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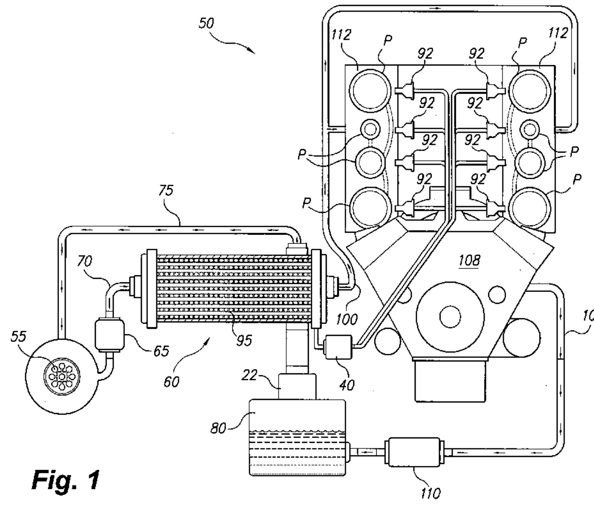

Fig. 1

(57) Abstract: The Rankine engine with efficient heat exchange system (10) provides a rapidly rechargeable thermal energy storage bank operably connected to a heat engine capable of propelling a vehicle (V). Microwave energy is supplied to the system via a network of waveguides (200). A thermal storage bank has slurry (S) in a heat exchanger (60) capable of sustaining operation of the engine without requiring the microwave source (55). The slurry (S) provides a mixture of powdered stainless steel and silicone oils functioning as the working fluid in the hot side of the heat exchanger (60). The slurry (S) may be heated by plugging the system into standard AC power for a predetermined microwave heat charging duration. A closed, triple-expansion, reciprocating Rankine cycle engine capable of operating under computer control via a high pressure micro-atomized steam working medium is provided to propel the vehicle (V).

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RANKINE ENGINE WITH EFFICIENT HEAT EXCHANGE SYSTEM

TECHNICAL FIELD

The present invention relates to heat exchangers, and particularly to a Rankine engine with an efficient heat exchange system that may be used, e.g. to power a vehicle without expending non-renewable fuel (i.e., traditional fossil, alcohol, hydrogen, soy or agriculturally based, etc), to power the engine.

BACKGROUND ART

Chemical energy in the form of batteries has been used since the dawn of automotive history for storage of electrical energy required to operate the automobile. Modern hybrid automobiles use the rechargeable energy storage system (RESS) with a small diesel or gas engine to turn electrical generating equipment and battery banks. However, batteries are not an optimal energy storage solution due to their poor charge time to discharge ratios and their toxicity upon disposal.

Microwave radiation has proven to be efficient at heating powdered metals in the sintering process, since powdered metal offers minimum reflectivity. Certain stainless steel alloys exhibit tremendous heat capacity, nearly that of water. Powdered metal in oil, another semi-viscous media, to produce slurry may provide a substantial improvement over current thermal energy storage technology because microwave energy is capable of heating the permeable powdered metal / silicone oil or similarly engineered heat retentive slurry in minutes, instead of the hours and significant expense of battery recharging.

The ability to charge the working fluid of a heat exchanger in minutes instead of hours charging and maintaining/exchanging/replacing batteries may be highly appreciated as current technology hybrid vehicle accrue mileage and extended usage in the real world environment.

Recharging locations may become as universal as current refueling stations. Thermal energy storage is an ideal scenario from an energy usage standpoint, and a direction that is currently and technologically practical to explore.

Thus, a Rankine engine with efficient heat exchange system solving the aforementioned problems is desired.

DISCLOSURE OF THE INVENTION

The Rankine engine with efficient heat exchange system has a rapidly rechargeable thermal energy storage bank operably connected to a heat engine capable of propelling a vehicle. Microwave energy is supplied to the system via a network of waveguides.

The thermal storage bank comprises a slurry in a heat exchanger capable of sustaining operation of the engine without requiring constant powering of the microwave source. The slurry provides a mixture of a compressed powdered metal / ceramic matrix and silicone oils / heat retentive viscous media functioning as the working fluid in the hot side of the heat exchanger. The slurry may be heated (thermally enabled) by plugging the system into standard AC power for a predetermined microwave charging duration.

A closed, highly insulated, triple-expansion, reciprocating Rankine cycle engine capable of operating under the computer control via a high pressure micro-atomized steam working medium is provided to propel the vehicle. A variety of working fluids are capable of powering the Rankine cycle engine.

These and other features of the present invention will become readily apparent upon further review of the following specification and drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a diagram of a Rankine engine with efficient heat exchange system according to the present invention.

Fig 2A is a partial diagrammatic sectional view of heat exchanger internal components of the Rankine engine with efficient heat exchange system according to the present invention, showing general layout of components and internal geometric configuration of the assembly.

Fig 2B is a partial diagrammatic sectional view of heat exchanger components of the Rankine engine with efficient heat exchange system according to the present invention exchanging heat and producing working gas during operation of the engine.

Fig. 3 is a diagrammatic top view of an automobile equipped with a Rankine engine with efficient heat exchange system according to the present invention.

Fig. 4 is a diagrammatic view of an enroute charging system for a Rankine engine with efficient heat exchange system according to the present invention.

Fig. 5 is a perspective view of the Rankine engine with efficient heat exchange system according to the present invention.

Fig. 6 is a partial, side cross-sectional view of the heat exchange system according to the present invention.

Fig. 7A is a diagrammatic view of an airfoil for exemplary geometric purposes.

Fig. 7B is a diagrammatic view of a chamber of a pressure exchange system used with the Rankine engine with efficient heat exchange system according to the present invention.

Fig. 8A is a diagrammatic view of a plurality of the chambers shown in Fig. 7B.

Fig. 8B is a cross-sectional diagrammatic view of a contra-rotating triple layer cylinder of the pressure exchange system.

Fig. 9 is a side, diagrammatic view of the pressure exchange system.

Fig 10 is a partial diagrammatic sectional view of an alternative embodiment of the heat exchanger internal components of the Rankine engine with efficient heat exchange system according to the present invention, showing general layout of components and internal geometric configuration of the assembly.

Similar reference characters denote corresponding features consistently throughout the attached drawings.

BEST MODES FOR CARRYING OUT THE INVENTION

As shown if Figs. 1, 2A and 2B, the present invention relates to a Rankine engine with efficient heat exchange system having a quickly rechargeable thermal energy bank with a slurry **S** circulating through an energy storage heat exchanger **60**, wherein the slurry **S** can be rapidly heated by electromagnetic energy in the form of microwave heating. The microwave energy may be supplied to the system via a network of waveguide/heat exchange gasifier tubes **200** and waveguide interconnections **205a** and **205b**.

The microwave source may include, but is not limited to, at least one magnetron tube **55** that can be coupled to the waveguide network at waveguide interconnection **205a**. The magnetron **55** can be charged by time/distance of operation desired, i.e., a commuter trip may be estimated for travel time or calculated by GPS for distance. Under computer control, a high pressure fed-finely atomized working fluid dispersed tangentially into a favorable low pressure environment created and enhanced through velocity / pressure trade-off enabling geometry heat exchanging gasifier tubes ensuring a minimum amount of stored thermal energy be drawn from the system under normal operation regime to achieve the trip with safety reserve. Since the magnetron(s) **55** may be a part of the onboard system **50**, thermal recharging stations could be located conveniently at place of employment or popular destinations, enroute smart-rail recharging, as well as regenerative braking in a feedback loop. The ability of the magnetron **55** to deliver the energy quickly precludes time and energy consuming recharging periods.

The thermal energy storage of a slurry **S** in heat exchanger **60** can sustain operation of a Rankine cycle engine **108** to operate a vehicle for extended periods of time without a constant or direct connection to an electrical power grid, while retaining the potential to be quickly and conveniently recharged enroute if necessary.

The slurry **S** is an engineered slurry comprising, for example, highly refined micro-powdered stainless steel and finely powdered ceramic materials in a viscous or semi-viscous mixture combined with silicone-based oils or in combination with other suitable materials of high heat capacity such as clays or salts which may repeatedly absorb, retain, and disperse the waveguide supplied microwave energy. Heat retentive viscous fluid, of high heat capacity, such as a silicone based oils, or aforementioned engineered slurry is capable of functioning as the thermal energy supply fluid in the hot side of the heat exchanger **60**. Some degree of viscosity is preferred in the engineered slurry **S** so that the slurry **S** can be slowly pumped through or directly heated by the permeable matrix containing the waveguide connections in order to bring it up to (and maintain for extended periods) the maximum possible storage of heat energy (without significant outgassing). The viscous nature of the slurry is ideal for maximum heat transfer to the working fluid, while limiting deleterious oxidation events to the primary matrix. Liquid ceramics, liquefied metals, clays, or salts may be used in place of silicone oils as the optimum engineered thermal energy retention fluid. The stored thermal energy produces the last percentage of conversion of the pre-heated engine working fluid (preheated by first circulating, via preheat line **105b**, proximate the slurry in heat exchanger **60**) to the working gas as produced in the changing cross-section tubes **95** of heat exchanger **60**. The cross-sectional geometric change is intended to facilitate the vapor phase transformation through localized reduction of withdrawn thermal energy requirements from the thermal reservoir.

Insulation is provided in order to maintain the slurry **S** at sufficient temperature to effect the conversion, and can comprise a plurality of layers of zirconium applied by plasma-spray process, over which several inches of ceramic-based insulation could be applied. Vacuum chambers, other thermal barriers, etc., may be introduced into the layers of insulation in order to reduce radiated heat from the entire device to a negligible level.

Preferably the heat exchanger **60**, including gasifier tubes **95**, is constructed primarily of an austenitic nickel-base superalloy, such as Inconel®, or other typically high temperature-resistant material, high-nickel content, superhigh performance alloy, such as Hastelloy® or the like, capable of withstanding the long duration elevated temperatures of the slurry **S**. The heat exchanger operates to draw thermal energy from the heated slurry **S**, which may be either thermosiphoned or, alternatively, may be mechanically pumped across a plurality of shaped diffuser tubes **95**. The advantage of the powdered metal or permeable powdered metal / ceramic matrix coincident to the slurry **S** is the ability to be heated almost instantly to extreme temperatures by the supplied microwave energy. Powdered materials absorb microwave energy readily, as they display huge cumulative surface area and low coefficients of reflectivity. The engineering of a strategically positioned permanently permeable matrix composed of a mixture of compressed powdered materials, both ceramic and metal based, provide sufficient waveguide conductivity to repeatedly heat within a near percentage of solidification/coalescence, while retaining capability of efficient heat transfer to slowly circulating heat retentive slurry.

The quantity of slurry **S** in the base of the heat exchanger **60** is sufficient to ensure adequate thermal energy transfer in order to operate the engine **108**, which is capable of operating via a high pressure micro-atomized steam working medium. The slurry **S** may be heated by plugging the system into standard AC power for a predetermined heat-charging duration, or, alternatively, by utilizing an enroute rail charging system while the vehicle is on the road.

As shown in Fig. 3, the Rankine engine with efficient heat exchange system comprises on-board microwave generator **55** (OBMWG) connected to the heat exchanger via waveguide interconnection **205a**. High temperature slurry pump **65** slowly pumps the slurry S via slurry supply line **70** through "hot" side of heat exchanger **60**. The slurry **S** recirculates back to the slurry pump **65** via slurry return line **75**. In actual practice, the slurry reservoir and the heat exchanger can be most efficiently constructed and thermally insulated as a single integral unit.

As shown in Figs 2A –2B, the waveguide interconnection **205A** in the heat exchanger **60** joins an enclosed, circular, heat transfer / waveguide continuation tube **200** that is disposed concentrically within the internally hourglass shaped gasifier tube **95**. Tube **200** acts as a central conductor of thermal energy, an axis about which the finely atomized working fluid is dispersed. Atomized working fluid is thusly exposed to the maximum possible area of heat exchanger wall surface area to promote efficient heat transfer.

There may be plurality of such gasifier tubes **95** disposed adjacent to each other within the heat exchanger **60**. The gasifier tube **95** is configured so that the engine-driving work fluid is kept isolated from the slurry S. The working fluid powering engine **108** may be a variety of formulation, including, but not limited to, pure water, a recapturable refrigerant, such as ammonia or Puron and the like.

Disposed inside the central heat absorption / transfer tube **200** is a continuation of the waveguide charged permeable powdered metal and ceramic matrix member **202**. As shown in the section drawing of fig 2A, the central conductor of the heat rejection tube **200** interconnects the two wall-adjacent portions of the tube **200** in the section drawing. In actual practice, the matrix **202** extends about the entire circumference of the changing cross-section gasifier tube. Preferably, member **202** is capable of high electromagnetic energy absorption, while encountering minimum reflection from the waveguide charged by magnetron **55**. Members **202** may also remain capable of repeated extreme thermal cycling without significant degradation of material properties, such as permanent permeability, in order to act as an efficient conduit for thermal energy introduced into the entire slurry S.

Microwave energy conducted through the absorption tube **200**, effects a conversion of EM energy into thermal energy, rapidly heating anything in contact with, or inside, the tube **200**. The tube **95** has a plurality of perforations or slotted opening **97** through its outer walls **232**. The slotted openings **97** allow slurry S circulating thought the heat exchanger **60** to enter, remain, and gradually flow within the central heat absorption / transfer tube **200**. Since the slurry S has a directional flow (imparted by slurry pump **65**) from the integral slurry reservoir through the heat exchanger gasifier tube section **60** to the opposite end of the heat exchanger **60**, slurry S circulates throughout tube **200** and will flow directionally through absorption tube **200** until it can escape back to the common reservoir of heated slurry through the slotted openings **97** on the opposite side. This slow directional flow of high heat capacity slurry in constant contact with the walls of the gasifier enables the maximum amount of thermal energy dispersal into the regime of the highly atomized working fluid. Slurry S that flows through the heat absorption tube **200** in this manner may be initially heated and then remain heated for extended periods to temperatures between 1100 C to 1300 C (the maximum temperature remaining below sintering threshold, whereupon the slurry charging matrix may coalesce into a solid, losing some degree of it's desired permeability, E-M energy absorption capability, and further, the ability to transfer heat to the slurry). Inconel® 718 or higher temperature capable grade superalloy is the preferred material for gasifier tube **95** construction, as it maintains sufficient structural integrity to house the powdered metal and ceramic matrix at or near sintering temperatures, while repeatedly performing it's role as a structured enclosure of geometry as a gasifier.

Microwave radiation has proven to be highly efficient at heating powdered metals. Thus, the powdered metal suspended in silicone oils offers the ability to flow through a heat exchanger and transfer heat energy to the diffuser tube, while minimizing outgassing, and can be maintained in a vacuum to improve retention of thermal energy, while limiting oxidation. It is contemplated that the slurry **S** can retain these temperatures for a considerable duration once the microwave energy is removed from the waveguide.

Referring again to Fig. 3, working fluid originates in reservoir **80**, which is connected to the working fluid supply high pressure pump **85**, which, in turn, has an output connected to the heat exchanger **60**. As shown in Fig. 2B, high pressure pump **85** has a manifolded output, which connects to a pair of atomizer nozzles **210a** and **210b** disposed tangentially within opposing sidewalls **232** of each one of the gasifier tubes **95**. The pump connection places atomizer nozzles **210a** and **210b** (and all succeeding nozzles plumbed in a plurality of gasifier tubes) in a commonly manifolded arrangement connecting to a pressure regulator **215** having return line **216**, and back to reservoir **80**. The output line of atomizer **210b** in fig 2A can be connected to a manifold capable of feeding the high pressure working fluid to remaining pairs of atomizers **210a** and **210b** in remaining gasifier tubes **95**, which comprise the working fluid portion of the heat exchanger **60**.

As shown in Figs 2A-2B, the atomizers **210a** and **210b** are disposed in a region of sidewalls **232** above the lower conic section of the gasifier tube **95**. The atomizers **210a** and **210b** may, alternatively, be disposed in the conic portion of the gasifier tube **95** at or below the geometric transition of the gasifier tube **95**, the location depending primarily on region of pressure gradient advantage. Moreover, the nozzle orientations of atomizers **210a** and **210b** are preferable non-coplanar with respect to each other. The non-coplanar orientation of the atomizers **210a** and **210b** may be provided to facilitate a spiraling action of working fluid finely atomized spray/steam around central coincident conductor tube **200**, to maximize the time in contact with the highest temperature regime of the gasifier tube.

During motor (non-charging) operations of the device **50**, the combination of the high thermal energy of slowly circulating slurry **S** in gasifier tube **200** and pressure differential created by Bernoulli tube **95** acting upon the spray mist of working fluid ejected from the atomizers **210a** and **210b** creates a rapid phase change of the working fluid from liquid phase to a steam/vapor phase. The steam/ working gas can be manifolded from the gasifier tubes **95** by a computer controlled ingress/egress output manifold that takes working gas from the dome of the heat exchanger and feeds a high pressure steam output line **100**. In this way, the working gas can be momentarily stored during periods of deceleration or braking of the vehicle, and a recirculation valve may be employed to reheat or superheat unused or underutilized output working gas. The high pressure steam in output line **100** is ultimately fed to the engine **108**. While the engine **108** can be a variety of designs, including but not limited to, a turbine engine or the like, preferably, the engine **108**, as shown in Fig. 1, has a closed, triple-expansion, reciprocating configuration utilizing a Rankine cycle to do work based on adiabatic expansion of the working medium in the engine **108**.

The system in engine **108** may be open if water is used as the working fluid, or completely closed (sealed) if a suitable convertible fluid is used that can be recaptured indefinitely (Freon/Puron). As shown in Fig 1, the engine **108** is a V-8 configuration, having opposing cylinder head **112** and opposing cylinder bores disposed therein (and within the cylinder block of engine **108**). Designated as **C1**, **C2**, and **C3**, cylinders **C1** have a low volume, high pressure bore, Cylinders **C2** have a medium volume, medium pressure bore, and Cylinders **C3** have a high volume, low pressure bore. Thus, the configuration offers increasing bore and/or stroke in opposed pairs. The high pressure steam output line **100** connects to the first set of bores **C1**. The **C1** (high pressure) bores may incorporate additional waveguide-fed matrix and slurry locations integral to their chamber heads in order to effect / promote and sustain superheat status of certain eligible working fluid(s) in closest mechanical proximity to the expansion phase.

As shown in Fig. 1, the **C1** bores have insulated steam outlet ports connecting to the **C2** bores, and the **C2** bores have steam outlet ports connecting to the **C3** bores. Under electromechanical and/or computer control (e.g., computer and electronically controlled square-wave pulse-activated high degree-of-atomization nozzles, in combination with mechanically controlled cam-action poppet valves), when pistons **P** in the **C1** bores have completed a power stroke, intermediate pressure steam is permitted to escape via steam outlet to drive pistons **P** in the **C2** bores. Subsequently, when the pistons **P** in the **C2** bores have completed their power stroke, lower pressure steam is permitted to escape via steam outlet to drive pistons **P** in the **C3** bores, and when pistons **P** in the **C3** bores have finished their power stroke, the low pressure work medium is exhausted to return line **105a**. Basic aspects of the triple expansion engine **108** have long been understood by those of ordinary skill in the art.

As is known by one of ordinary skill in the art, the reciprocating motion of the pistons **P** is transmitted to a crankshaft, which ultimately powers differential **310** for rotational motion of the vehicle wheels. The precisely controlled timing of steam power through reciprocating engine **108** is accomplished by a set of electrical solenoid or variable timing camshaft actuated poppet valves **92** connected to computer **40** via control lines **91**. Common, split, or multiple camshafts can control the entire poppet valve inlet and egress system, which may incorporate methods of variable timing of poppet valve events to achieve localized performance enhancements, such as may be offered by these variations.

As shown in Fig. 3, the return line **105a** is routed back to the heat exchanger **60** where the medium can be preheated for another cycle of flow through the heat exchanger **60**. The preheated working medium is then routed via line **105b** to condenser **110**. Output of condenser **110** is routed via continuation of line **105b** back to the reservoir **80**. The control computer **40** has a control connection to the heat exchanger **60** in order to precisely control atomization flow (typically square wave pulse width) provided to the atomizers **210a** and **210b**, as well as to perform other functions related to functions of the heat exchanger **60**.

The atomizers **210a** and **210b** are controlled by computer **40** so that only the minimum necessary amount of working gas is produced based on real-time evaluation of current need (throttle position versus load calculation). Producing the gas near-instantaneously on a need-only basis allows for significantly reduced consumption of the thermal energy stored in the slurry. Computer **40** can accept inputs from a variety of sensors disposed in the system in order to make the executive command decisions required to achieve the objective of the on-demand vapor/steam supply.

Preferably, computer **40** is a digital convertible fluid injection (DCVI), and is capable of accurately addressing the pulse width of the liquid atomization nozzles **210a** and **210b** in the heat exchanger **60**, as well as the pulse width of the solenoid operated poppet valves **92** in the inlet of engine **108**. For example, computer **90** can take a reading of the exhaust gas pressure and temperature, and loop it back to the gas-producing nozzle pulse width. Hence, the device is both load and demand (acceleration or deceleration) sensitive to real time.

Sensors could be added to read inlet (liquid) feed temperature and pressure (from feed pump), working gas temperature and pressure in the plenum/dome, load encountered, condition desired (accelerate/decelerate/stop/reverse), mean effective pressure in any of the cylinders (high/medium/low pressure) to vary the timing of poppet valve events through such mechanism as described (mechanical systems: multiple cams/articulating rocker arm stanchions/lobe advance or retard mechanism. Digitally controlled electrical systems may include solenoid-activated poppet valves). Precise event timing control (DCVI computerized nozzles, as well as poppet valve events) is desirable as the slurry **S** gradually and continuously loses temperature to the working fluid as the working fluid transitions to working gas. The longest range is available when only the precise and minimum amount of gas is produced to meet the load and condition requirements.

As shown in Fig. 4, in the case of enroute recharging, a buried smart rail conductor **405** that is basically flush with a road surface **R** may be utilized, either by direct contact (brush/roller) or by inductive coupling, to provide the electrical energy necessary to operate the microwave generator **55** or charge a supercapacitor to fire the magnetron **55** when desired onboard the vehicle **V**. The rail is segmented by insulation and can be powered by any existing power grid from which (preferably) rectified DC current can be obtained. Each segment can be fed by a solid state, e.g., transistor or SCR circuit, whereby the high current only flows to the particular segment when the associated gating circuit is energized.

The gate of each semiconductor can be actuated by an inductively coupled or otherwise induced discrete signal from the vehicle **V** directly above it, thereby allowing the smart rail **405** to remain safe from lethal contact with accidentally contact by humans, animals, or the like. Segments **405** may be of a length only sufficient for a conducting condition while the vehicle **V** needing the recharge is directly above it, thereby shielding the rail **405** from accidental contact. As such, rail segments **405** conduct only in response to an induced signal from above, which can come from several sources, such as a coil **410** inducting the trigger (gating) current, or an ultrasound device, or a laser signal, or any other device that can perform the task of momentarily (locally) charging the gate of a main power transistor or SCR, which connects the high current power grid to the segmented rail **405**, forcing it to conduct. Once the vehicle V has passed beyond a particular energized one of the segments **405**, the smart rail **405** returns to a nonconducting and thoroughly (safe) condition.

The smart rail **405** may be accessed to charge the on-board microwave generator (OBMWG) **55** directly, or to charge a supercapacitor that can store the charge and supply it to the OBMWG **55** whenever desired or necessary.

The signal that suggests the smart rail conductor **405** may eventually be capable of discrete operation, whereby the information of which distinct vehicle **V** is drawing power from the rail can be recorded and used for energy billing purposes. The smart rail system **405** allows a commuter the ability to access the smart rail **405** if in need of a recharge (and have the energy transfer recorded), or pass over it with no energy transfer.

The smart rail **405** may be an ideal enroute recharging mechanism for a variety of vehicles utilizing some form of electrical or chemical energy as a means of propulsion, and may be incorporated into existing highways while remaining unobtrusive, safe, and non-interfering with the operation of existing technology vehicles.

Fig. 5 illustrates heat exchanger **60** seated on top of the Rankine engine, as would be conventionally appropriate. High pressure gas **HP** is shown feeding out of the heat exchanger, with relatively low pressure gas **LP** feeding into the heat exchanger **60**. Magnetron tube **55** is shown positioned at the front of the engine block. Fig. 5 is, essentially, a perspective view of the diagrammatic view of Fig. 3, applied to a conventional engine, as may be used in an automobile.

The heat exchanger **60** is similarly shown in further detail in Fig. 6, as may be applied to an actual automobile engine, including the various elements described in detail above, such as atomizers **210a** and **210b**, a high pressure tank **300**, the permeable matrix **310** and slurry S.

In an alternative embodiment, pressure exchange may be performed in the Rankine cycle engine through the usage of wave rotors. Wave rotors are typically rotating drums in close fitted housings with a plurality of axial grooves which are located as to periodically index with ports located on both end housings. These devices are conventionally used to transfer energy by allowing the groove to fill from the medium pressure side and, after some degree of rotor rotation and port re-indexing, to be exposed to high pressure exhaust gas, which then pressurizes the medium pressure gas in the axial cells (while undergoing some unavoidable mixing of gases at the interface).

The unavoidable gas mixing occurs at the interface of the high pressure exhaust pulse or driver fluid, and the medium pressure, or driven fluid. Fluids may be redirected internally to provide enhanced scavenging, utilizing column inertia, behind which new medium pressure fluid is drawn into the device by way of the enhanced scavenging.

The alternative embodiment utilizes a rotating pressure exchange mechanism for the Rankine cycle engine. The supercharging of the internal combustion engine includes pressurizing the entire intake tract to some degree above ambient atmospheric pressure, using high pressure/high temperature exhaust gas to provide the energy. A wave rotor is provided to act as a rotating barrel valve to enable the interaction of fluids.

In Figs. 8A and 8B, all working fluids used with the Rankine engine are the same constitution, varying only in pressure and temperature. The pressure exchange occurs between stages of multiple expansion of the same gas, taking advantage of the passage of high temperature/high pressure working gas **HP** (of Fig. 5) on its way from the gas generator or heat exchanger **60**, as described above with particular regard to Figs. 1-3, to the high pressure/low volume cylinders, and utilizing that gas to add energy to the lower pressure gas **LP** shuttling to and between the multiplicity of low pressure/high volume cylinders. In this particular case, unavoidable gas mixing at the interface is negligible in terms of emissions, since the working gas in the Rankine cycle has no negative impact emissions to control.

Although typical wave rotors are relatively simple, straight axial channels formed on a drum, they only act as convenient chambers for the pressure exchange to take place, since their drum rotation is solely for the purpose of aligning the inlet and egress ports at proper intervals.

In Figs. 8A and 8B, the pressure exchange rotor provides additional qualities of energy addition to the driven gas by further addition of shear wave compression due to the devolving volume of chambers **340** formed in a contra-rotating triple layer cylindrical arrangement. Chambers **340** are formed with an accurate cross sectional contour similar to airfoil-type shapes as their side edges.

In Fig. 7A, as an example, an airfoil **AF** is shown. The left-hand side is labeled **A**, and the right-hand side is labeled **B**. If a cut is made (as indicated by the dashed line), substantially centrally therethrough, and the left-hand side and right-hand side are transposed, as shown in Fig. 7B, then chamber **340** is formed between sides **B** and **A**, respectively, with Fig. 7B being a cross-sectional side view.

As shown in Fig. 8A, a plurality of chambers **340** may be formed together, with these representing the cross-sectional views of the walls of a contra-rotating triple layer cylinder **350**, shown in Fig. 8B. Contra-rotating the central section **380**, formed between two pairs of side walls with respective **A** and **B**-type contours, with respect to outer shell **370** and inner shell **360** creates constantly devolving chamber geometry.

This particular geometry can be used for pressure exchange purposes as expanding high pressure working fluid **HP** forces rotation as the walls of the chamber are shaped to use airfoil shapes to transfer impinging gas energy into rotary motion. The system can be configured to incorporate rows of stator cells in between rows of devolving chambers, adding rotational torque output to the pressure exchange device.

In Fig. 9, pressure exchange system **400** utilizes such a contra-rotating cylindrical arrangement, where the high pressure fluid **HP** is fed into high pressure region **460** (via inlet **410**, formed through end plate **430**), and medium pressure fluid (**MP**) is output through outlet **420** (through end plate **440**). Low pressure fluid **LP** enters the pressure exchange region **480** via inlet **450**. The system **400** is rotated about a central shaft **500**.

In the above, medium pressure fluid **MP** can be admitted to one entire row of devolving cells, and high temperature/high pressure fluid **HP** admitted can be admitted to the row of devolving cells on the opposite ends from the stator **470**. The high pressure fluid **HP** is ducted through the stator **470** to impinge on the medium pressure fluid **MP** through rotationally indexing ports in the row of stator cells. Thus, both pressure exchange and useful rotational torque are produced in the Rankine cycle engine. The pressure exchange can be useful to the engine by making it perform well beyond the triple expansion process. Only a single chamber formed from one A-shaped wall and one B-shaped wall is shown in Fig. 9 for exemplary purposes. Fluid flow is shown exiting this chamber 340, within the impeller section **460**, and passing through intermediate nozzle plate **490**, stator **470**, into the pressure exchange region **480**, and then back to the impeller section **460**, following an airfoil-type path.

Shuttling is enabled by the ability to transfer working fluid to any low pressure cylinder of the engine at any time, regardless of crankshaft position. As described above, the low pressure poppet valves may be computer directed and solenoid actuated, and are not dependent on rotational position of a mechanical camshaft tied to piston position (crank rotation). This configuration enables usage of already created working gas to be utilized for significantly longer periods of time, undergoing reheat, pressure exchange, and multiple expansion to as many stages as the gas remains above condensation temperature, such as in light load cruise or deceleration.

With the highest R factor obtainable through usage of zirconia-based thermal barrier coatings and layers of frozen smoke insulation, extended range is provided by the economical use of stored thermal energy to convert the minimum (necessary) volume of ultrasonically atomized fluid into high temperature/high pressure working gas in the gasifier section of the heat exchanger **60**.

While Rankine cycle pressure exchange can be accommodated through straight or canted channel single row rotors, the ability to add a component of torque production through devolving chamber geometry adds a component of compounding to the engine's output torque. The wave rotor described above uses a relatively small component of torque to rotate itself to index the plurality of inlet and egress ports, and the contra-rotating devolving chamber triple layer system exchanges pressure, as well as adding usable torque to the device, by coupling to the crankshaft, without the necessity of adding a fuel or internal combustion component.

Under conditions of cold engine starting, or in regions of the performance envelope where additional heating may be required, an additional heating source may be used to transmit spot heating, similar to that used in conventional laser welding and cutting operations. In the alternative embodiment of Fig. 10, nozzles **210a** and **210b** (of Fig. 2A) are replaced by ultrasonic nozzles **211a** and **211b**, respectively. An industrial laser **213** or the like is in communication with ultrasonic nozzles **211a** and **211b** by fiber optic waveguides **217a**, **217b**, respectively, or the like.

Fiber optic waveguides **217a**, **217b** or the like direct a laser beam produced by laser **213** to each individual convertible vapor injection nozzle exit cluster **211a**, **211b**. Optical paths are preferably relatively straight, thus reducing potential losses through steering of laser energy, as would be the case with induced curvature of the beam path.

The nozzles **211a**, **211b** are preferably ultrasonic nozzles, which break up low viscosity working fluid into a pure fog. With this type of atomization, the microspherical droplet fog assumes that vaporization and phase change will occur within the least amount of time and with the minimal of thermal energy extracted from the highly insulated thermal energy bank.

Preferably, nozzles **211a** and **211b** are non-coplanar in displacement, thus highly atomized fog emitted therefrom swirls around the heated central conductor within the gasifier tubes. This swirling action is intended to increase the time the fog is within the highest temperature area of the gasifier, thus enabling heat absorption and subsequent transformation into a high temperature working gas.

Preferably, the ultrasonic nozzles **217a**, **217b** terminate in a specially engineered cluster of sintered nickel or ceramic permeable matrix, with this particular cluster containing specially formed internal truncations, in order to minimize backward flow of working gas throughout the system. Correctly formed sintered geometric changes in the nozzle discharge path can completely eliminate the need of a reed valve arrangement to preclude pressurized working gas traveling backwards in the system, which potentially inhibits flow-through of recirculated gas in the gasifier tubes. Pressure-velocity delta geometry is used throughout the entire system to direct flow without resorting to reed valving.

The nozzle exit cluster can be heated directly from the fiber optic output(s) **217a**, **217b** of the onboard auxiliary laser **213** when so instructed by the DCVI computer. Laser heating of the exit cluster reduces start-up times, as well as acts as an adjunct to high performance needs of the operator. Additionally, laser **213** may articulate through a small range of motion (as shown by the directional arrows) in order to eliminate any curvature whatever from the fiber optic transmission system. The minor articulation may be provided through a miniature gimbaled arrangement. Laser **213** may operate from the same energy source as the various electric feed and scavenge pumps in the system, such as a 36V Ni-Cad cell similar to that used in gas turbine helicopters, or a supercapacitor, for example. The battery can be kept recharged through any suitable method, such as a shaft or belt driven alternator, while a supercapacitor is preferably rechargeable by a smart rail system.

It is to be understood that the present invention is not limited to the embodiment described above, but encompasses any and all embodiments within the scope of the following claims.

CLAIMS

1. A Rankine engine with efficient heat exchange system, comprising:

a vapor phase change engine connected to vehicle propulsion means;

an energy storage heat exchanger;

a high operating temperature slurry capable of rapid heating under microwave energy exposure and being capable of retaining the high temperature for a substantial duration;

means for circulating the slurry in a closed loop within the heat exchanger;

a working fluid;

means for circulating the working fluid through the heat exchanger to pick up sufficient heat content from the slurry in order to change phase to a high pressure vapor/steam; and

means for directing the high pressure vapor/steam to an inlet of the engine in order to operate the engine;

whereby the vehicle can be propelled under vapor/steam power from stored heat energy in the slurry until the slurry temperature cools down to a temperature ineffective to cause the work fluid to vaporize.

2. A Rankine engine with efficient heat exchange system, comprising:

a vapor phase change engine connected to a vehicle transmission;

an energy storage heat exchanger operably connected to the vapor phase change engine;

a high operating temperature slurry capable of rapid heating under microwave energy exposure and being capable of retaining the high temperature for a substantial duration;

a slurry pump circulating the slurry in a closed loop within the heat exchanger;

a working fluid;

a working fluid pump circulating the working fluid through the heat exchanger to pick up sufficient heat content from the slurry in order to change phase to a high pressure vapor/steam; and

a high pressure steam output line directing the high pressure vapor/steam to an inlet of the engine in order to operate the engine;

whereby the vehicle can be propelled under vapor/steam power from stored heat energy in the slurry until the slurry temperature cools down to a temperature ineffective to cause the work fluid to vaporize.

3. The Rankine engine according to claim 2, wherein the microwave energy exposure comprises:

a microwave energy source proximate the heat exchanger; and

a waveguide network connected to the microwave energy source, the waveguide network guiding microwave energy from the microwave energy source to the slurry.

4. The Rankine engine according to claim 2, further comprising:

manifolded high pressure output lines extending from the working fluid pump; and

a plurality of gasifier tubes proximate the heat exchanger, the gasifier tubes receiving high pressure fluid from the manifolded high pressure output lines, the gasifier tubes outputting a rapid phase change of the working fluid from liquid to the high pressure vapor steam/vapor.

5. The Rankine engine according to claim 4, further comprising:

output manifolds disposed on the gasifier tubes; and

a computer operably connected to the gasifier output manifolds, the computer modulating the high pressure vapor steam/vapor to the engine inlet.

6. The Rankine engine according to claim 4, further comprising atomizers disposed within the gasifies, the atomizers atomizing high pressure fluid at the inputs to the gasifiers.

7. The Rankine engine according to claim 6, further comprising a plurality of waveguide continuation tubes disposed within the gasifier tubes, the continuation tubes centrally conducting thermal energy about an axis through which atomized working fluid is dispersed by the atomizers, wherein atomized working fluid is exposed to the maximum possible area of heat exchanger wall surface area to promote efficient heat transfer to the working fluid.

8. The Rankine engine according to claim 4, wherein the gasifier tubes are disposed in a housing of the heat exchanger.

9. The Rankine engine according to claim 4, further comprising a permeable powdered metal/ceramic matrix disposed within the heat exchanger and coincident to the slurry, the matrix accelerating the heating of the slurry when the microwave energy is applied.

10. The Rankine engine according to claim 4, wherein the gasifier tubes are made from a high grade, high temperature capable superalloy, the gasifier tubes maintaining structural integrity at sintering temperatures.

11. The Rankine engine according to claim 7, wherein a first atomizer within a gasifier tube is disposed in a non coplanar manner with respect to a second atomizer disposed in the same gasifier tube, the non-coplanar atomizers facilitating a spiraling action of working fluid finely atomized spray/steam around the central coincident conductor tube, thereby maximizing the time in contact with a highest temperature regime of the gasifier tube.

12. The Rankine engine according to claim 2, wherein the engine has a closed, triple-expansion, reciprocating configuration utilizing the Rankine cycle to do work based on adiabatic expansion of the working medium in the engine.

13. The Rankine engine according to claim 2, further comprising an engine control computer, the engine control computer controlling a set of inlet and outlet valves of the engine, thereby precisely controlling timing of steam power through the engine.

14. The Rankine engine according to claim 13, further comprising a control line forming an interconnection between the engine control computer and the atomizers, the engine control computer controlling the atomizers via the interconnection, wherein only the minimum necessary amount of working gas is produced based on real-time evaluation of current throttle position versus a load calculation computed by the engine control computer.

15. The Rankine engine according to claim 3, further comprising means for capturing electrical energy generated remotely from the vehicle, said energy capturing means powering the microwave energy source while the vehicle is on the road.

16. The Rankine engine with efficient heat exchange system as recited in claim 2, further comprising means for selectively optically heating the high pressure vapor/steam.

17. A Rankine engine with efficient heat exchange system, comprising:

a vapor phase change engine connected to vehicle propulsion means;

an energy storage heat exchanger;

a high operating temperature slurry capable of rapid heating under microwave energy exposure and being capable of retaining the high temperature for a substantial duration;

means for circulating the slurry in a closed loop within the heat exchanger;

a working fluid;

means for circulating the working fluid through the heat exchanger to pick up sufficient heat content from the slurry in order to change phase to a high pressure vapor/steam;

means for directing the high pressure vapor/steam to an inlet of the engine in order to operate the engine;

a pressure exchange system, the pressure exchange system including an impeller portion having opposed first and second ends, the first end being adapted for receiving high pressure working fluid, a stator, a pressure exchange portion having opposed first and second ends, the second end thereof being adapted for expelling medium pressure working fluid and receiving low pressure working fluid, the stator being sandwiched between the second end of the impeller portion and the first end of the pressure exchange portion;

whereby the vehicle can be propelled under vapor/steam power from stored heat energy in the slurry until the slurry temperature cools down to a temperature ineffective to cause the work fluid to vaporize.

18. The Rankine engine with efficient heat exchange system as recited in claim 17, wherein said pressure exchange system has a plurality of chambers formed concentrically therein, said plurality of chambers driving fluid through said pressure exchange system in a substantially airfoil-type path.

19. The Rankine engine with efficient heat exchange system as recited in claim 17, further comprising means for selectively optically heating the high pressure vapor/steam.

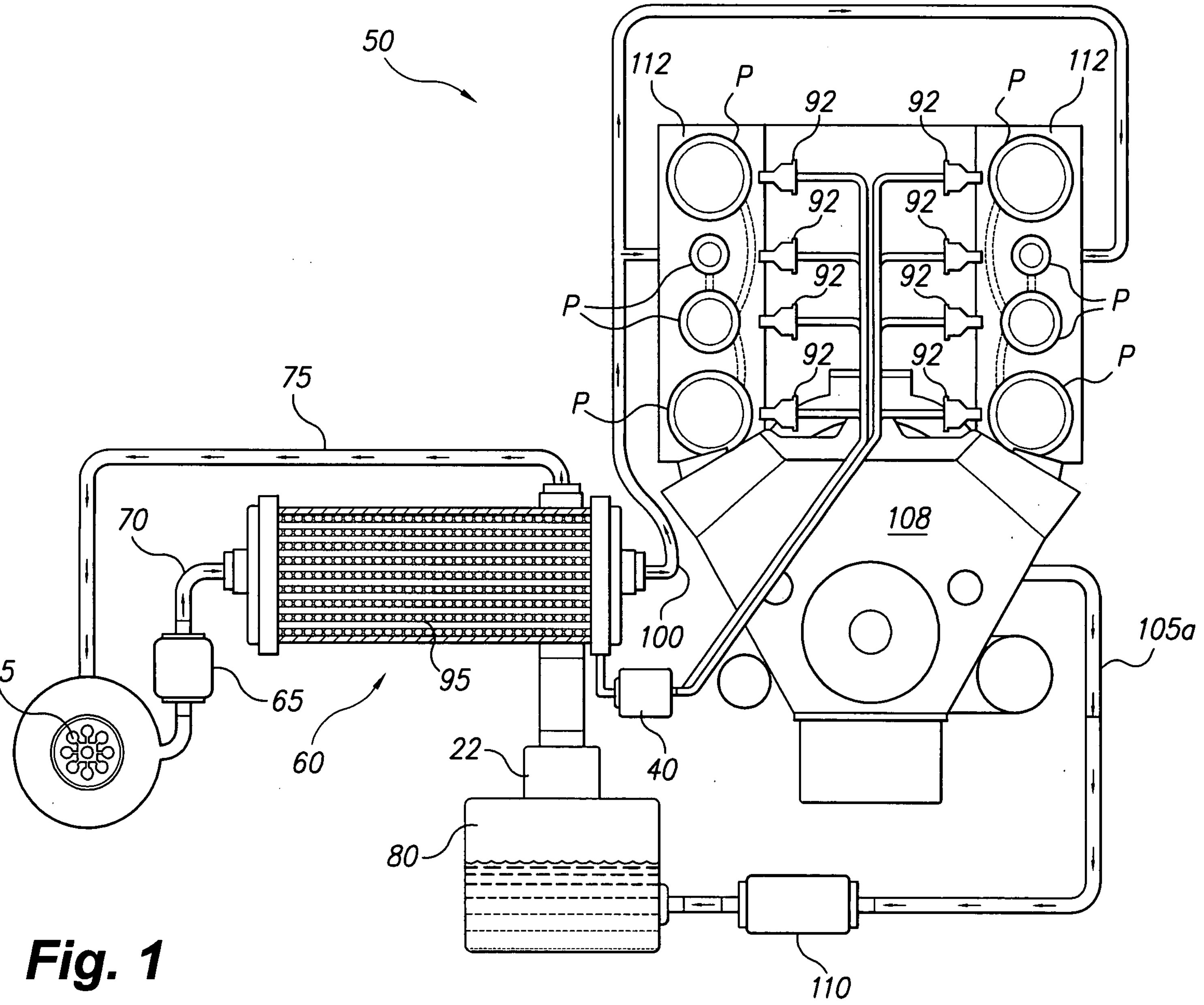
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Fig. 1

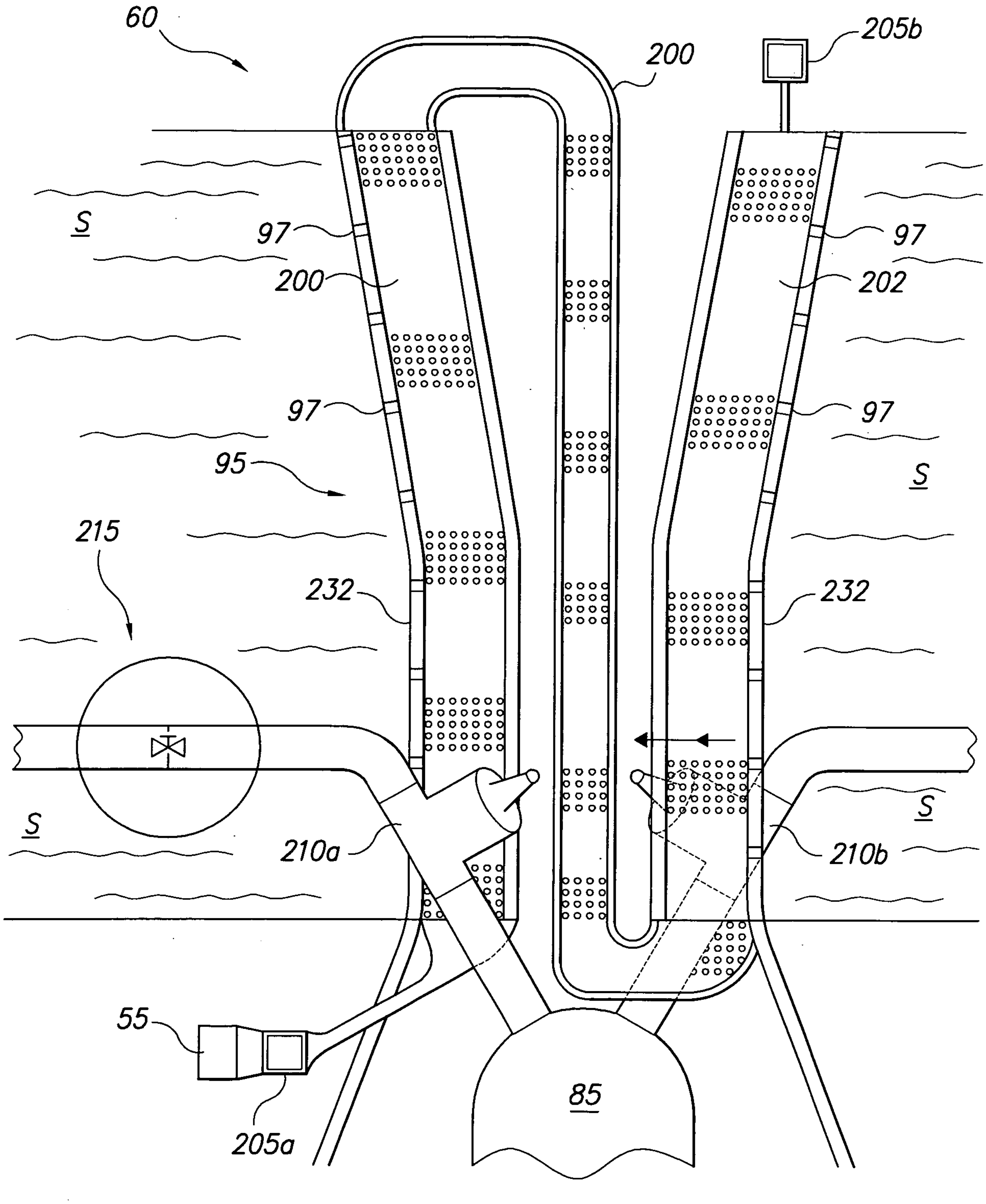
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Fig. 2A

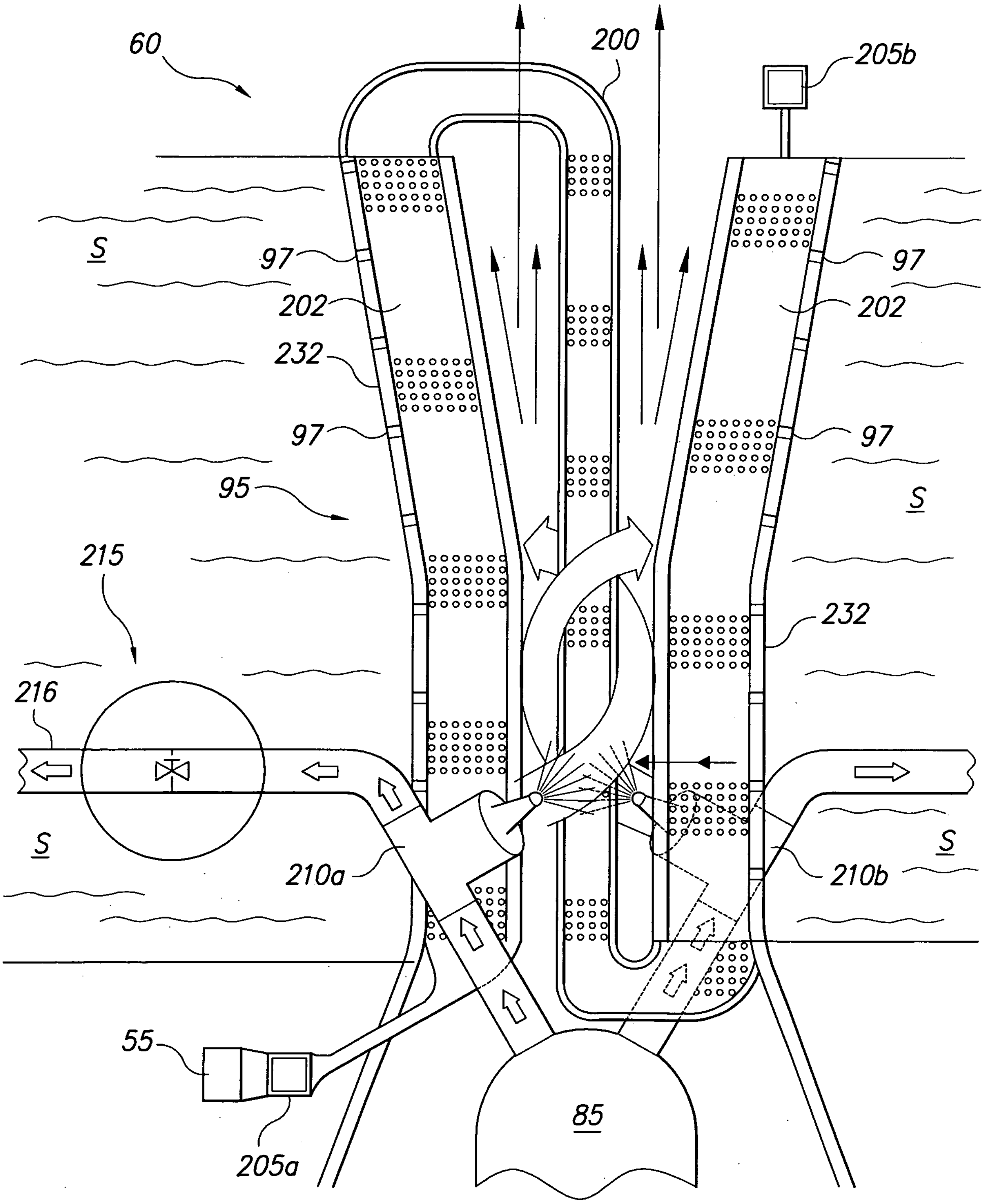
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Fig. 2B

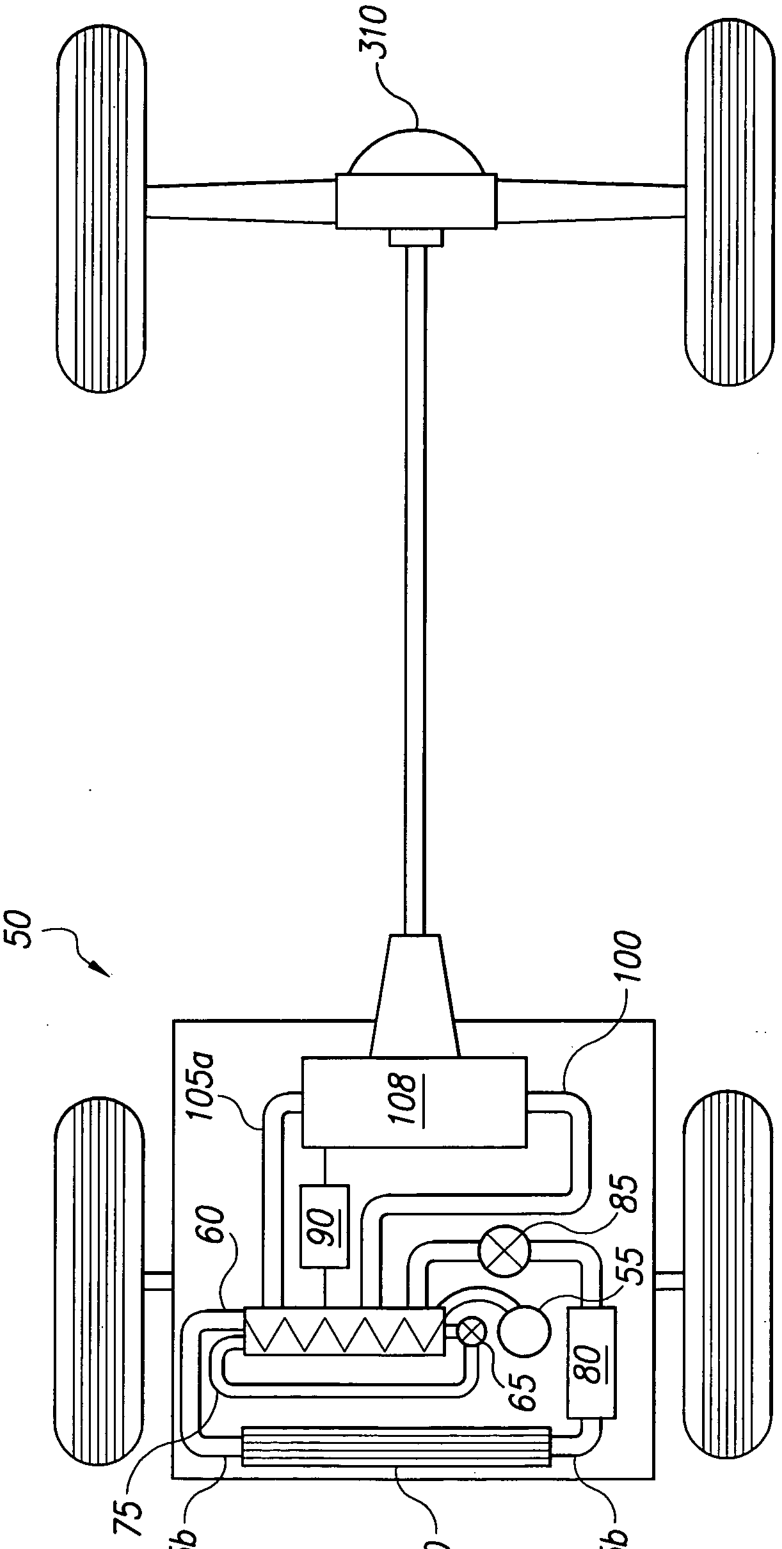

Fig. 3

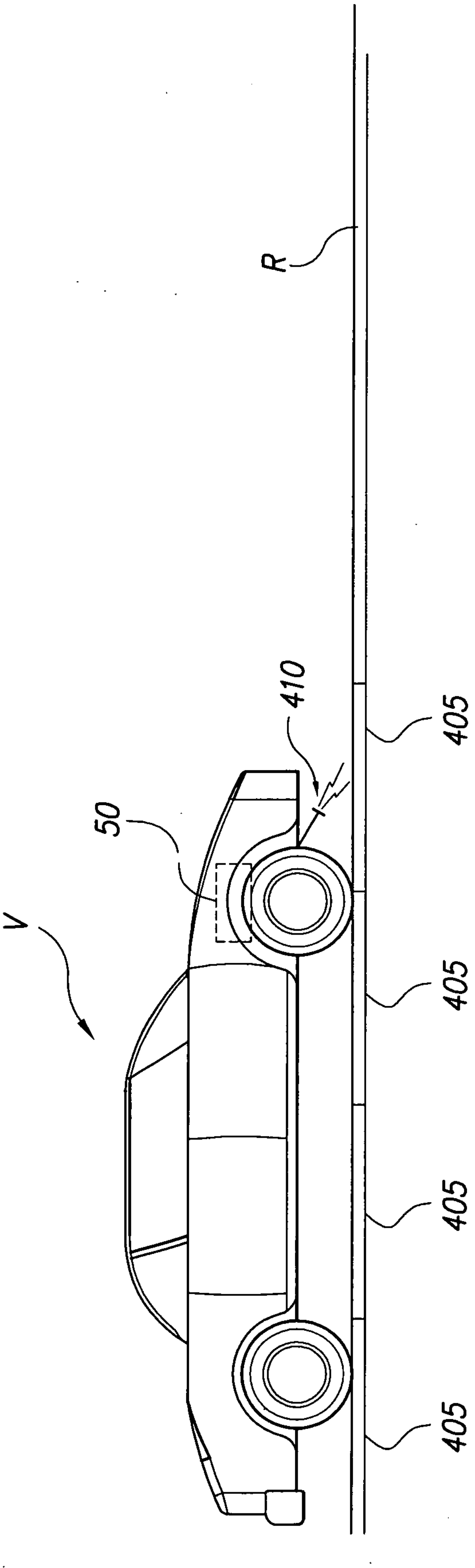

Fig. 4

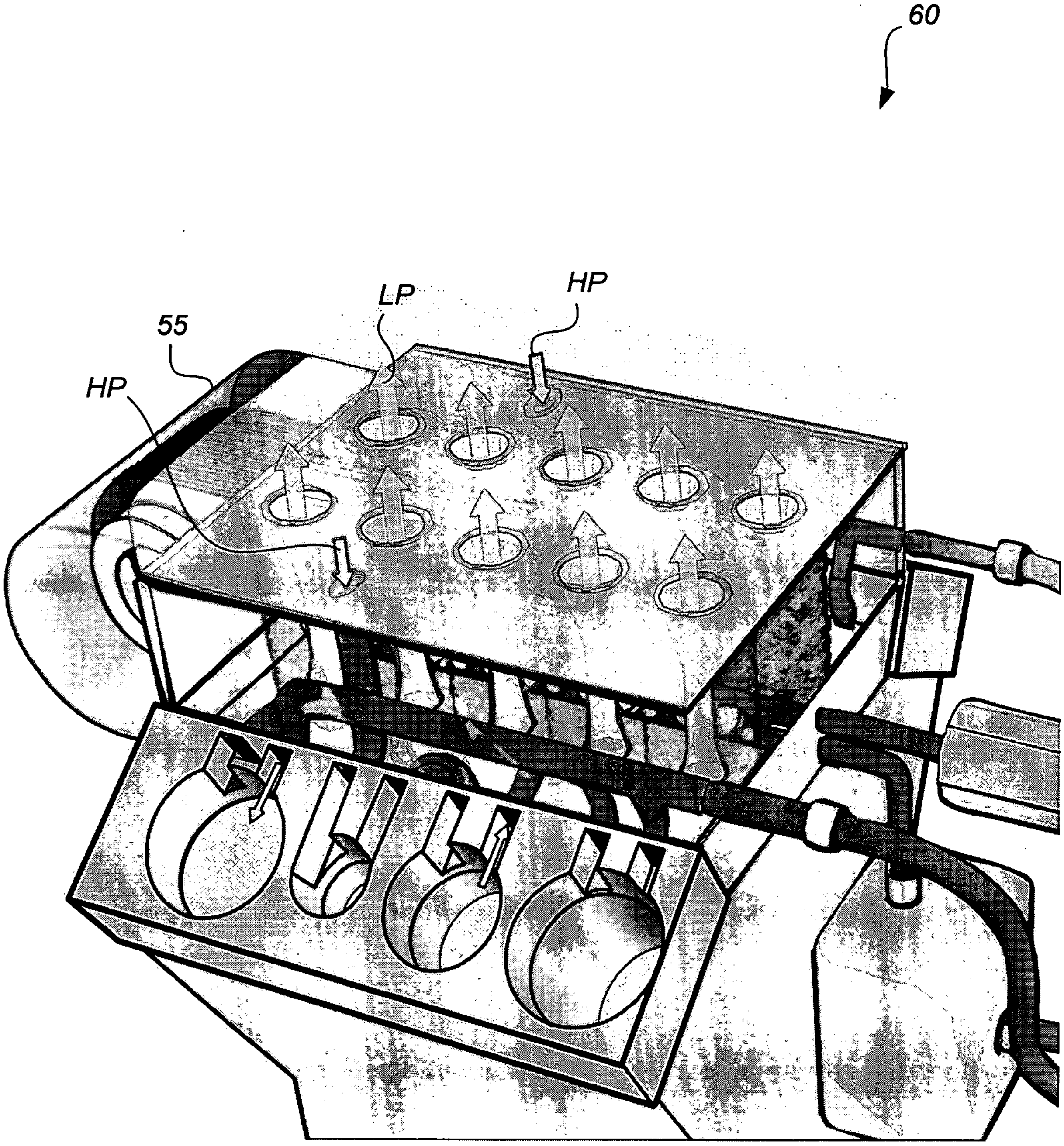

Fig. 5

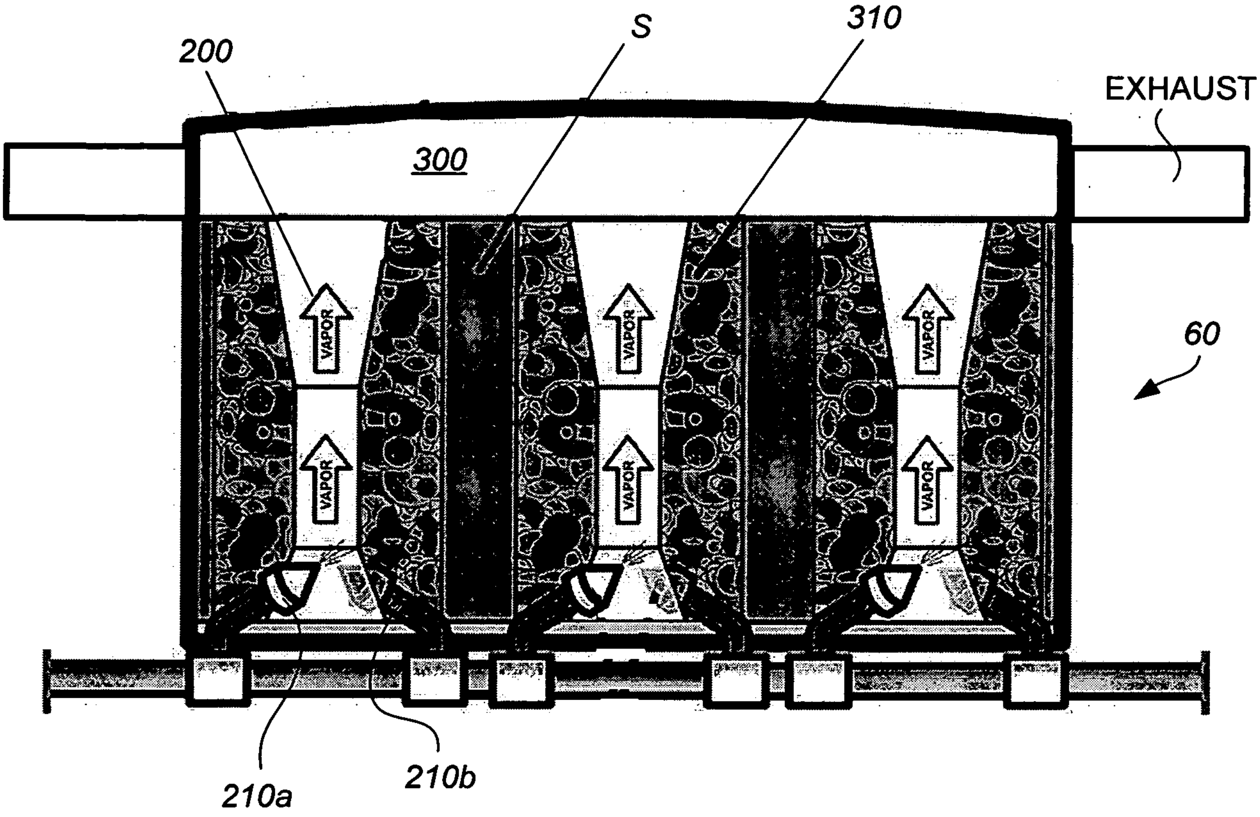
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Fig. 6

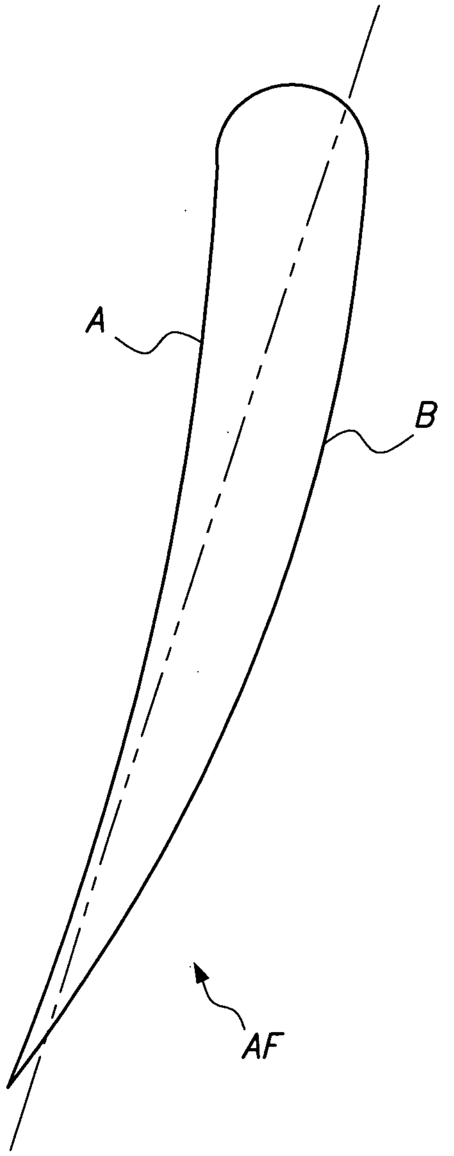


Fig. 7A

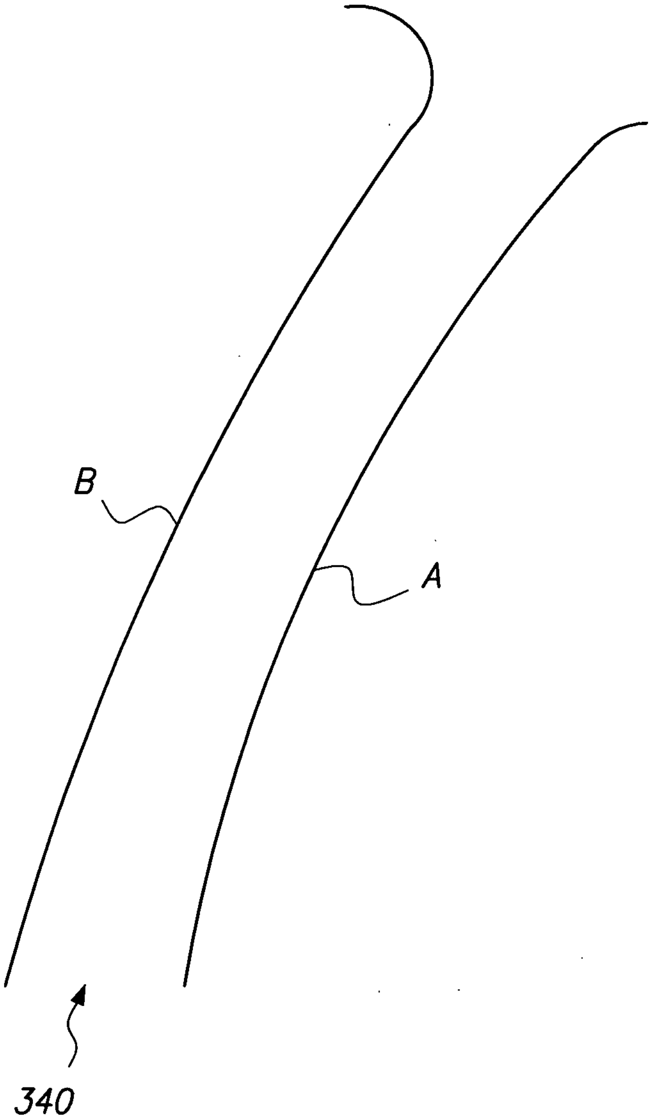


Fig. 7B

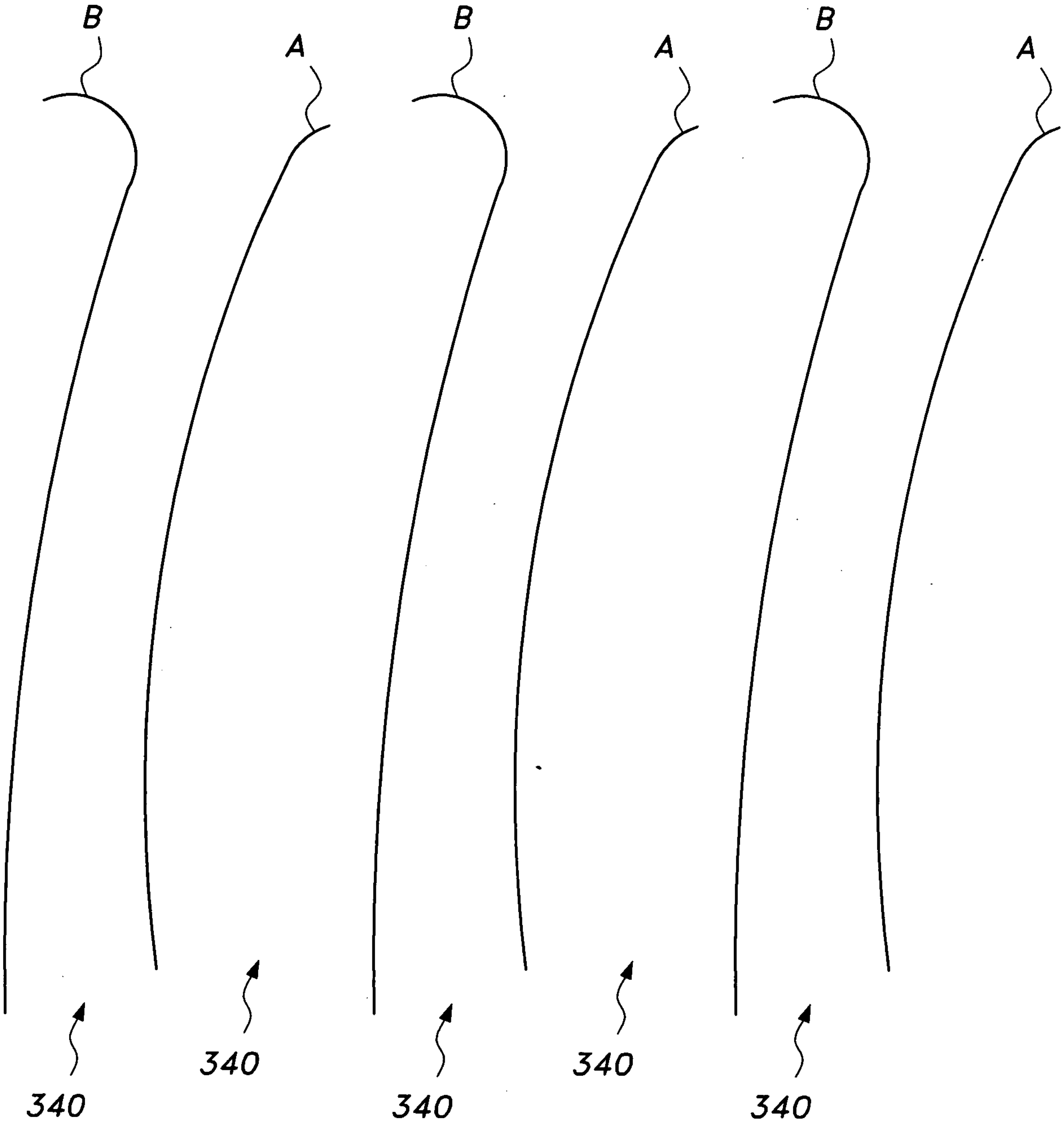


Fig. 8A

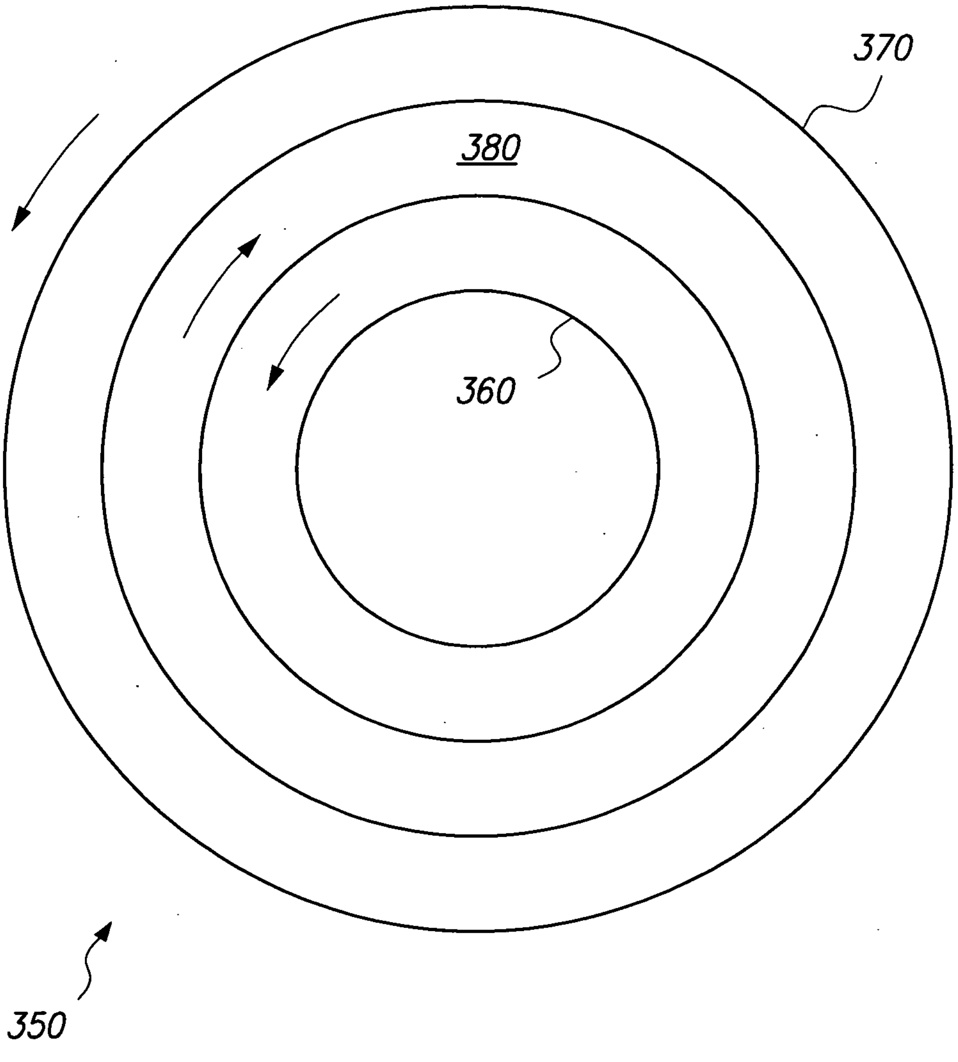


Fig. 8B

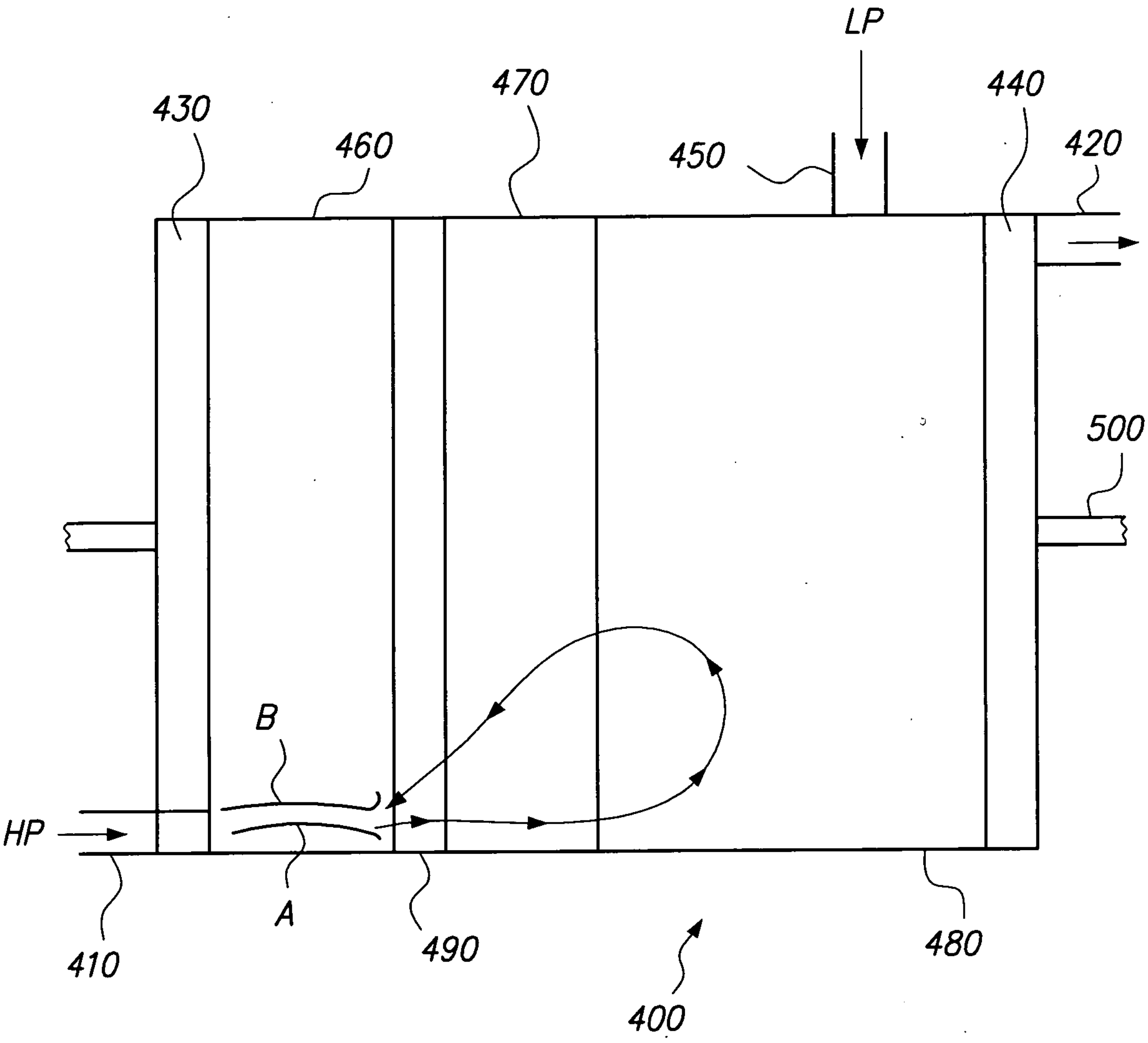
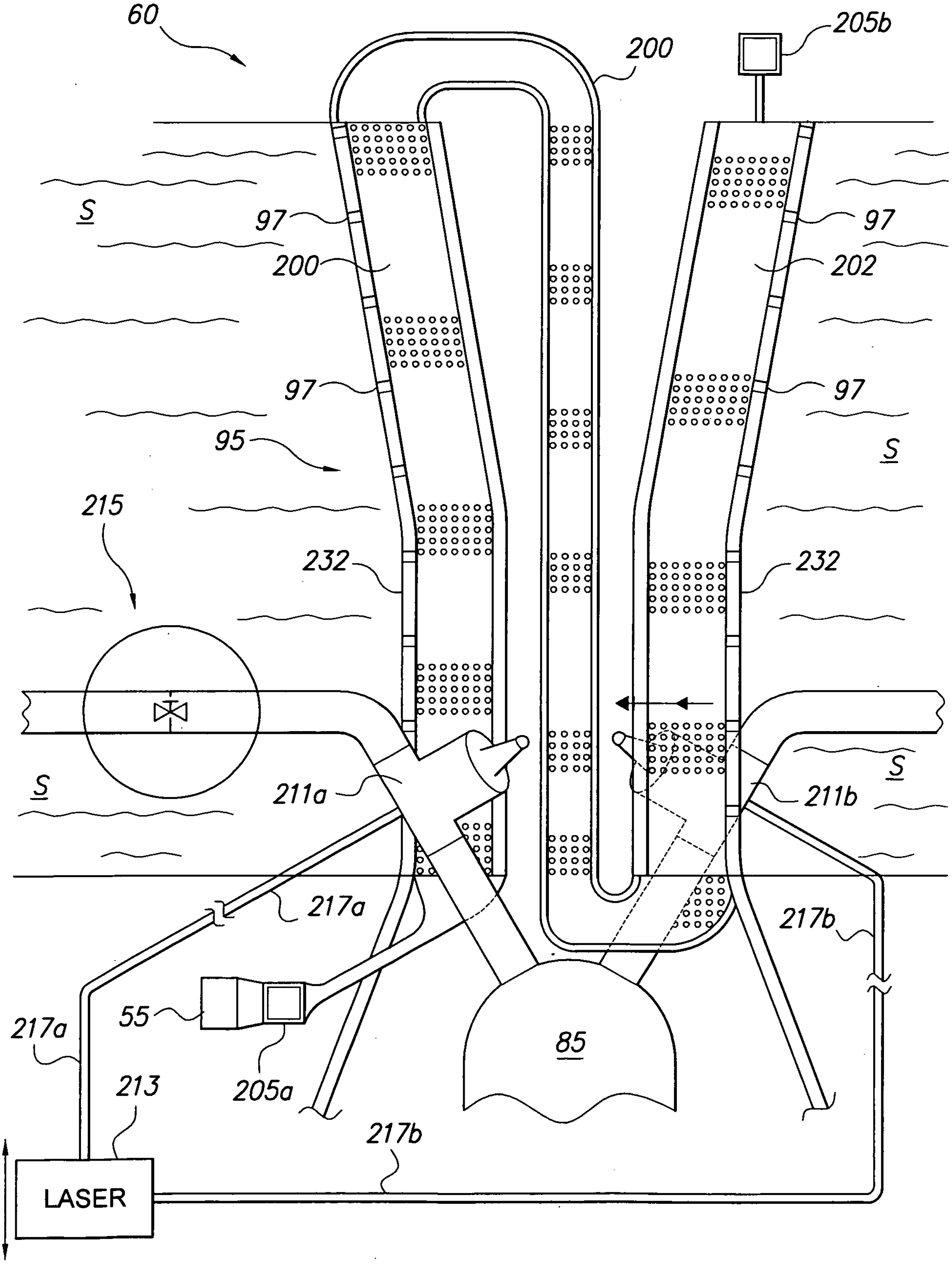


Fig. 9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LASER

Fig. 10