from the fuel cell stack assembly 10 *via* burner 120 and heat exchanger 340 which burns off any remaining hydrogen and un-reformed fuel, and heat energy released is recovered by the heat exchanger.

The first side of enclosure heat exchanger 310 is additionally coated with a platinum-based oxidising catalyst such that during a start-up phase of the fuel cell stack assembly 10, heating of the air stream entering at fuel cell stack oxidant-side inlet 50 can be effected without requiring heat generation by the fuel cell stack 20 itself. Specifically, this is achieved by providing an auxiliary fuel feed 350 which is in fluid communication with return fuel outlet 330, and allows the direct provision of non-oxidised fuel to the fuel-side gases outlet from fuel cell stack 20. This then passes across reformer heat exchanger 190 and expansion bellows 280 and when it reaches enclosure heat exchanger 310, the catalyst on the first side of enclosure heat exchanger 310 acts to catalyse the oxidation of fuel from auxiliary fuel feed 350, and the heat energy released is transferred across enclosure heat exchanger 310 to inlet air crossing heat exchange surface 40.

Flow of air into and through fuel cell stack assembly 20 is effected by pumps/fans (not shown). Flow of fuel into and through fuel cell stack assembly 20 is effected by the provision of either a pump or the use of a pressurised fuel supply.

The above system is highly thermally efficient, and is mechanically simple to construct, particularly with the incorporation of the air pre-heater into the enclosure 30.

In an alternative embodiment shown in Figure 1A, burner 120 is provided with an additional fuel supply 126 to enhance heat heneration and heating of oxidant by heat exchanger 340.

The different component parts of the fuel cell stack assembly, together with e.g. control circuitry, have different operational temperatures, and so in order to ensure their correct operation and enhance overall system efficiency, the fuel cell stack assembly is provided with a plurality of temperature zones, the various zones being thermally insulated from one another.

As can be seen from Figure 2, hot box enclosure 400 is a thermally insulating enclosure and contains first and second partitions 460, 470 which define within it hot box first, second and third volumes 410, 420 and 430 respectively. First hot box volume 410 contains enclosure 30 and fuel cell stack 20, together with counter-current heat exchanger 320, and has an operational temperature of 400-650 °C or more preferably 500-620 °C.

Second hot box volume 420 contains within it reformer 90 and expansion bellows 280, and has an operational temperature of 500-750 °C or more preferably 620-700 °C.

Third hot box volume 430 contains within it WGS reactor 100 and has an operational temperature of 200-450 °C or more preferably 300-400 °C.

Each of the first, second and third hot box volumes 410, 420 and 430 are thermally insulated from one-another.

Exterior to the hot box enclosure 400, an external housing 440 defines a cool zone 450 which contains within it system electronics, pumps and suchlike, and which has an operational temperature of <80 °C.

An alternative arrangement of the fuel cell stack system assembly is shown in Figure 3 in which the contents of thermal enclosure 30 are arranged with oxidant-side inlet 50 and heat exchange surface 40 located at the bottom in a structure which effectively operates as an end-plate for fuel cell stack 20. In use, oxidant enters the enclosure 30 at the bottom, passes over heat exchange surface 40 and is heated and then passes over the at least one fuel cell stack assembly 20, entering into the oxidant side of the at least one fuel cell stack assembly 20, and exiting via fuel cell stack oxidant-side outlet 60.

A further alternative embodiment is shown in Figure 3A in which a burner 121 is provided thermally adjacent reformer 90. Flow from fuel cell stack oxidant-side outlet 60 and fuel outlet 80 pass to burner 121 where they are mixed and burnt to provide a hot burner 121 exhaust stream. The thermal energy in this hot exhaust stream is then used to heat reformer 90. Fuel cell stack is mounted on top of fuel cell stack base plate structure 480.

A preferred embodiment is shown in Figure 4. The embodiment corresponds to that shown in Figure 1, with the exception that burner 120A is situated in the enclosure heat exchanger 310A, rather than being separate. No further heat exchanger (340) coupled to the fuel cell stack oxidant-side inlet 50 is therefore provided in this embodiment. In this case, a catalyst is coated to the mixed hot fuel and oxidant gas side of the burner 120A of the enclosure heat exchanger 310. This location of the burner 120A provides reduced parts and therefore simplified design.

A further embodiment is shown in Figure 5. The embodiment corresponds to that shown in Figure 1, with the exception that the burner (120) and heat exchanger (340) are moved so that the expansion bellows 280, provides a heat exchanger 340B with burner 120B. This takes the place of separate heat exchanger 340. Similarly to the embodiment described above with relation to Figure 4, a catalyst is coated to the mixed hot fuel and oxidant gas side. Once again, this arrangement reduces the overall number of parts required in the system.

A yet further embodiment is shown in Figure 6. This embodiment corresponds to that shown in Figure 1, with the exception that the gas flow is altered after the mixed hot fuel and oxidant gases exit the reformer heat exchanger 190. In this embodiment, rather than passing through bellows (280) on leaving the reformer heat exchanger 190, the mixed hot fuel and oxidant gases are passed into the enclosure heat exchanger 310, exit the reformer heat exchanger 310 and then pass through the expansion bellows 280C. Once they have passed through the expansion bellows 280C, the mixed hot fuel and oxidant gases pass back to the burner and heat exchanger 120, 340.

By various arrangements, the relative flow position of the expansion bellows and the inlet air pre-heater can be changed to optimise thermal flow effects depending on the power and temperature gradients of the overall system, for example where different size power units are used.

An alternative fuel cell stack assembly arrangement is shown in Figure 2A, in which instead of oxidant being fed directly from the outside of the fuel cell stack assembly to the fuel cell stack oxidant side inlet 50, hot box 400 is provided with inlet 401 that allows oxidant to flow from the volume (cool zone 450) defined between external housing 440 and hot box 400 to oxidant-side inlet 50. In turn, oxidant flow to cool zone 450 from the exterior of external housing 440 is effected via external housing oxidant inlet 441. Thus, in the case of any event which results in the leakage of fuel etc. into the volume (cool zone 450) defined between external housing 440 and hot box 400, the contaminated gas in cool zone 450 is drawn into the fuel cell stack oxidant side inlet 50 via hot box oxidant inlet 401, preventing leakage external to external housing 440.

In other embodiments (not shown) the fuel cell stack assembly does not include a water gas shift (WGS) reactor. More specifically, in certain embodiments a heat exchanger arrangement is retained to effect heat exchange between fluid exiting the reformer through reformer outlet 210 and fuel and water coming from fuel inlet 125 and water inlet 140. This heat exchanger arrangement can be located in the first hot box volume 410, the second hot box volume 420, or in third hot box volume 430.

It will be appreciated that it is not intended to limit the present invention to the above example only, many variations being readily apparent to the person of ordinary skill in the art without departing from the scope of the appended claims.

Reference numerals:

10 - fuel cell stack assembly
20 - fuel cell stack
30 - thermal enclosure
40 - heat exchange surface
50 - fuel cell stack oxidant-side inlet
60 - fuel cell stack oxidant-side outlet
70 - fuel inlet
80 - fuel outlet
90 - reformer
100 - water gas shift (WGS) reactor
110 - condenser
120, 120A, 120B burner
121 - burner
125 - fuel inlet
126 - additional fuel supply
130 - first inlet
140 - water inlet
150 - first WGS passageway
160 - heat exchanger
170 - first WGS outlet
180 - reformer inlet
190 - reformer heat exchanger
200 - reformer catalyst surface
210 - reformer outlet
220 - WGS second inlet
230 - WGS second passageway
240 - WGS second outlet
245 - conducting elements
250 - electronics system
255 - electrical load
260 - reformer heat exchanger inlet
270 - reformer heat exchanger outlet

280, 280C - expansion bellows
290 - expansion bellows first side
300 - expansion bellows second side
310, 310A - enclosure heat exchanger
320 - counter-current heat exchanger
325 - outbound fuel outlet
330 - return fuel outlet
340, 340B - heat exchanger
350 - auxiliary fuel feed
400 - hot box enclosure
401 - hot box oxidant inlet
410 - first hot box volume
420 - second hot box volume
430 - third hot box volume
440 - external housing
441 - external housing oxidant inlet
450 - cool zone
460 - first partition
470 - second partition
480 - fuel cell stack base plate structure

CLAIMS

1. A fuel cell stack system assembly comprising:
    - (a) at least one fuel cell organised into at least one fuel cell stack defining an open oxidant inlet manifold; and
    - (b) an enclosure housing:
        - (i) said at least one fuel cell stack;
        - (ii) a fuel cell stack oxidant-side inlet to said enclosure;
        - (iii) a fuel cell stack oxidant-side outlet from said enclosure;
        - (iv) a fuel inlet and outlet to said at least one fuel cell stack; and
        - (v) at least one heat exchange surface of a heat exchanger, said at least one heat exchange surface having an in-use cool side on the interior of said enclosure and an in-use hot side external to said enclosure and in thermal communication with said fuel cell stack oxidant-side outlet;

    wherein said fuel cell stack assembly defines an oxidant flow path:
    - (A) from said fuel cell stack oxidant-side inlet;
    - (B) across said at least one heat exchange surface;
    - (C) across said at least one fuel cell stack;
    - (D) to said fuel cell stack oxidant-side outlet.

2. A fuel cell stack system assembly according to claim 1, said enclosure being a thermal enclosure.

3. A fuel cell stack system assembly according to either of the preceding claims, said fuel cell stack oxidant-side inlet and fuel cell stack oxidant-side outlet comprising an air inlet and an air outlet respectively.

4. A fuel cell stack system assembly according to any of the preceding claims, said heat source comprising said fuel cell stack oxidant-side outlet.

5. A fuel cell stack system assembly according to any of the preceding claims, said at least one heat exchange surface comprising an enclosure heat exchanger.

6. A fuel cell stack system assembly according to claim 5, said enclosure heat exchanger being in fluid communication with said fuel cell stack oxidant-side outlet.

7. A fuel cell stack system assembly according to any of the preceding claims, additionally comprising a reformer.

8. A fuel cell stack system assembly according to claim 7, additionally comprising a water supply for said reformer.

9. A fuel cell stack system assembly according to claim 8, said water supply comprising a steam supply.

10. A fuel cell stack system assembly according to any of claims 7-9 when dependent upon claim 6, said reformer having a reformer heat exchanger in fluid communication with and positioned between said fuel cell stack oxidant-side outlet and said enclosure heat exchanger.

11. A fuel cell stack system assembly according to claim 10, in which said reformer is in fluid connection with said fuel cell stack fuel inlet.

12. A fuel cell stack system assembly according to any of the preceding claims, additionally comprising a water gas shift (WGS) reactor.

13. A fuel cell stack system assembly according to claim 12 when dependent upon claim 11, in which said WGS reactor is positioned between said reformer and a fuel cell stack fuel inlet.

14. A fuel cell stack system assembly according to claim 12 or 13, said WGS reactor comprising a water inlet.

15. A fuel cell stack system assembly according to claim 14, said water inlet comprising a steam inlet.

16. A fuel cell stack system assembly according to any of claims 11-13, said WGS reactor comprising first and second passageways, said first passageway comprising a first inlet and a first outlet, said second passageway comprising a second inlet and a second outlet.

17. A fuel cell stack system assembly according to claim 16, said first and second passageways being in thermal communication with one another across a WGS heat exchanger.

18. A fuel cell stack system assembly according to claim 17, said second passageway having a second inlet-proximal portion not having a WGS catalyst and a second outlet-proximal portion having a WGS catalyst.

19. A fuel cell stack system assembly according to claim 18, said second outlet-proximal portion having a WGS catalyst on the wall of said passageway.

20. A fuel cell stack system assembly according to any of claims 17-19 when dependent upon claim 7, said reformer having an inlet and an outlet, said WGS reactor and said reformer being coupled to define a fuel flow path from said WGS first inlet, along said WGS first passageway across said WGS heat exchanger, to said WGS first outlet, to said reformer inlet, across said reformer, to said reformer outlet, to said WGS second inlet, along said WGS second passageway, across said WGS heat exchanger, to said WGS second outlet, to said fuel cell stack fuel inlet.

21. A fuel cell stack system assembly according to any of the preceding claims, additionally comprising a condenser in fluid communication with said fuel outlet.

22. A fuel cell stack system assembly according to claim 21, said condenser having a condenser inlet in fluid communication with said fuel outlet and a condenser outlet in fluid communication with said fuel cell stack oxidant-side outlet.

23. A fuel cell stack system assembly according to any of claims 2 to 22, additionally comprising a burner in fluid communication with said fuel outlet and said fuel cell stack oxidant-side outlet.

24. A fuel cell stack system assembly according to claim 23, said burner comprising a catalyst.

25. A fuel cell stack system assembly according to any of the preceding claims, having a maximum power output of 0.5, 1, 2, 2.5, 5, 10, 15, 20, 25, 30, 35, 40, 45 or 50 kW.

26. A fuel cell stack system assembly according to claim 25, comprising a micro-CHP, small power generator, or vehicle auxiliary power unit or uninterruptible power supply (UPS).

27. A fuel cell stack system assembly according to claim 26, said vehicle auxiliary power units comprising a car, truck, boat, yacht, submersible, semi-submersible, or space vehicle auxiliary power unit.

28. A fuel cell stack system assembly according to claim 26, said uninterruptible power supply being a back up power supply or one that provides base-load power.

29. A fuel cell stack system assembly according to any of the preceding claims, wherein said at least one fuel cell is a solid oxide fuel cell.

30. A fuel cell stack system assembly according to claim 29, wherein said solid oxide fuel cell is an intermediate-temperature solid oxide fuel cell having an operating temperature of between 400-650 °C.

31. A fuel cell stack system assembly according to any of the preceding claims, said fuel for said at least one fuel cell being selected from the group consisting of: natural gas, LPG, automotive gas, automotive gasoline, methane, and town gas.

32. A fuel cell stack system assembly according to any of the preceding claims, when dependent upon claim 7, comprising a hot box enclosure defining within it at least first and second hot box volumes, said first hot box volume containing within it said enclosure, and said second hot box volume containing within it said reformer, said first and second hot box volumes being thermally insulated from one another.

33. A fuel cell stack system assembly according to claim 32 when dependent upon claim 12, said hot box enclosure additionally defining a third hot box volume thermally insulated from said first and second hot box volumes and containing within it said WGS reactor.

34. A fuel cell stack system according to either of claims 32 or 33, said at least first and second hot box volumes being thermally insulated from the exterior of said hot box enclosure.

35. A fuel cell stack system assembly according to any of the preceding claims, said enclosure being contained within a housing, said housing and said enclosure defining between them an in-use cool zone containing at least one additional component.

36. A fuel cell stack system assembly according to claim 35 when dependent upon any of claims 32-34, said hotbox being contained within said housing, said hotbox and said housing defining between them said in-use cool zone.

37. A fuel cell stack system assembly according to either of claims 35 or 36, said at least one additional component located in said in-use cool zone being selected from the group consisting of: system control electronics, power electronics, a pump, a fan, a blower, wiring loom, a control valve, water delivery system, heat recovery heat exchanger, condenser, air filter, and safety shut down equipment.

38. A fuel cell stack system assembly according to any of claims 35-37, said in-use "cool zone" having an in-use operating temperature of <80 °C.

39. A fuel cell stack system assembly according to claim 10, when dependent on claim 9, further comprising an expansion bellows to generate the steam supply, the expansion bellows being in thermal communication with the fluid flow between the reformer heat exchanger and the enclosure heat exchanger, the expansion bellows comprising a water inlet and a steam outlet.

40. A method of generating heat and electricity from fuel and oxidant, comprising operating a fuel cell stack system assembly according to any of the preceding claims.

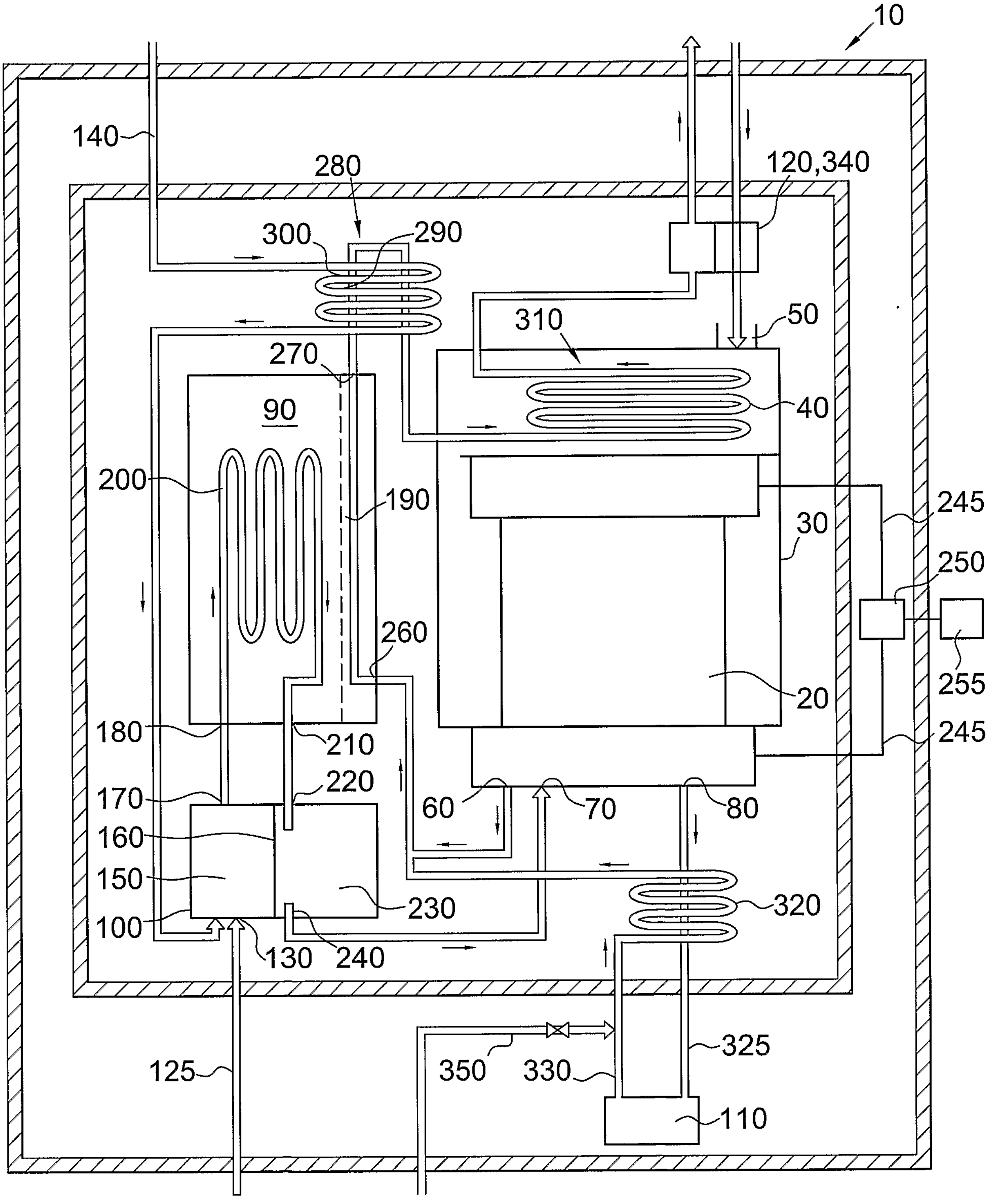
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Fig.1

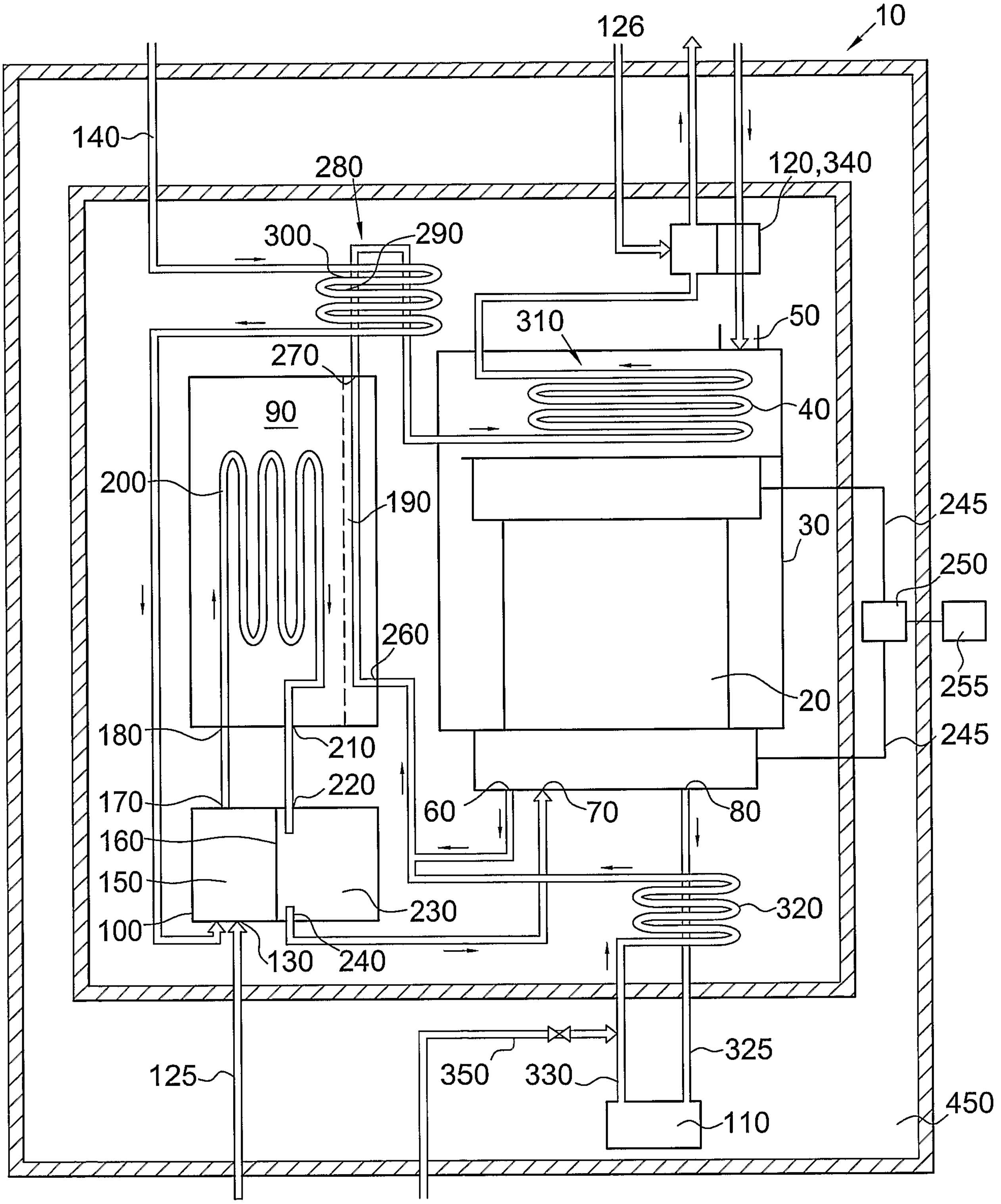
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Fig.1A

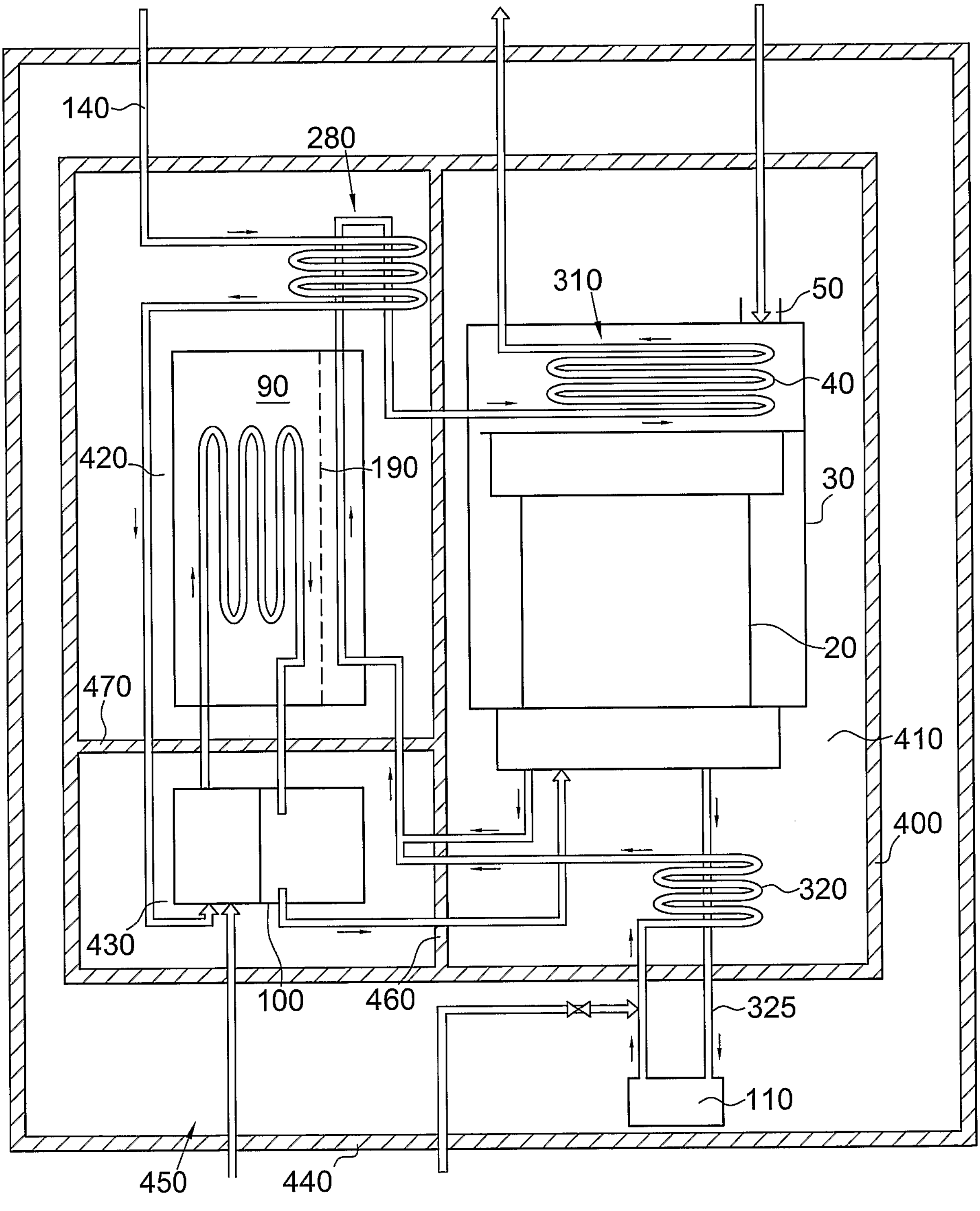
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Fig.2

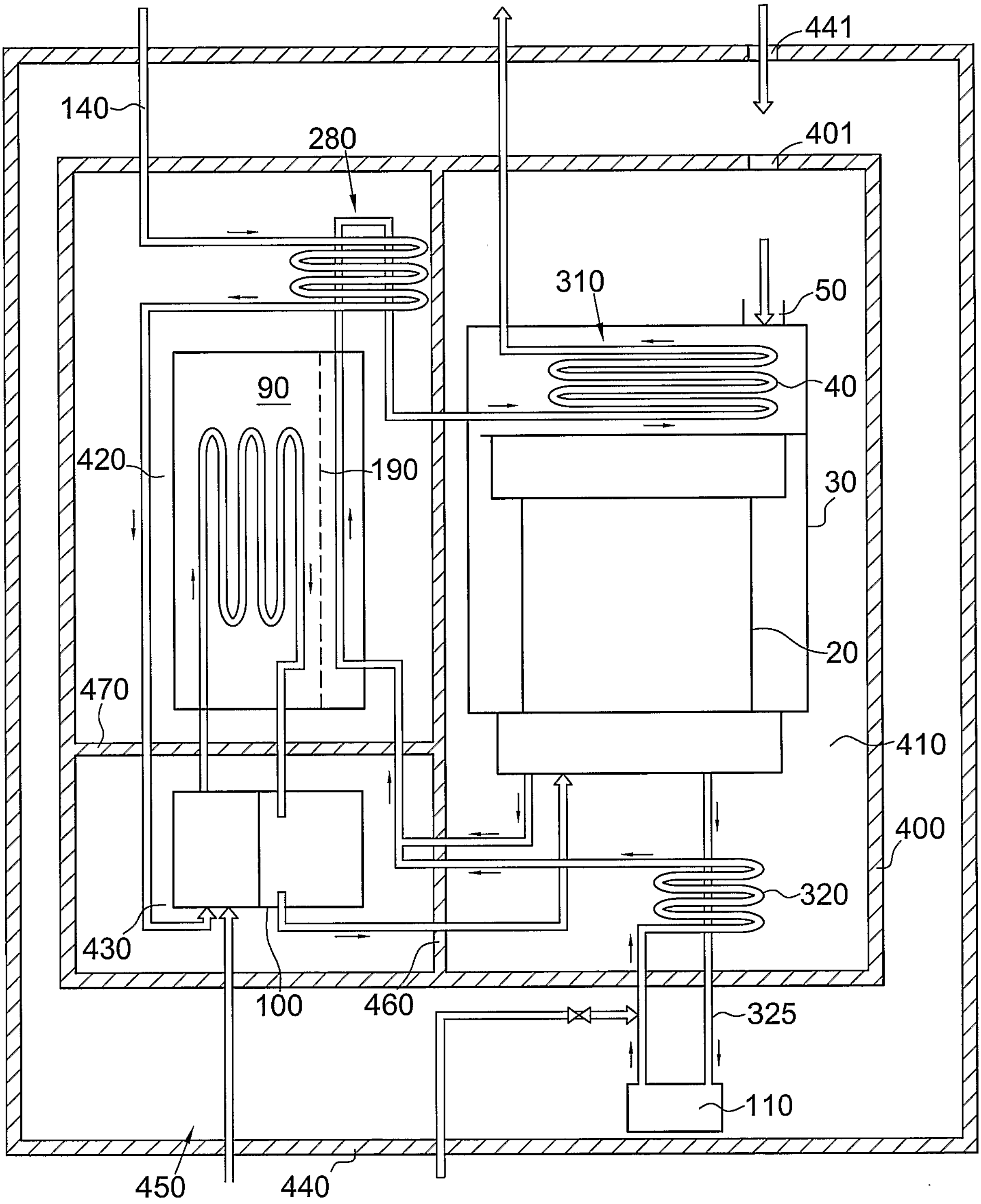
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Fig.2A

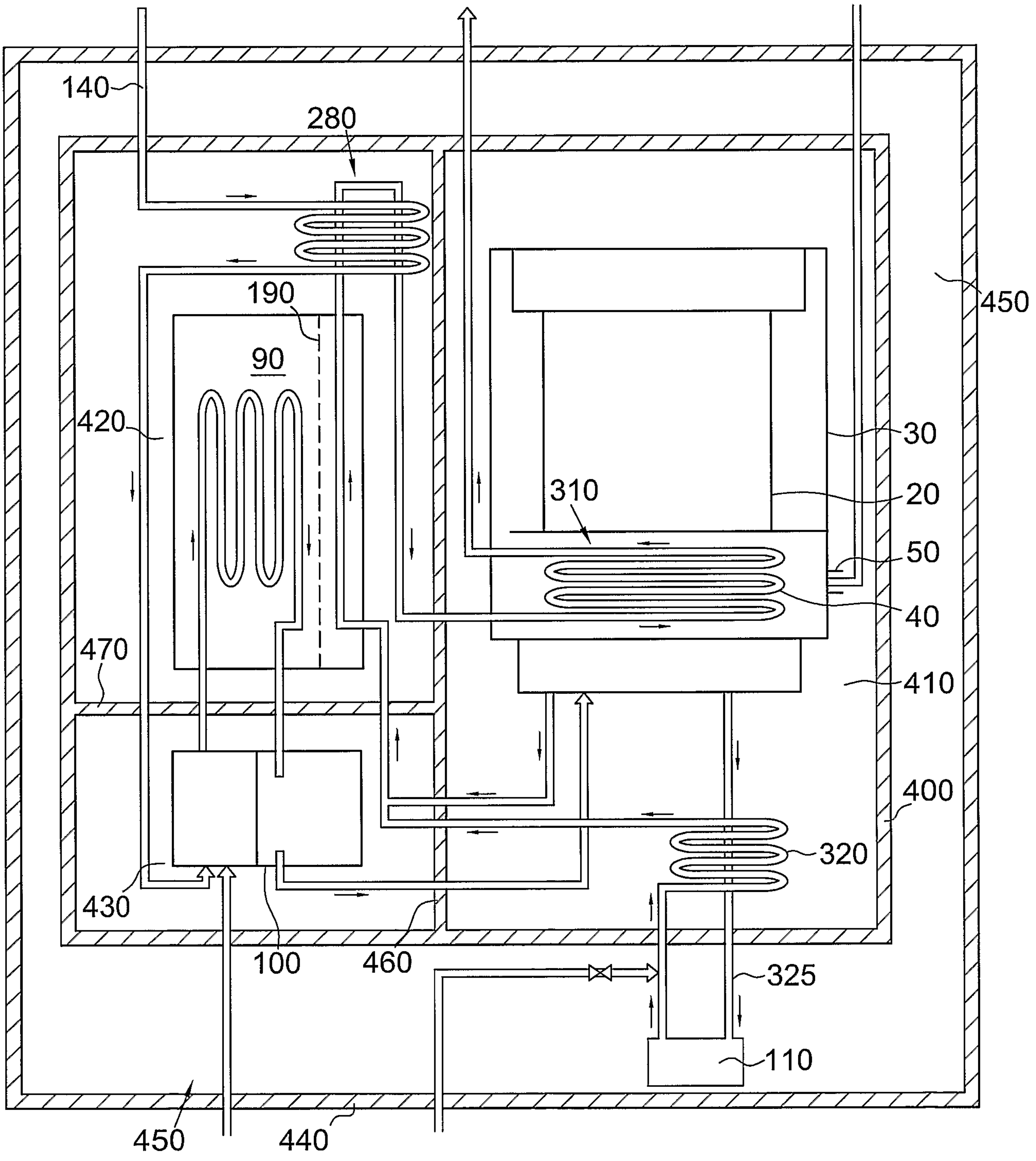
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Fig.3

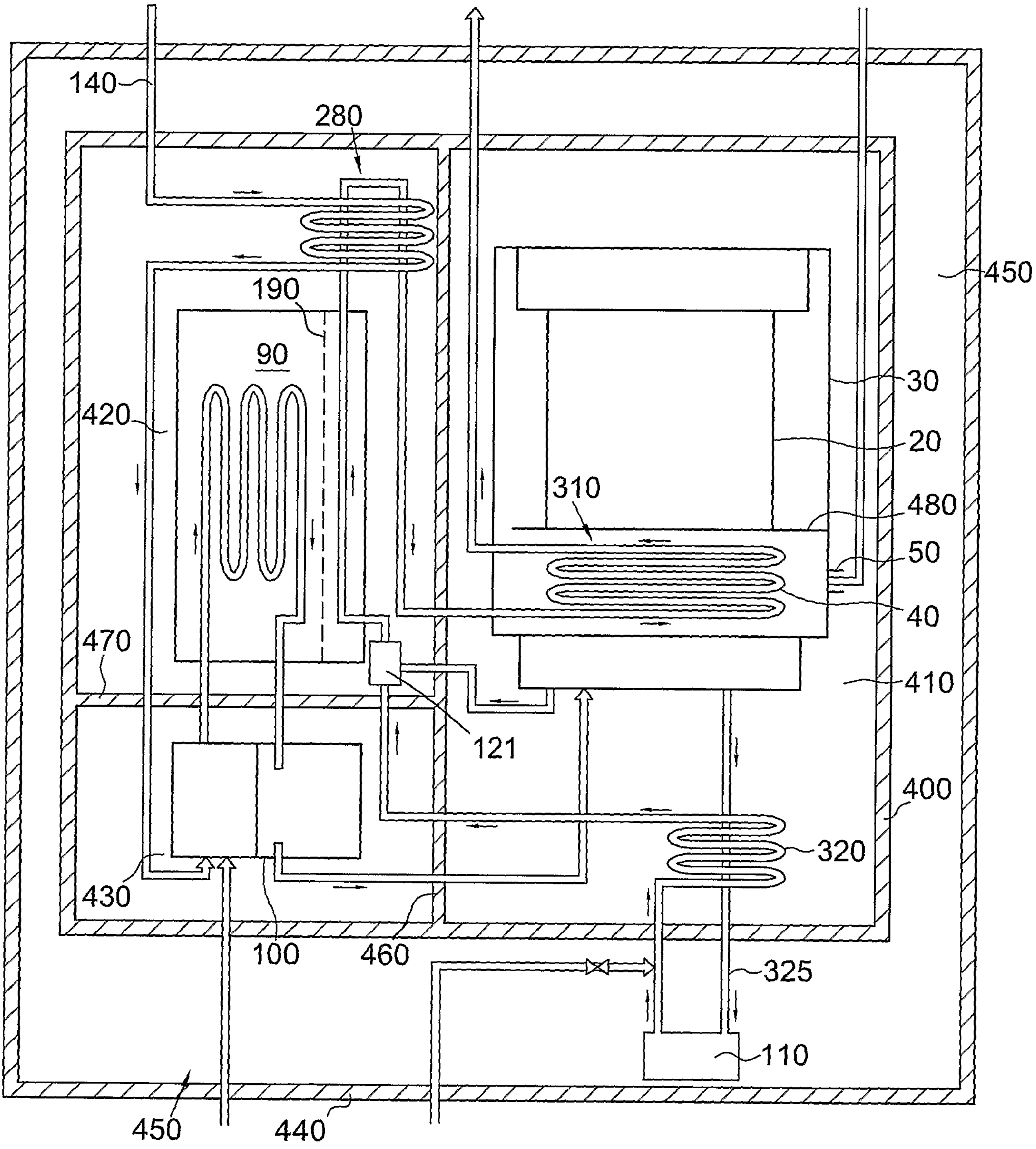
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Fig.3A

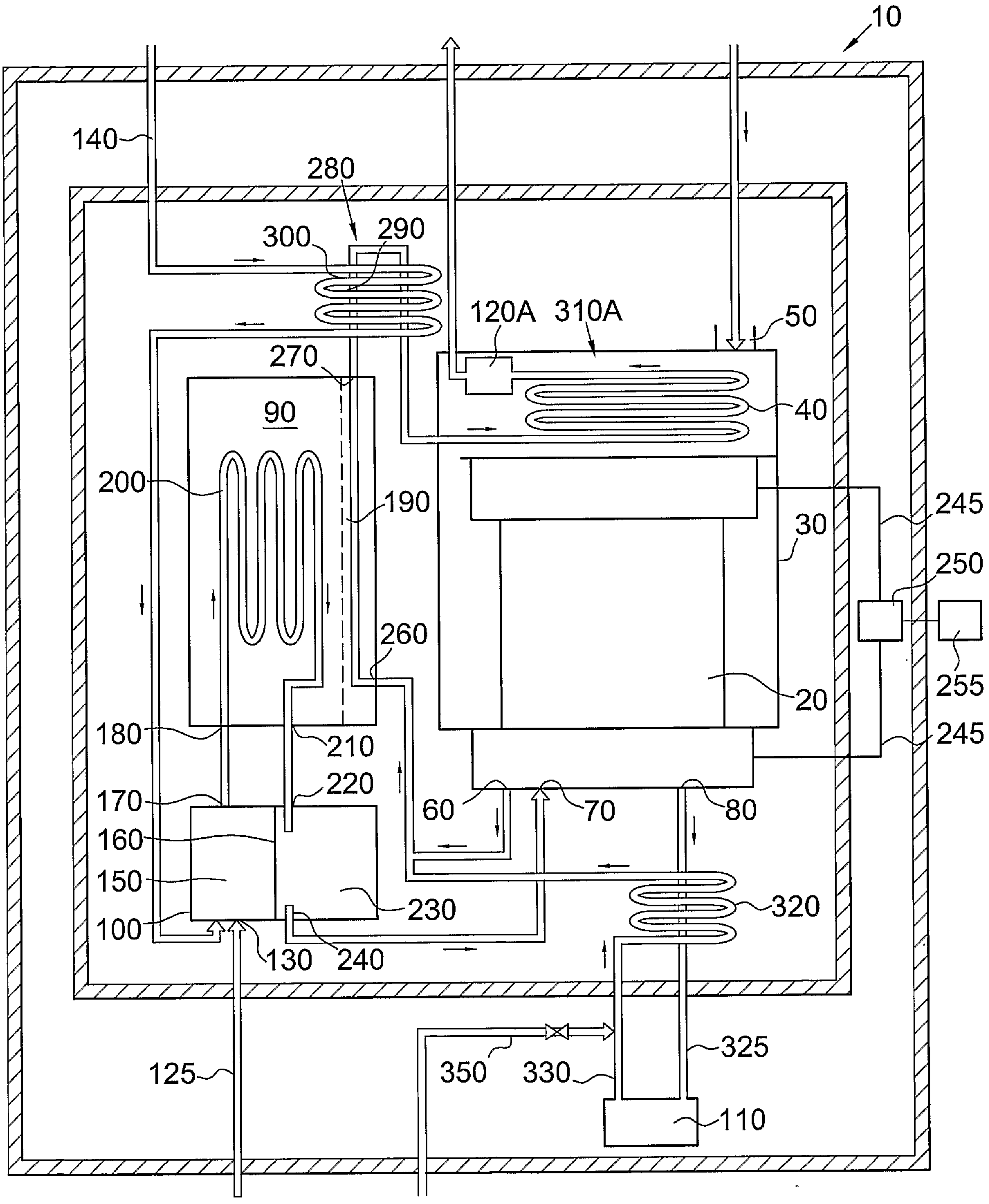
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Fig.4

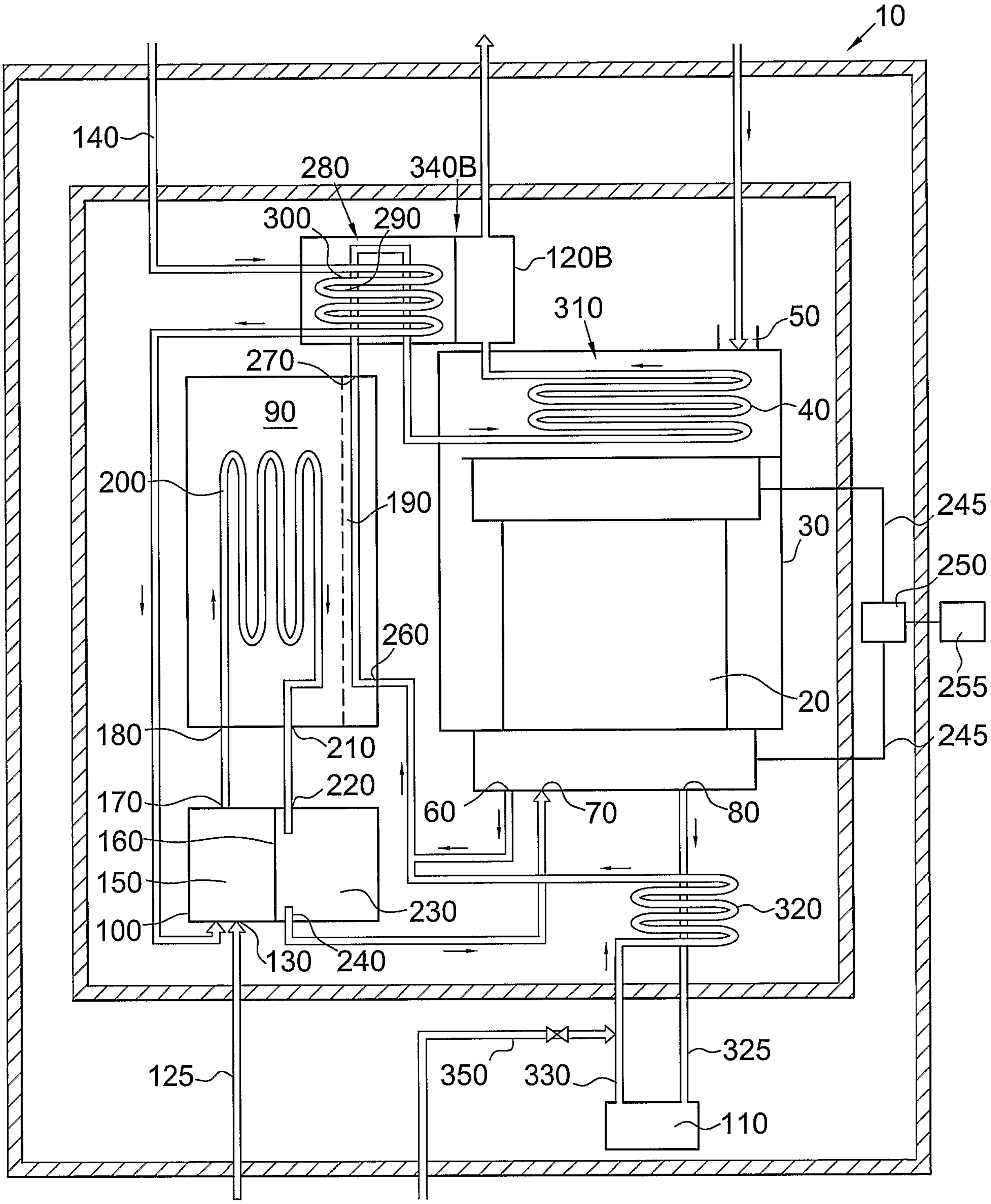
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Fig.5

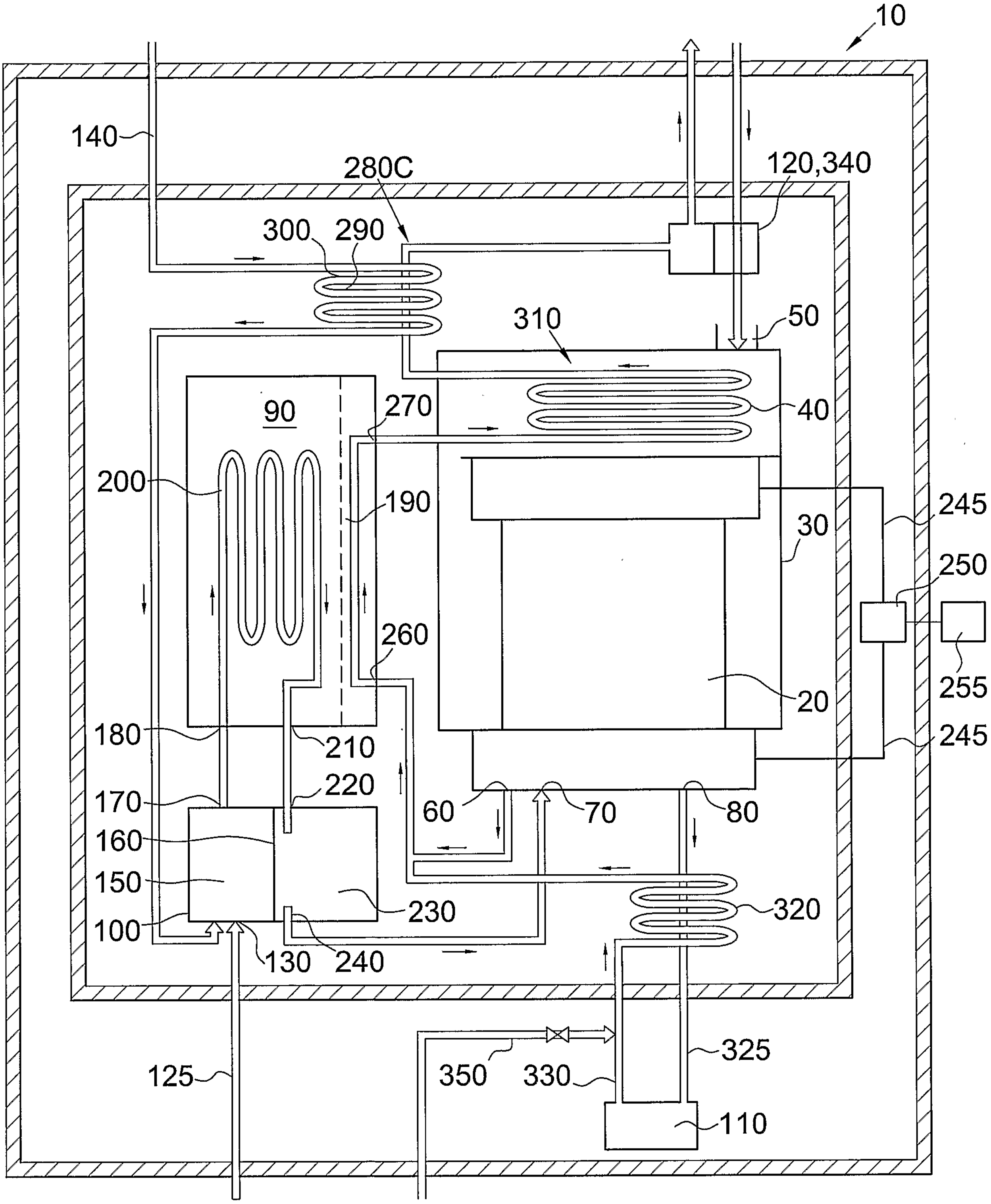
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Fig.6