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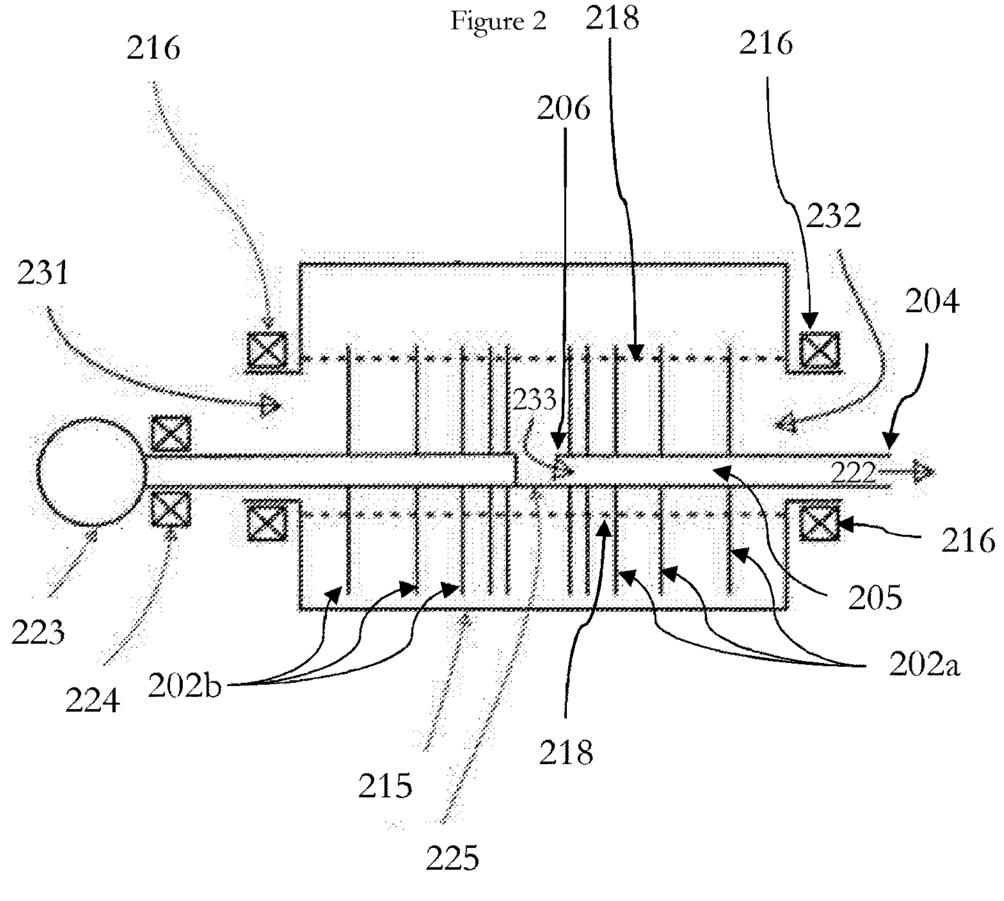
(54) Title of the Invention: **A liquid ring rotor**
Abstract Title: **A liquid ring rotor with a hollow shaft for use in a heat pump**

(57) A liquid ring rotor comprises a shaft 225 and one or more fluid diverting members. The shaft includes a hollow interior portion 205 having a first opening 204 and a second opening 206, the second opening disposed in a surface that extends along a length of the shaft and spaced apart from the first opening. A working fluid can pass along the shaft through the hollow interior portion between the openings. The one or more fluid diverting members, which may be a plurality of plates 202a, 202b and a plurality of vanes (108, 109, fig 1), extend radially from the shaft and are fixedly attached thereto. The fluid diverting members divert fluid along the shaft when rotated. The rotor may be used with a second rotor in a heat pump.

Figure 2



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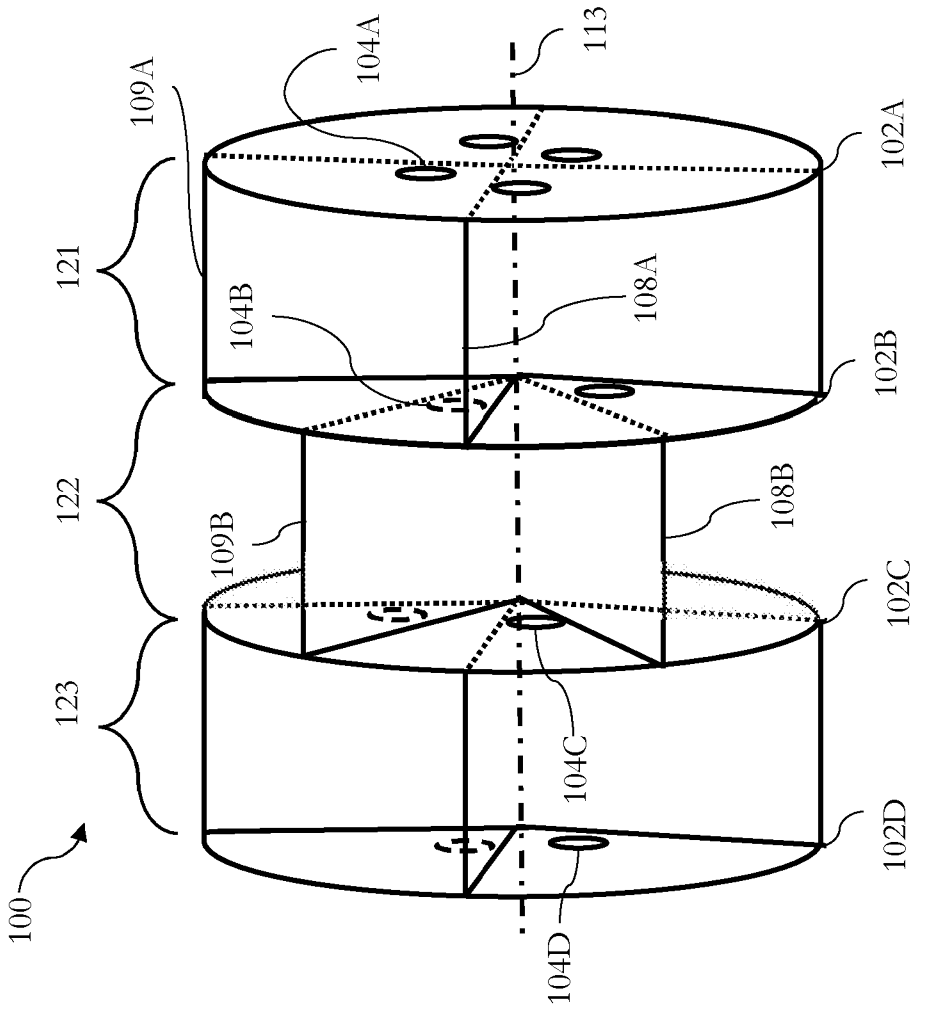
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Figure 1

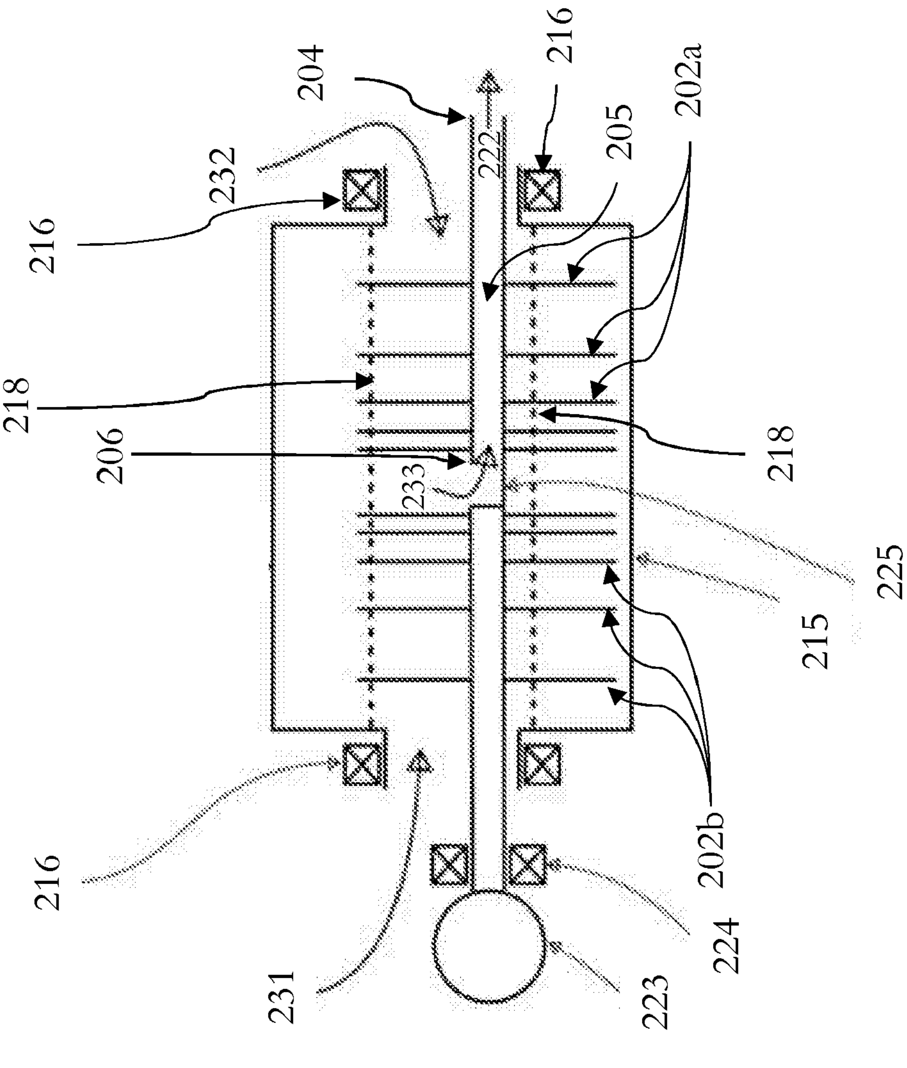
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Figure 2

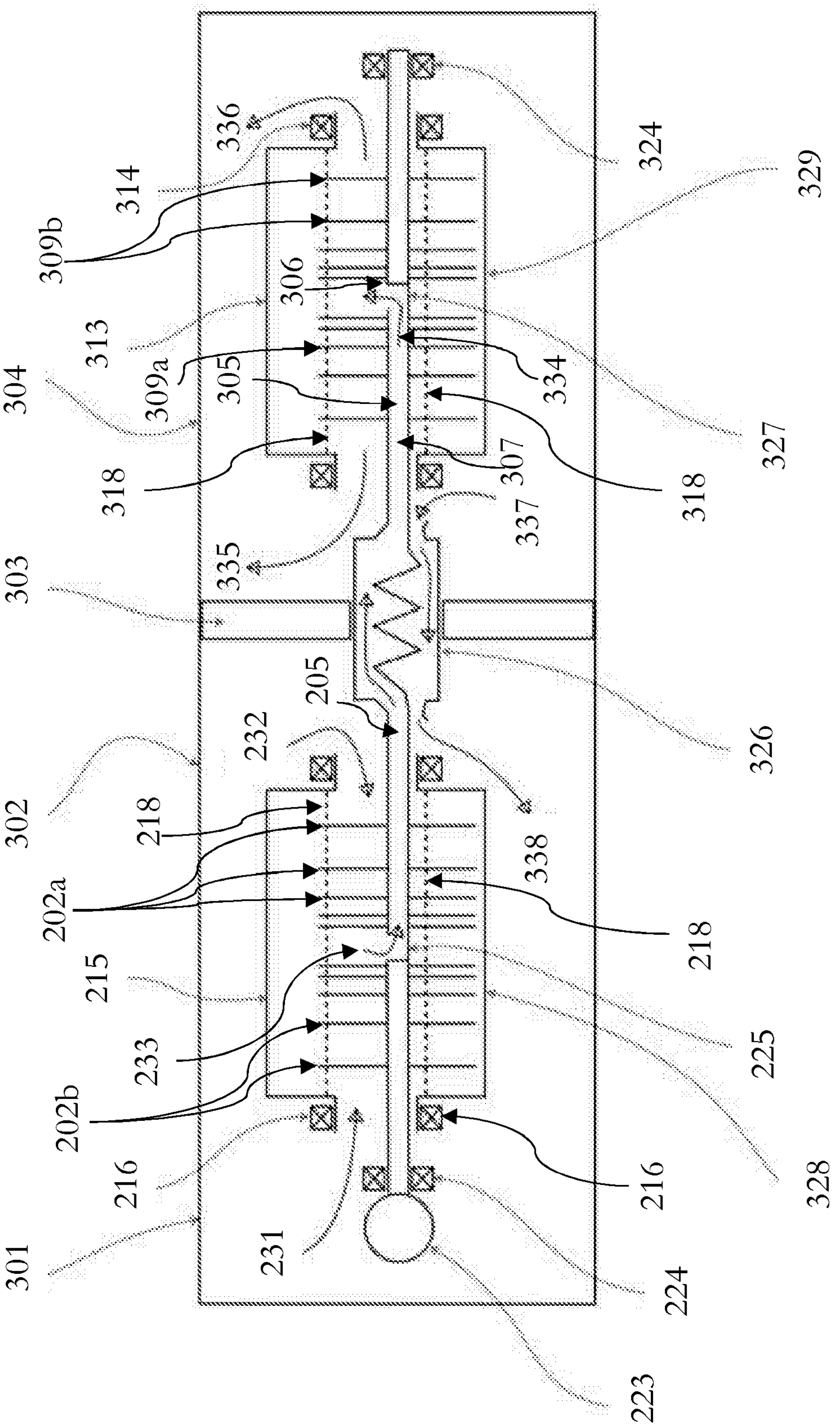
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Figure 3

A LIQUID RING ROTOR

The present invention relates generally to a rotor for use in a liquid ring system, such as a liquid ring heat pump and a method of distributing a working fluid using said rotor. The rotor finds particular, although not exclusive, utility as a fluid delivery system in liquid ring based heat pump arrangements.

Liquid ring systems, such as liquid ring pumps, liquid ring compressors, liquid ring decompressors and/or liquid ring expanders are known.

Existing liquid ring systems necessitate time consuming high precision manufacturing techniques, which are costly and prohibit access to the energy efficient technology from price conscious markets, such as the domestic heat pump markets.

A liquid ring compressor includes a vaned impeller moving about an axis offset from the centre of a container. Inlet and outlet valves are provided in a fixed position on the container, such that a gas enters a chamber through the inlet valve into a chamber formed between the container and the vanes of the vaned impeller. The vaned impeller rotates with respect to the container. High precision machining is required to ensure the moving edges of the vaned impeller are sealed against the ends of the container without preventing movement between the container and the vanes. The gas is moved, about the axis offset from the centre of the container, by the rotation of the vaned impeller to an outlet valve. As the vaned impeller rotates, the volume of the chamber between the vanes of the vaned impeller changes based on an amount of sealing liquid that fills the space between the vanes. The nature of the change between the inlet and the outlet varies depending on the type of liquid ring system. For example, the volume of the chamber in a compressor decreases between the inlet and the outlet, thereby compressing the gas in the chamber.

Multistage liquid ring systems may be used to compound the efficacy of a system by using a series of multiple containers, each retaining an amount of sealing liquid therein. Multiple high precision interfaces between the respective containers and vaned impellers decreases the system durability as the system will fail when a single high precision interface fails.

The durability of multistage liquid ring systems can be lower than single stage systems due to the increased complexity of sealing multiple moving components to multiple static components.

This means that there is a problem in liquid ring systems of how to reduce the need for high precision manufacturing techniques and how to increase the durability of liquid ring systems.

In a **first aspect**, there is provided a liquid ring rotor, for a liquid ring system, comprising: a shaft with a hollow interior portion, the hollow interior portion having a first opening and a second opening, the second opening disposed in a surface that extends along a length of the shaft and spaced apart from the first opening in the length of the shaft, wherein the shaft is configured to enable a working fluid to pass along the shaft through the hollow interior portion between the openings; and one or more fluid diverting members extending at least partially radially from the shaft and fixedly attached thereto, wherein the one or more fluid diverting members are configured to divert fluid along the shaft when rotated about the shaft in use.

In this way, a liquid ring system implementing this rotor can transport working fluid into or out of a liquid ring system with the shaft and fluid diverting members that form part of the rotor also providing the seal to retain the working fluid, with no additional moving parts and no need for additional precise seals.

The liquid ring rotor may be for a liquid ring system, and more specifically for transporting a working fluid through the liquid ring system.

The one or more fluid diverting members may be configured to divert fluid along the shaft when rotated about the length of the shaft.

In some examples, the one or more fluid diverting members may comprise plates and vanes e.g. forming chambers. The one or more fluid diverting members may comprise one or more spiral vanes protruding from the shaft and arranged in a helical pattern around the shaft. The one or more fluid diverting members may be one or more ramped protrusions extending from the shaft and arranged in a helical pattern around the shaft.

In some examples, the one or more fluid diverting members may be configured to, when rotated in use, divert fluid with one or more helical flow paths about the shaft with respect to the shaft. For example, the helical flow paths may flow toward the second opening, such as for a liquid ring compressor, or away from the second opening, such as for a liquid ring expander.

In some examples, the fluid diverting members may comprise a first set of fluid diverting members and a second set of fluid diverting members, wherein the first set of fluid diverting members is configured to move a working fluid with a helical flow path in a left-handed helical pattern, and wherein the second set of fluid diverting members is configured to move the working fluid with a helical flow path in a right-handed helical pattern.

In some examples, the one or more fluid diverting members may be configured to divert fluid along the shaft with one or more helical flow paths around the shaft when the one or more fluid diverting members are rotated about the shaft in use. For example, the one or more helical flow paths around the shaft may be helical with respect to the shaft.

In some examples, the fluid diverting members may comprise a first set of fluid diverting members and a second set of fluid diverting members. The first set of fluid diverting members may be configured to divert a working fluid with a first helical flow path, and the second set of fluid diverting members may be configured to divert the working fluid with a second helical flow path that mirrors the rotational direction and/or direction of propagation of the first helical flow path. For example, the second helical flow path may be a mirrored helical flow path of the first helical flow path.

In some examples, the first and second sets of fluid diverting members may be configured to divert the working fluid toward the second opening. Alternatively, the first and second sets of fluid diverting members may be configured to divert the working fluid away from the second opening.

In some examples, the first set of fluid diverting members may be fixedly attached to the shaft between the first opening and the second opening. Alternatively, or additionally, the second set of fluid diverting members may be fixedly attached to the shaft in positions further from the first opening than the second opening is from the first opening.

In some examples, the one or more fluid diverting members may be or comprise a first plurality of plates, each extending at least partially radially from the shaft and fixedly attached to the shaft between the first opening and the second opening, wherein each plate of the first plurality of plates includes at least one plate opening therethrough, and wherein each plate of the first plurality of plates is spaced apart from other plates of the first plurality of plates; a first vane set comprising one or more vanes disposed between adjacent plates of the first plurality of plates; and a first chamber set comprising at least one chamber, wherein a first chamber of the chamber set is bounded at least by a pair of adjacent plates of the first plurality of plates and one or more vanes of the first vane set, the first chamber configured to admit liquid through a first chamber opening disposed further from the shaft than the at least one plate opening of each plate, and wherein the plate opening of each of the pair of adjacent plates opens into the first chamber.

In this way, the helical flow path that passes a plurality of plates provides a particularly large surface area for heat exchange. For example, for extracting heat from the working fluid as it is compressed relatively efficiently. The heat is then transferred from the plate to the sealing liquid at each rotation of the plate. This also provides relatively efficient compression by minimising the temperature increase of the working fluid during compression.

It may be understood that examples described herein may include more than one plurality of plates, more than one chamber set, and more than one vane set. For the avoidance of doubt, references herein to a plurality of plates, a chamber set, or a vane set may refer, respectively, to: one or more of the first, second, third and/or fourth plurality of plates; one or more of the first, second, third and/or fourth chamber sets; and one or more of the first, second, third and/or fourth vane sets described herein.

In some examples, in use, each chamber of a chamber set is sealed by the surrounding plates, a vane set, the shaft, and sealing liquid. The shaft contains the hollow portion which allows transport therethrough to other rotating systems, such as another liquid ring system, without directing the working fluid through a stationary connection. This reduces the need for high precision manufacturing and increases the durability of the system.

The sealing liquid may be denser than the working fluid, as measured by at least one known measurement technique. The at least one known measurement technique may be, or include the use of, one or more of: a hydrometer, a hydrostatic balance method, an immersed body method, a pycnometer, or an oscillating densitometer.

The sealing liquid may be selected or configured such that it is denser than the working fluid. The working fluid may be selected or configured such that it is less dense than the sealing liquid. Selection or configuration in this manner may enhance a pressure seal of the chamber such that the working fluid does not bypass the chambers around the outer perimeter of the plates and/or through plate openings in the plates when they are sealed with sealing liquid. In some examples, the working fluid is a gas.

It may be understood that the sealing liquid may include one or more of water, silicone oil, low-viscosity silicone oil, or a relatively low-viscosity hydrocarbon (such as kerosene). The working fluid may include one or more of air, nitrogen, hydrogen or helium.

In some examples, the shaft may have a square, rectangular, circular, or any other cross section. The shaft may be a cylindrical shaft. The length of a shaft may refer to a longest dimension of the shaft and/or the longitudinal axis of the shaft and/or a length parallel to an axis about which the shaft of the rotor is configured to be rotated in use.

Each plate of a plurality of plates may be arranged to face each other. A plurality of plates may comprise a first plate and a second plate spaced apart by a first distance. Each plate of a plurality of plates may include a smooth outer edge to reduce friction when rotating through the sealing liquid. A face of each plate of a plurality of plates may be square, rectangular, or circular.

A vane set comprising one or more vanes may be disposed between each pair of plates of a plurality of plates. The first plate of a plurality of plates and a second plate of a plurality of plates may form a pair of plates of a plurality of plates, wherein a pair of plates refers to adjacent or neighbouring plates of a plurality of plates. Each pair of plates of a plurality of plates may include a vane set comprising one or more vanes therebetween. Each vane of the vane set may include a first face portion and a second face portion.

A chamber set may include one or more chambers. A first chamber of a chamber set may be bounded by a first plate of a plurality of plates, a second plate the plurality of plates, the first face of a first vane of a vane set, and the second face of a second vane of the vane set. Each vane of a vane set may contain no openings therethrough and/or be non-porous. Each vane may extend between the first plate and the second plate of a plurality of plates to prevent working fluid from bypassing the vane between the vane and the first plate, between the vane and the second plate, and/or between the vane and the shaft. The first and second plates of the plurality of plates may be adjacent plates and be referred to as a pair of adjacent plates. Adjacent plates, such as a pair of adjacent plates, may be two plates that are arranged successively on the rotor, e.g. immediately successively and/or without additional plates therebetween.

The first chamber of a chamber set may be configured to admit a liquid, such as a sealing liquid, through a first chamber opening. In use, the first chamber of a chamber set may form an enclosed volume except for the plate openings associated with the chamber. For example, in use, the chamber opening may be completely covered by a sealing liquid at a point in, or throughout, the rotation of the rotor.

The first chamber of a chamber set may comprise a first plate opening, disposed on the first plate, wherein at least a portion of the first plate opening is configured to be closer to the first face of a first vane of a vane set than the second face of the second vane of said vane set; and a second plate opening, disposed on a second plate, wherein at least a portion of the second plate opening is configured to be closer to the second face of the second vane than the first face of the first vane. In some examples, one, multiple, or each of the plate openings described herein is a valve. For example, the valve may be a backflow prevention valve that allows working fluid to pass in only one direction therethrough. In some examples, the valve may be operated on reaching a maximum or minimum pressure threshold. The pressure threshold may be predetermined. The valve may be opened by exiting and closed entering a ring of sealing fluid in use.

Each plate of a plurality of plates may be thin relative to its length and/or width. For example, the length and/or width of each plate may be at least 10, 100, or 1000 times larger than the thickness of the plate. Each plate may be a separate sheet of material. The sheet of material may be substantially flat across at least 50%, 65%, 80%, or 95% of its surface. Perturbations, such as protrusions or indentations, in the surface of each plate may not exceed 10, 100 or 1000 times the thickness of the plate. Each plate of a plurality of plates may be the same shape. For example, the largest surface of each plate may form a geometric shape, such as a rhombus, a circle, an ellipse, a square, a rectangle, and/or a triangle. In some examples, each plate may be a disc.

An orientation of each plate may be fixed with respect to each other plate in a plurality of plates. It may be understood that any plate opening of a given plate of a plurality of plates may be both an inlet to one chamber and an outlet into another successive chamber along the rotor. For example, an inlet plate opening may allow working fluid into one chamber but out of a preceding area and/or chamber. Each plate opening may be a hole cut away from or out of the plate. Each plate of a plurality of plates may be connected by the shaft to each other plate in the plurality of plates. The shaft connecting each plate of a plurality of plates may be connected to each plate closer to the centre of the plate than the edge of the plate and/or connected to the centre of each plate.

A vane set may be arranged to provide an impeller, or more specifically a vaned impeller. Each vane of a vane set may be directed toward a common point on the first and/or second plate. For example, each vane of a vane set may be arranged at least partially radially from a shaft. Each vane of a vane set may be directed toward a central point on a surface of the first and/or second plate. Vanes of a vane set may branch out from or be directed towards a common point and/or common centre of a surface of the first and/or second plate.

Each vane of a vane set may be formed from a sheet of material. Each vane of a vane set may be thin relative to its length and/or width. Each vane of the vane set may have a twisted profile, a curved profile, or any other profile. Alternatively, or additionally, the profile of each vane may be twisted such that a profile of an edge of the vane in contact with the first plate is different to a profile of an edge of the vane in contact with the second plate.

A vane face, or face of a vane, is a surface of the vane which is exposed to the chamber. Each vane of the vane set may have two faces. The two vane faces may be the two largest surfaces of a vane. A first chamber of the chamber set may be bounded by the first plate, the second plate, the first face of a first vane of the vane set, and the second face of a second vane of the vane set. A second chamber of the chamber set may be bounded by the first plate, the second plate, the first face of a second vane of the vane set, and the second face of a third vane of the vane set, wherein the third vane and the first vane may be the same vane, e.g., if only two chambers are present. The second chamber may be adjacent to the first chamber. More specifically, two chambers formed using a common or shared vane may be described as adjacent or directly adjacent chambers.

The liquid ring rotor, in use, may be rotated in a container that contains sealing liquid to form a liquid ring system, such as a liquid ring compressor that compresses a working fluid, liquid ring expander that decompresses a working fluid, or liquid ring pump that moves a working fluid. The sealing liquid in the container may form a hollow tubular shape in use as the rotor and, optionally, the container rotate.

The hollow tubular shape may have an interior cross section perpendicular to its length which is a rounded geometric shape, such as a rounded rectangle or a circle, or any other rounded geometric shape. The rotor may be configured to operate with a predetermined interior cross section of the hollow tubular shape, or range of predetermined interior cross sections of the hollow tubular shape. The interior cross sections of the hollow tubular shape may be predetermined based on a volume of sealing liquid along with container size and shape. A plurality of plates of the rotor may be configured to cover an area of more than a half of said interior cross section of the hollow tubular shape, an area of at least said interior cross section of the hollow tubular shape, or an area greater than said interior cross section of the hollow tubular shape. The rotor may be disposed in the container. The edge, or at least a portion of the edge, of each plate of the plurality of plates of the rotor may be, in use, arranged in the container and extend beyond said interior cross section of the hollow tubular shape. In some examples, the axis about which the rotor is configured to rotate, in use, is offset from the centre of the interior cross section. The container may be configured to rotate about an axis closer to the centre than the edge of the container or in the centre of the container.

In use, the rotor may be rotated by a drive system, such as a motor. As the rotor rotates, in use, it passes through a sealing liquid within the container and the resulting movement of the sealing liquid may cause the container to rotate. The rotor may rotate about the length of the shaft in use, or about an axis defined by the length of the shaft in use.

In some examples, a vane set may comprise a single vane. In these examples, the shaft may be in direct contact along its length with said interior cross section, such that a chamber is formed between the vane, the plates, the shaft, and the sealing liquid, to provide a more lightweight liquid ring system. Alternatively, each vane set may comprise a plurality of vanes, such as at least two vanes, at least three vanes, or at least five vanes.

In some examples, the one or more fluid diverting members may be or comprise a second plurality of plates, each extending at least partially radially from the shaft and fixedly attached to the shaft in positions further from the first opening than the second opening is from the first opening, wherein each plate of the second plurality of plates includes at least one plate opening therethrough, and wherein each plate of the second plurality of plates is spaced apart from other plates of the second plurality of plates; and a second vane set comprising one or more vanes, wherein each vane of the second vane set is impermeable to the working fluid, and wherein each vane of the second vane set extends between adjacent plates of the second plurality of plates and the shaft; and/or wherein the at least one plate opening of the first plurality of plates has an overlapping area of zero with the at least one plate opening of another plate of the first plurality of plates and the at least one plate opening of the second plurality of plates has an overlapping area of zero with the at least one plate opening of another plate of the second plurality of plates.

In this way, the working fluid can be transported into or out of a liquid ring system that is open at both ends with the plates that form part of the rotor also providing the seal to retain the working fluid. Both ends being open allows a relatively high flow rate of working fluid to be realised by the system, as the additional opening reduces the flow resistance through the pump. The second plurality of plates may also provide a shaft balancing effect that reduces the net force acting along the length of the shaft, such as thrust imbued by the operation of the rotor.

The centre of at least one plate opening of a plurality of plates may be offset, e.g. in at least two dimensions or in at least three dimensions, from the centre of at least one plate opening of another plate of the plurality of plates, such as an adjacent plate of the plurality of plates. In some examples, the at least one plate opening of a plurality of plates may have an overlapping area of zero with the at least one plate opening of another plate of the plurality of plates. More specifically, the at least one plate opening of another plate of the plurality of plates may refer to the at least one plate opening of each adjacent plate of the plurality of plates. The plate openings of each adjacent plate of a plurality of plates, or each plurality of plates of the rotor, may be arranged with an overlapping area of zero. Adjacent plates may be immediately successive plates on a rotor. Plate openings that have an overlapping area of zero are non-overlapping plate openings and may be defined as plate openings arranged such that if shifted or translated along the shaft into the same plate, they would not share any common area. Plate openings arranged with an overlapping area of zero may be, for example, plate openings which are arranged such that no portion of each opening enters a predetermined maximum inner diameter of a hollow tube (e.g. representing sealing liquid) at the same time as a portion of each other opening or, in use, no portion of each opening enters the sealing liquid at the same point in the rotation of the rotor as a portion of each other opening.

In some examples, the second plurality of plates is arranged to mirror an arrangement of the first plurality of plates about the second opening.

In this way, the pressure between the plates during operation is equalised, which provides a greater pump flow rate and increases the total flow rate of the arrangement.

A single plurality of plates disposed in a container with only one open end may result in a higher pressure being created at one end of the container than the other. The pressure difference may push the plurality of plates and, in turn, the shaft away from the higher pressure. This force along the shaft can result in premature wear of moving parts and requires additional thrust limiters, such as a thrust bearing, to stop the shaft moving away from the relatively high pressure end of the container.

The second plurality of plates and second vane set may be configured to provide an opposing liquid ring system that mirrors the first plurality of plates and the first vane set about the second opening. The opposing liquid ring system configured in this way provides an equal magnitude force along the shaft as the first plurality of plates and first vane set, but in the opposite direction to provide no overall force along the length of the shaft. These balanced forces remove the need for thrust limiters to keep the shaft in place.

The second plurality of plates may be arranged to mirror an arrangement of the first plurality of plates about the second opening to provide an opposing liquid ring system, wherein the plate openings of the first plurality of plates are arranged to provide a helical flow path through the first plurality of plates, and wherein the plate openings of the second plurality of plates are arranged to provide a mirrored helical flow path through the second plurality of plates. A mirrored helical flow path is a left-handed helical pattern if the helical flow path is a right-handed helical pattern. A mirrored helical flow path is a right-handed helical pattern if the helical flow path is a left-handed helical pattern.

In some examples, the first plurality of plates includes at least three plates, and a first spacing between a first plate of the first plurality of plates and a second plate of the first plurality of plates is different to a second spacing between the second plate of the first plurality of plates and a third plate of the first plurality of plates.

In this way, the pumping pressure possible from an associated liquid ring system can be increased.

It may be understood that a plurality of plates may include at least three plates or at least five plates. A first spacing between a first plate of a plurality of plates and a second plate of said plurality of plates is different to a second spacing between the second plate of said plurality of plates and a third plate of said first plurality of plates. The spacing may increase or decrease between successive plates in a plurality of plates.

The vanes of each vane set may be connected to the adjacent plates and the shaft to prevent the working fluid from bypassing said connections.

In this way, a more efficient liquid ring system is realised.

In some examples, the liquid ring rotor may further comprise a heat exchanger with a first port arranged to exchange the working fluid with the first opening of the shaft, such that in use the working fluid is able to pass between the hollow interior portion of the shaft and the heat exchanger, and wherein the heat exchanger is fixedly connected to the shaft to rotate with the shaft in use.

In this way, the working fluid can be used to cool or heat other systems, such as liquid ring systems, with relatively simple fixed seals or joints between the systems, rather than complex moving seals. This may be especially useful for interfacing with other systems that include rotating ports, such as other liquid ring systems.

In some examples, one or more of the ports may include an opening into or out of the heat exchanger, and/or a non-return valve into or out of the heat exchanger. In some examples, the first port of the heat exchanger may be in fluid communication with a second port of the heat exchanger. The second port of the heat exchanger may be fixedly attached to a companion shaft. A liquid ring system arrangement may include one or more liquid ring systems.

The first port of the heat exchanger may be in fluid communication with a second port of the heat exchanger. A third port of the heat exchanger may be in fluid communication with the fourth port of the heat exchanger. The first and second ports of the heat exchanger may not be in fluid and/or liquid communication with the third and fourth ports of the heat exchanger. Working fluid passing between the first and second ports of the heat exchanger may be in thermal communication with fluids passing between the third and fourth ports of the heat exchanger. Thermal communication may be provided by a heat exchange material, such as a thermal conductor or a heat exchange membrane. The heat exchange material may be arranged to form a heat sink. In some examples, the heat exchanger may be one or more of: a shell and tube heat exchanger; a plate heat exchanger; a shell and plate heat exchanger; a plate-fin heat exchanger; and a pillow plate heat exchanger.

In some examples, liquid ring rotor further comprises: a companion shaft with a companion hollow interior portion, the companion hollow interior portion having a companion first opening and a companion second opening, the companion second opening disposed in a surface that extends along a length of the companion shaft and spaced apart from the companion first opening in the length of the companion shaft, wherein the companion shaft is configured to enable the working fluid to pass along the companion shaft through the companion hollow interior portion between the openings, and wherein the companion first opening is arranged to exchange working fluid with a second port of the heat exchanger that is in fluid communication with the first port of the heat exchanger, such that in use the working fluid is able to pass between the companion hollow interior portion and the heat exchanger, and wherein the heat exchanger is fixedly connected to the companion shaft to rotate with the companion shaft in use; a companion first plurality of plates, each extending at least partially radially from the companion shaft and fixedly attached to the companion shaft between the companion first opening and the companion second opening, wherein each plate of the companion first plurality of plates includes at least one plate opening therethrough, and wherein each plate of the companion first plurality of plates is spaced apart from other plates of the companion first plurality of plates and each plate opening of the companion first plurality of plates has an overlapping area of zero with the plate openings of another plate of the companion first plurality of plates; and a companion first vane set comprising one or more vanes, wherein each vane of the companion first vane set is impermeable to the working fluid, and wherein each vane of the companion first vane set extends between adjacent plates of the companion first plurality of plates and the shaft.

In this way, the rotor is able to form the basis of a heat pump with fewer complex connections between parts with fixed positions and moving positions and, therefore, a more durable heat pump system is provided. Moreover, this arrangement removes the need for precise seals between the various liquid ring systems and enables approximately double the flow rate of working fluid without increasing the diameter of transport tubing between the systems or the pressure resistance of a vessel containing the systems. Larger diameter components are not desirable as they are typically more expensive, less flexible, limit system configuration options, and are less readily available. Furthermore, by reducing the number of seals, the viscous losses in use due to seals interacting with the liquid in the liquid ring system are further reduced.

The companion shaft, companion plurality of plates, and companion vane set may be arranged to provide a complementary liquid ring system in use. For example, the shaft, plurality of plates, and vane set may be arranged to provide either a liquid ring compressor or a liquid ring expander and the companion shaft, the companion plurality of plates, and the companion vane set may be arranged to provide the other of a liquid ring expander or liquid ring compressor.

In some examples, the liquid ring rotor further comprises: a companion second plurality of plates, each extending at least partially radially from the companion shaft and fixedly attached to the companion shaft in positions further from the companion first opening than the companion second opening is from the companion first opening, wherein each plate of the companion second plurality of plates includes at least one plate opening therethrough, and wherein each plate of the companion second plurality of plates is spaced apart from other plates of the companion second plurality of plates and each plate opening of the companion second plurality of plates has an overlapping area of zero with the plate openings of another plate of the companion second plurality of plates, and wherein the companion second plurality of plates is arranged to mirror an arrangement of the companion first plurality of plates about the companion second opening; a companion second vane set comprising one or more vanes, wherein each vane of the companion second vane set is impermeable to the working fluid, and wherein each vane of the companion second vane set extends between adjacent plates of the companion second plurality of plates and the companion shaft; and/or wherein the companion first plurality of plates includes at least three plates, and a first spacing between a first plate of the companion first plurality of plates and a second plate of the companion first plurality of plates is different to a second spacing between the second plate of the companion first plurality of plates and a third plate of the companion first plurality of plates.

In this way, a balanced and more powerful rotor arrangement is provided to form the basis of a heat pump with fewer complex connections and fewer regions that operate at the maximum pressure, therefore, a more durable heat pump system is provided without the need for various reinforcing members.

In a **second aspect** there is provided a liquid ring system arrangement, the arrangement comprising: the liquid ring rotor of the first aspect; a vessel configured to enclose a container and a companion container; the container disposed inside the vessel and arranged to surround each edge of the plates of the first plurality of plates and each edge of the plates of the second plurality of plates, and wherein the container is configured to retain a sealing liquid; the companion container disposed inside the vessel and arranged to surround each edge of the plates of the companion first plurality of plates and each edge of the plates of the companion second plurality of plates, and wherein the companion container is configured to retain a sealing liquid; and an insulation wall disposed inside the vessel between the container and the companion container to reduce the direct flow of working fluid and/or thermal energy therebetween, such that a majority of working fluid and/or thermal energy passed between the container and the companion container is passed via the heat exchanger.

In this way, heat transfer between the container and companion container is controlled to provide a more efficient liquid ring system arrangement.

The vessel may be a tubular vessel. The vessel may be fully enclosed.

The drive system may include one or more of a motor directly connected to a shaft, a motor, a cog, a gear, a chain, and a belt. The drive system may be configured to rotate the rotor. The drive system may be configured to rotate the shaft and the plates attached to the shaft. The canister may be configured to rotate about an axis parallel to the shaft and offset from the shaft. The companion canister may be configured to rotate about an axis parallel to the companion shaft and offset from the companion shaft.

In some examples, the canister and/or companion canister may be rotated by a mechanical connection to the drive system. In some examples, the canister and/or companion canister may be configured to be rotated in use by interactions with a sealing fluid contained therein. The sealing fluid within a container and/or companion container may be is set in motion by physical interactions with a rotor disposed in the container as the rotor is driven by the drive system in use.

In some examples, in use, the rotation of a canister and/or rotor within said canister imbues the sealing liquid in said canister with centripetal force, forming a ring of sealing liquid at the inner surface of said canister. The thickness of the ring of sealing fluid may be determined based on the volume of sealing fluid along with the size and shape of the canister.

A container may be a tubular container. The container may be open at one end or open at both ends. Relatively low pressure working fluid (e.g. a gas) may enter a container at an open end. The plates and vanes of a rotor may compress the working fluid toward, or decompress the working fluid away from, an opening disposed in a surface that extends along a length of the shaft.

In some examples, the vessel encloses one or more reservoirs to collect sealing liquid spillages from the container and/or companion container in use, and wherein a sealing liquid return system is configured to transport the spillage into the container and/or companion container.

In this way, the liquid ring system arrangement can operate for a longer period of time without manual intervention as the quantity and/or level of sealing liquid may be more carefully controlled over extended periods of time.

For example, the one or more reservoirs may be integrated with the vessel. The sealing liquid return system may be a pump, optionally including one or more hoses, that moves sealing liquid from a reservoir into an open end of a container. In some examples, the sealing liquid return system may also transport sealing liquid into the heat exchanger to facilitate heating or cooling of the working fluid.

In a **third aspect**, there is provided a method for operating a liquid ring rotor that comprises: providing the liquid ring rotor of the first aspect; and causing the liquid ring rotor to rotate about the shaft using a drive system.

In a **fourth aspect**, there is provided a method for operating a liquid ring system arrangement comprising: providing the liquid ring system arrangement of the second aspect; and causing the liquid ring rotor to rotate about the shaft using a drive system.
It may be understood that causing the liquid ring rotor to rotate about the shaft using a drive system includes causing the liquid ring rotor to rotate about an axis that passes through all plates of the first, second, third and/or fourth plurality of plates, for example through the centre of each plate of the first, second, third and/or fourth plurality of plates. The rotor may be caused to rotate with at least a portion of an edge, or an entire edge, of each plate submerged in the sealing liquid.

Figure 1 shows a three-dimensional schematic representation of multiple plates 102A-D with associated vane sets of a rotor 100 for use in a liquid ring system.

Figure 2 shows an example liquid ring system arrangement that includes two opposing liquid ring systems.

Figure 3 shows an example liquid ring system arrangement that includes a liquid system arrangement with two companion liquid ring systems each having two opposing liquid ring systems.

The present invention will be described with respect to certain drawings but the invention is not limited thereto but only by the claims. The drawings described are only schematic and are non-limiting. Each drawing may not include all of the features of the invention and therefore should not necessarily be considered to be an embodiment of the invention. In the drawings, the size of some of the elements may be exaggerated and not drawn to scale for illustrative purposes. The dimensions and the relative dimensions do not correspond to actual reductions to practice of the invention.

Furthermore, the terms first, second, third and the like in the description and in the claims, are used for distinguishing between similar elements and not necessarily for describing a sequence, either temporally, spatially, in ranking or in any other manner. It is to be understood that the terms so used are interchangeable under appropriate circumstances and that operation is capable in other sequences than described or illustrated herein. Likewise, method steps described or claimed in a particular sequence may be understood to operate in a different sequence.

Moreover, the terms top, bottom, over, under and the like in the description and the claims are used for descriptive purposes and not necessarily for describing relative positions. It is to be understood that the terms so used are interchangeable under appropriate circumstances and that operation is capable in other orientations than described or illustrated herein.

It is to be noticed that the term "comprising", used in the claims, should not be interpreted as being restricted to the means listed thereafter; it does not exclude other elements or steps. It is thus to be interpreted as specifying the presence of the stated features, integers, steps or components as referred to, but does not preclude the presence or addition of one or more other features, integers, steps or components, or groups thereof. Thus, the scope of the expression "a device comprising means A and B" should not be limited to devices consisting only of components A and B. It means that with respect to the present invention, the only relevant components of the device are A and B.

Similarly, it is to be noticed that the term "connected", used in the description, should not be interpreted as being restricted to direct connections only. Thus, the scope of the expression "a device A connected to a device B" should not be limited to devices or systems wherein an output of device A is directly connected to an input of device B. It means that there exists a path between an output of A and an input of B which may be a path including other devices or means. "Connected" may mean that two or more elements are either in direct physical or electrical contact, or that two or more elements are not in direct contact with each other but yet still co-operate or interact with each other. For instance, wireless connectivity is contemplated.

Reference throughout this specification to "an embodiment" or "an aspect" means that a particular feature, structure or characteristic described in connection with the embodiment or aspect is included in at least one embodiment or aspect of the present invention. Thus, appearances of the phrases "in one embodiment", "in an embodiment", or "in an aspect" in various places throughout this specification are not necessarily all referring to the same embodiment or aspect, but may refer to different embodiments or aspects. Furthermore, the particular features, structures or characteristics of any one embodiment or aspect of the invention may be combined in any suitable manner with any other particular feature, structure or characteristic of another embodiment or aspect of the invention, as would be apparent to one of ordinary skill in the art from this disclosure, in one or more embodiments or aspects.

Similarly, it should be appreciated that in the description various features of the invention are sometimes grouped together in a single embodiment, figure, or description thereof for the purpose of streamlining the disclosure and aiding in the understanding of one or more of the various inventive aspects. This method of disclosure, however, is not to be interpreted as reflecting an intention that the claimed invention requires more features than are expressly recited in each claim. Moreover, the description of any individual drawing or aspect should not necessarily be considered to be an embodiment of the invention. Rather, as the following claims reflect, inventive aspects lie in fewer than all features of a single foregoing disclosed embodiment. Thus, the claims following the detailed description are hereby expressly incorporated into this detailed description, with each claim standing on its own as a separate embodiment of this invention.

Furthermore, while some embodiments described herein include some features included in other embodiments, combinations of features of different embodiments are meant to be within the scope of the invention, and form yet further embodiments, as will be understood by those skilled in the art. For example, in the following claims, any of the claimed embodiments can be used in any combination.

In the description provided herein, numerous specific details are set forth. However, it is understood that embodiments of the invention may be practised without these specific details. In other instances, well-known methods, structures and techniques have not been shown in detail in order not to obscure an understanding of this description.

In the discussion of the invention, unless stated to the contrary, the disclosure of alternative values for the upper or lower limit of the permitted range of a parameter, coupled with an indication that one of said values is more highly preferred than the other, is to be construed as an implied statement that each intermediate value of said parameter, lying between the more preferred and the less preferred of said alternatives, is itself preferred to said less preferred value and also to each value lying between said less preferred value and said intermediate value.

The use of the term "at least one" may mean only one in certain circumstances. The use of the term "any" may mean "all" and/or "each" in certain circumstances.

The use of the term "expand" may mean "decompress" or "increase in volume" in some examples. Similarly, the use of the term "expandable" may mean "decompressible" or "increasable in volume" in some examples.

The expression "at least partially radially" may refer to one or more features that extend from or converge to a common central point, common central area, or common central feature. For example, features arranged "at least partially radially" may all be directed toward a shaft, or extend from a shaft. It is to be understood that features arranged "at least partially radially" include the specific example of being arranged "radially". The use of the term "radially" may refer to a feature that extends in at least one dimension from its centre of mass or geometric centre to a nearest portion of a common central point, a nearest portion of a common central area, or a nearest portion of a common central feature.

The principles of the invention will now be described by a detailed description of at least one drawing relating to exemplary features. It is clear that other arrangements can be configured according to the knowledge of persons skilled in the art without departing from the underlying concept or technical teaching, the invention being limited only by the terms of the appended claims.

Figure 1 shows a three-dimensional schematic representation of multiple plates 102A-D with associated vane sets of a rotor 100 for use in a liquid ring system. Dashed lines show edges that may not be visible if, for example, the vanes or plates are opaque. Some vanes are not shown between the plates to aid intelligibility.

The first plate 102A may be joined to one or more of the second plate 102B, the third plate 102C and the fourth plate 102D to create a multistage liquid ring system. Each plate 102A-D that extends at least partially radially from a shaft 113 may retain an orientation that is fixed relative to each other plate in the plurality of plates 102A-D. The first plate 102A and the second plate 102B may form a pair of plates. The second plate 102B and the third plate 102C may form a pair of plates. The third plate 102C and the fourth plate 102D may form a pair of plates. Each pair of plates may be spaced apart by a distance, wherein the distance between each pair of plates may increase, decrease, or stay the same for each successive pair of plates. Each pair of plates may have an associated vane set comprising one or more vanes disposed therebetween. Each pair of plates and the associated vane set therebetween may form a stage 121, 122, 123 or, more specifically, a first stage 121, a second stage 122 and a third stage 123. A first vane set may be disposed between the first plate 102A and the second plate 102B, a second vane set may be disposed between the second plate 102B and the third plate 102C, and a third vane set may be disposed between the third plate 102C and the fourth plate 102D. Each stage 121, 122, 123, may comprise a chamber set.

Each vane set of the rotor 100 for use in a liquid ring system may be arranged to match the orientation of every other vane set. An edge of each vane of a first vane set may overlap an edge of each vane of a second vane set. Alternatively, each vane set of the rotor 100 may be offset, by a vane offset, from an adjacent vane set, such as a vane set of a preceding stage. Each vane set may be offset, e.g. in at least two dimensions, from the adjacent vane sets to provide a helical path through the plates for the working fluid in use. Each plate opening of a plurality of plates may be offset, e.g. in at least two dimensions, from the plate openings of adjacent plates of the plurality of plates to provide a helical path through the plates for the working fluid in use.

By way of example, the rotor may be configured to enable working fluid to enter the rotor through plate opening 104A and follow a left-handed helical pattern through the rotor as the rotor rotates about the longitudinal axis 113 of the shaft. The rotor may be rotated such that plate opening 104A enters the sealing liquid before plate opening 104B. When rotating in this direction, the rotor is moving clockwise when viewed from the end which includes plate opening 104A. As the sealing liquid reduces the size of the chamber associated with plate openings 104A and 104B, the working fluid is compressed and then pushed out of the first stage 121, through plate opening 104B, to the second stage 122. As the sealing liquid reduces the size of the chamber associated with plate openings 104B and 104C, the working fluid is further compressed and then pushed out of the second stage 122, through plate opening 104C, to the third stage 123. As the sealing liquid reduces the size of the chamber associated with plate openings 104C and 104D, the working fluid is further compressed and then pushed out of the third stage 123 through plate opening 104D.

The plate openings may be configured to enable a right-handed helical pattern of working fluid to flow therethrough. For example, by moving plate opening 104A closer to vane 108A than vane 109A, and plate opening 104B to the other side of vane 109B. When the rotor is moving clockwise when viewed from the end which includes plate opening 104A, working fluid would now be ejected away from the plurality of plates from plate opening 104A, rather than plate opening 104D.

The helical path maximises the path length of the working fluid through the system and, in this way, maximises the change in volume of the working fluid provided by a rotor of a given size in a liquid ring system.

The vane set may be arranged to provide an impeller, or more specifically, a vaned impeller configured to move a working fluid through the plates as the vanes rotate with the rotor. The vanes may be fixedly connected to the shaft 113. Each vane of the vane set may be directed toward a common point on the first and/or second plate. For example, each vane of the vane set may be arranged at least partially radially from a shaft. Each vane of the vane set may be directed toward a central point on a surface of the first and/or second plate. Vanes of the vane set may branch out from or be directed towards a common point and/or common centre of a surface of the first and/or second plate. Each vane of the vane set may be directed towards a shaft.

Each vane of the vane set may be formed from a sheet of material. Each vane of the vane set may be thin relative to its length and/or width. For example, the length and/or width of the vane may be at least 10, 100, or 1000 times larger than the thickness of the vane. Each vane of the vane set may have a profile along the surface of at least one plate that is straight, curved, or any other shape. Each vane of the vane set may have a twisted profile, a curved profile, or any other profile. Alternatively, or additionally, the profile of each vane may be twisted such that a profile of an edge of the vane in contact with the first plate is different to a profile of an edge of the vane in contact with second plate. Each vane may comprise a non-porous surface, non-porous faces, or no porous faces. Each vane may be formed from a heat-resistant plastic, a metal, ceramic and/or a composite material.

A first chamber may be formed between two adjacent vanes 108A, 109A, the first plate 102A and the second plate 102B. A second chamber may be formed between two adjacent vanes 108B, 109B, the second plate 102B and the third plate 102C. aforementioned first and second chambers are successive chambers, because a plate opening 104B associated with the first chamber is also associated with the second chamber. For example, the first chamber may exchange a working fluid with the second chamber in use. Each successive chamber may act, in use, to further change the pressure of a working fluid. That is, if the first chamber is configured to increase the pressure of the working fluid, the second chamber through which the working fluid travels will further increase the pressure of the working fluid output from the first chamber. Alternatively, if the first chamber is configured to decrease the pressure of the working fluid, the second successive chamber of the rotor through which the working fluid travels will further decrease the pressure of the working fluid output from the first chamber.

A vane face, or face of a vane, is surface of the vane which is exposed to the chamber. Each vane of the vane set may have two faces. The two vane faces may be the two largest surfaces of a vane. For example, each vane of the vane set may have a forward face and a rearward face. The forward face may face the direction of rotation or face a direction closer to the direction of rotation than against the direction of rotation. The rearward face may face against the direction of rotation or may face a direction that is closer to against the direction of rotation than the direction of rotation.

Each plate 102A-D may have one or more plate openings to enable working fluid to pass therethrough. The plate openings may prevent working fluid from passing therethrough when they are submerged in a sealing liquid of a liquid ring system. The plate openings of each adjacent plate of a plurality of plates, or each plurality of plates of the rotor 100, may be arranged with an overlapping area of zero. For example, the plate opening 104A of the first plate 102A may not overlap the plate opening 104B of the second plate 102B and plate opening 104B of the second plate 102B may not overlap with the plate opening 104C of the third plate 102C. However, plate openings of non-successive plates may overlap, for example, the plate openings 104A and 104C of the first and third plates 102A and 102C may overlap. In some examples, the plate opening position may alternate between plates. For example, the plate opening(s) 104A of the first plate 102A may overlap the plate opening(s) 104C of the third plate 102C and plate opening(s) 104B of the second plate 102B may overlap the plate opening(s) 104D of the fourth plate 102D.

A complete liquid ring system, in use, includes a hollow cylinder of sealing liquid created by a rotating container. This hollow cylinder has a longitudinal axis that runs parallel to the longitudinal axis of the shaft 113 with an offset. In some examples, the offset and/or maximum inner diameter of the hollow cylinder of sealing liquid may be predetermined. Alternatively, or additionally, a given rotor may be configured to operate with a predetermined range of offsets and/or a predetermined range of inner diameters of the hollow cylinder of sealing liquid. For example, the offset range may be based in part on the plate opening size and/or position. The predetermined range of inner diameters of the hollow cylinder of sealing liquid may be based in part on the plate shape, plate size, and plate opening positioning.

The rotor 100 may be rotated at a first speed about the longitudinal axis of the shaft 113. Furthermore, at a stage of the rotation, the second plate opening 104B may emerge from the predetermined maximum inner diameter of a hollow tube of sealing liquid and be configured to allow working fluid to leave the first chamber enter the second chamber through said second plate opening 104B, wherein the first chamber and second chamber are successive chambers. Successive chambers may be configured to operate at alternate compression stages. For example, the rotor may have three successive chambers, the first chamber, the second chamber and a third chamber. The first chamber may fill with a working fluid at the same stage in the rotation of the rotor 100 as the third chamber.

The rotor may be configured to ensure that, in use, the sealing liquid does not migrate along the rotor with the working fluid. The rotor may be configured to ensure that, in use, there is relatively little force, or no overall force, exerted by said rotor on the sealing liquid in a direction perpendicular to the plates of the rotor.

As described above, an effective chamber may encompass different sub-chambers depending on the rotational stage of the rotor. For example, the effective chamber may encompass a chamber of stages 121 and 122 in one rotational stage and encompass a chamber of stages 122 and 123 in a second rotational stage. Rotational stages of the rotor refer to rotational positions of the rotor when it is rotated about the axis 113, about which the rotor is configured to be rotated.

Figure 2 shows an example liquid ring system arrangement that includes two opposing liquid ring systems.

The first liquid ring system shown includes a first plurality of plates 202a, and the second liquid ring system includes a second plurality of plates 202b. The first plurality of plates 202a and second plurality of plates 202b form part of a liquid ring rotor. The system includes a drive system 223 to rotate the rotor, such as a motor. The drive system 223 may be directly connected to the rotor. For example, the drive system 223 may be directly connected to a shaft of the rotor. The liquid ring rotor comprises a shaft 225 and a first plurality of plates 202a. Between each adjacent plate of the first plurality of plates 202a and/or each adjacent plate of the second plurality of plates 202b there is a vane set, as described in relation to Figure 1.

The shaft 225 is supported by shaft bearings 224. The shaft bearings 224 are in direct contact with the shaft 225 and may be disposed at one or more positions along the shaft 225. The shaft includes a hollow interior portion 205, a first opening 204 and a second opening 206. The first opening 204 is in fluid communication with the second opening 206. That is, fluid can flow freely between the first opening 204 and the second opening 206 through the hollow interior portion 205 of the shaft 225.

The example liquid ring system arrangement includes a container 215 that retains sealing liquid therein. In use, the container 215 is rotated such that the sealing liquid forms a hollow three-dimensional shape that covers the internal surface of container 215, wherein the hollow region is defined by the sealing liquid surface 218. The container 215 is in direct contact with the container bearings 216. One or more container bearings 216 may be present along the container 215, such as a container bearing 216 at each end of the container 215. The container 215 may be rotated by the same drive system 223 as the liquid ring rotor and with the same number of revolutions per minute as the liquid ring rotor, for example, using a power transfer system comprising one or more of a gear, a belt, and a chain. In some examples, the container 215 may be rotated by the same drive system 223 as the liquid ring rotor using the sealing liquid to transfer power therebetween.

The example shown in Figure 2 may include two opposing liquid ring systems each operated as a liquid ring compressor that, for example, compresses working fluid toward the space between the first plurality of plates 202a and the second plurality of plates 202b. In this example, working fluid at a relatively low pressure enters the container 215 as shown with the flow arrows 231 and 232. The rotor is rotated such that the working fluid is compressed toward the second opening 206. The resulting increase in pressure of the working fluid at the second opening 206 causes the working fluid to enter the second opening 206, as shown by flow arrow 233, and pass through the hollow interior portion 205 of the shaft 225 to the first opening 204. The working fluid proceeds to pass out of the first opening, as shown by flow arrow 222, at a higher pressure than the pressure at which it entered the container 215.

The example shown in Figure 2 may include two opposing liquid ring systems each operated as a liquid ring expander. The flow of working fluid in this example would be the reverse of the flow shown in direction of arrows 222, 231, 232 and 233. In this example, the working fluid enters the first opening 204 at a relatively high pressure and proceeds through the hollow interior portion 205 to the second opening 206. The rotor is rotated such that the working fluid is pulled away from the second opening 206 and out toward the ends of the container 215. Working fluid then leaves the container 215 at a relatively low pressure.

The two opposing liquid ring systems work synergistically with the plurality of plates of each system fixed to the same shaft by configuring each system to have a flow path through the plates in a direction opposite to the other, wherein the direction of the flow path is controlled by the locations of the plate openings of each plate. The flow path through the plates may be a helical flow path. The helical flow path can be a left-handed helical flow path or a right-handed helical flow path. One of the two opposing liquid ring systems is configured to have a left-handed helical flow path through the plates, and the other of the two opposing liquid ring systems is configured to have a right-handed helical flow path through the plates such that the liquid ring systems work synergistically, for example, to compress a working fluid to between the systems or expand a working fluid from between the systems.

It may be understood that a left-handed helical flow path is a mirrored path of a right-handed helical flow path. By way of example, if following a clockwise path from a first end of the helix around the helix moves away from said first end of the helix, then it is a right-handed helix; if following an anticlockwise path from a first end of the helix around the helix moves away from said first end of the helix, then it is a left-handed helix. A right-handed helix cannot be turned to look like a left-handed one unless it is viewed in a mirror, and vice versa.

Figure 3 shows an example liquid ring system arrangement that includes a liquid system arrangement with two opposing liquid ring systems and two companion liquid ring systems. In some examples, this liquid ring system arrangement may operate as a heat pump with opposing compressors on one side and opposing expanders on the companion side.

Two opposing liquid ring systems may refer to a liquid ring system and a liquid ring system that opposes said liquid ring system. A liquid ring system that opposes another liquid ring system may be configured to work together with the other liquid ring system to provide a synergistic effect, for example, each system of the opposing liquid ring systems may be a compressor, each system of the opposing liquid ring systems may be an expander, or each system of the opposing liquid ring systems may be a pump.

It may be understood that Figure 3 includes two of the example liquid ring system arrangements shown and described in relation to Figure 2 combined to operate as a liquid ring system arrangement. In this example, the liquid system arrangement includes two opposing liquid ring systems, and a companion set of two opposing liquid ring systems. The liquid system arrangement includes a single rotor that includes two opposing liquid ring systems, and a companion set of two opposing liquid ring systems. The arrangement may be suitable for being driven by a drive system 223 that does not include more than one motor.

A vessel 301 is provided. The vessel is a fully enclosed vessel configured to retain working fluid. The vessel is sealed to prevent the escape of gas. In some examples, the vessel 301 is only exposed to relatively low pressure working fluid as the liquid ring systems are configured to interact with the sealing liquid in use to constrain the working fluid pressurised by the liquid ring system arrangement.

The vessel 301 includes a divider 303 between the first end 302 and the second end 304. The second end 304 may also be referred to as the companion end 304. The divider 303 may be an insulation wall 303 configured to reduce the conductive heat transfer between the first end 302 and the companion end 304. The divider 303 extends from the vessel 301 toward the heat exchanger 326 and is arranged to minimise working fluid passing between the first end 302 and the opposing end 304 without passing through the heat exchanger 326. The divider 303 may cover more than 95% of the cross sectional area of the vessel around the liquid ring rotor between the first end 302 and the companion end 304. The divider 303 may comprise one or more portions, each portion being fixedly attached to only one of the vessel 301 or the liquid ring rotor. In some examples, the divider 303 may be fixedly attached to the heat exchanger 326. The divider 303 may include a gap between the portions, between the divider 303 and the vessel 301 or between the divider 303 and the heat exchanger 326, for example, to permit the liquid ring rotor to rotate freely. The gap may cover no more than 5% of the cross sectional area of the vessel. A small gap in the divider does not significantly degrade performance, as both sides of the divider are at a similar pressure that is relatively low. Relatively high pressure working fluid is largely constrained within the hollow interior portion of each shaft 205, 305, the heat exchanger, and between the pluralities of plates 202a, 202b, 309a, 309b.

In some examples the liquid ring system arrangement may operate as a heat pump. The vessel 301 includes a hot end 302 and a cold end 304. In use, the temperature of the hot end 302 may be high relative to the cold end 304. The hot end 302 includes a liquid ring system configured to compress working fluid into the shaft, in the direction indicated by flow arrow 233. Heat is released from the working fluid as the working fluid is compressed by opposing liquid ring compressors 328. The cold end 304 is configured to receive compressed working fluid from the hot end 302 through the shaft in the direction indicated by flow arrow 334. The cold end 304 includes opposing liquid ring expanders 329 configured to expand, or decompress, the working fluid. Heat is absorbed by the working fluid as the working fluid is expanded or decompressed.

The heat exchanger 326 is fixedly attached to the rotor to rotate with the shafts 225, 327 of the rotor. The working fluid compressed by the opposing liquid ring compressors 328 passes through the hollow interior portion 205 to a first port of a heat exchanger 326. The compressed working fluid passes from the second port of the heat exchanger 326 to the opposing liquid ring expanders 329 via hollow interior portion 305. The opposing liquid ring expanders 329 decompress the working fluid, which pushes the working fluid away from the opposing liquid ring expanders (as shown by flow arrows 335 and 336), to a third port of the heat exchanger 326 (as shown by flow arrow 337) then out of a fourth port of the heat exchanger 326 to the hot end 302 (as shown by flow arrow 338). From here the working fluid may continue to cycle through the liquid ring system arrangement by entering the container 215 as shown by flow arrows 231 and 232.

The first port of the heat exchanger 326 is in fluid communication with a second port of the heat exchanger 326. The third port of the heat exchanger 326 is in fluid communication with the fourth port of the heat exchanger 326. The first and second ports of the heat exchanger 326 are not in fluid and/or liquid communication with the third and fourth ports of the heat exchanger 326. Fluid passing between the first and second ports of the heat exchanger 326 are in thermal communication with fluids passing between the third and fourth ports of the heat exchanger 326, wherein thermal communication is provided by a heat exchange material, such as a thermal conductor or a heat exchange membrane.

As it passes through the heat exchanger 326, the pressurised working fluid may be cooled by the heat exchanger 326 to cool it at a constant pressure, which also reduces the volume of the pressurised working fluid. The heat exchanger 326 transfers a portion of the heat energy of the compressed working fluid compressed by the liquid ring system of the hot end 302 to the decompressed working fluid exiting the cold end 304. In this way, the heat exchanger 326 increases the efficiency of the heat pump. The efficiency is increased as the heat exchanger 326 enables the working fluid entering the liquid ring system arrangement of the cold end 304 to capture more heat due to a decreased temperature, whilst simultaneously providing additional heat energy to the working fluid to be compressed at the hot end 302 of the system. The working fluid entering the liquid ring system of the cold end 304 may capture more heat due to a decreased temperature that increases a temperature differential with an environment surrounding of the cold end 304. The working fluid may provide additional heat energy when compressed at the hot end 302 of the system due to an increased temperature differential with an environment surrounding of the hot end 304.

The companion set of two opposing liquid ring systems system includes a companion container 313 that retains sealing liquid therein. In use, the companion container 313 is rotated such that the sealing liquid forms a hollow three-dimensional shape that covers the internal surface of companion container 313, wherein the hollow region is defined by the sealing liquid surface 318. The companion container 313 is in direct contact with the companion container bearings 314. One or more companion container bearings 314 may be present along the companion container 313, such as companion container bearing 314 at each end of the companion container 313. The companion container 313 may be rotated by the same drive system 223 as the liquid ring rotor and with the same number of revolutions per minute as the liquid ring rotor, for example, using a power transfer system comprising one or more of a gear, a belt, and a chain. In some examples, the companion container 313 may be rotated by the same drive system 223 as the liquid ring rotor using the sealing liquid to transfer power therebetween.

Liquid ring system containers, such as the container 215, or the companion container 313, may be caused to rotate in use by the movement of sealing liquid as the rotor rotates in said sealing liquid, e.g., due to viscous forces.

The companion shaft 327 is supported by companion shaft bearings 324. The shaft bearings 324 are in direct contact with the companion shaft 327 and may be disposed at one or more positions along the companion shaft 327. The companion shaft 327 includes a hollow interior portion 305, a first opening 307, and a second opening 306. The first opening 307 of the companion shaft 327 is in fluid communication with the second opening 306 of the companion shaft. That is, fluid can flow freely between the first opening 307 and the second opening 306 through the hollow interior portion 305 of the companion shaft 327.

A first companion plurality of plates 309a, otherwise referred to as a third plurality of plates 309a, is fixedly attached to the companion shaft 327. In some examples, a second companion plurality of plates 309b, otherwise referred to as a fourth plurality of plates 309b, is fixedly attached to the companion shaft 327. Between each adjacent plate of the first companion plurality of plates 309a and/or each adjacent plate of the second companion plurality of plates 309b there is a vane set including at least one vane (not shown).

The rotor may comprise the shaft 225, the companion shaft 327, the heat exchanger 326, and four pluralities of plates 202a, 202b, 309a, 309b. In some examples, references to a shaft, or the shaft of the rotor, may include the shaft 225 and the companion shaft 327.

When power is applied to the drive system 223 in use, the rotor rotates and moves heat from the cold end 304 of the vessel 301 into the hot end 302 of the vessel 301. The heat is moved by compressing the working fluid in the hot end 302 to release heat and increase the hot end temperature, and expanding the working fluid in the cold end 304 to cause the working fluid to absorb heat and decrease the temperature of the environment surrounding the cold end 304 of the vessel 301. The working fluid cycles repeatedly around inside the vessel 301. The divider 303 and heat exchanger 326 may provide at least some insulation between the hot end 302 and the cold end 304 to enable the efficient movement of heat from a relatively cold environment surrounding the cold end 304 into a relatively hot environment surrounding the hot end 302.

The transfer of heat between the cold end 304 of the vessel and the relatively cold environment surrounding the cold end 304 may be facilitated by a thermal energy conveyancer. The transfer of heat between the hot end of the vessel and the relatively hot environment surrounding the hot end 302 may be facilitated by a thermal energy conveyancer. A thermal energy conveyancer may include one or more of a heatsink, liquid cooling system, or Peltier cooling system.

CLAIMS

1. A liquid ring rotor, for a liquid ring system, comprising:

a shaft with a hollow interior portion, the hollow interior portion having a first opening and a second opening, the second opening disposed in a surface that extends along a length of the shaft and spaced apart from the first opening in the length of the shaft, wherein the shaft is configured to enable a working fluid to pass along the shaft through the hollow interior portion between the openings; and

one or more fluid diverting members extending at least partially radially from the shaft and fixedly attached thereto, wherein the one or more fluid diverting members are configured to divert fluid along the shaft when rotated about the shaft in use.

2. The liquid ring rotor of claim 1, wherein the one or more fluid diverting members are configured to divert fluid along the shaft with one or more helical flow paths around the shaft when the one or more fluid diverting members are rotated about the shaft in use, and/or wherein the fluid diverting members comprise a first set of fluid diverting members and a second set of fluid diverting members, the first set of fluid diverting members configured to divert a working fluid with a first helical flow path, and the second set of fluid diverting members configured to divert the working fluid with a second helical flow path that mirrors the rotational direction and/or direction of propagation of the first helical flow path, and/or wherein the first and second sets of fluid diverting members are configured to divert the working fluid toward the second opening or the first and second sets of fluid diverting members are configured to divert the working fluid away from the second opening.

3. The liquid ring rotor of any preceding claim, wherein the one or more fluid diverting members comprise:

a first plurality of plates, each extending at least partially radially from the shaft and fixedly attached to the shaft between the first opening and the second opening, wherein each plate of the first plurality of plates includes at least one plate opening therethrough, and wherein each plate of the first plurality of plates is spaced apart from other plates of the first plurality of plates;

a first vane set comprising one or more vanes disposed between adjacent plates of the first plurality of plates; and

a first chamber set comprising at least one chamber, wherein a first chamber of the chamber set is bounded at least by a pair of adjacent plates of the first plurality of plates and one or more vanes of the first vane set, the first chamber configured to admit liquid through a first chamber opening disposed further from the shaft than the at least one plate opening of each plate, and wherein a plate opening of the at least one plate opening of each of the pair of adjacent plates opens into the first chamber.

4. The liquid ring rotor of any preceding claim, wherein the one or more fluid diverting members comprise:

a second plurality of plates, each extending at least partially radially from the shaft and fixedly attached to the shaft in positions further from the first opening than the second opening is from the first opening, wherein each plate of the second plurality of plates includes at least one plate opening therethrough, and wherein each plate of the second plurality of plates is spaced apart from other plates of the second plurality of plates; and

a second vane set comprising one or more vanes, wherein each vane of the second vane set is impermeable to the working fluid, and wherein each vane of the second vane set extends between adjacent plates of the second plurality of plates and the shaft; and/or

wherein the at least one plate opening of the first plurality of plates has an overlapping area of zero with the at least one plate opening of another plate of the first plurality of plates and the at least one plate opening of the second plurality of plates has an overlapping area of zero with the at least one plate opening of another plate of the second plurality of plates.

5. The liquid ring rotor of any preceding claim, wherein the second plurality of plates is arranged to mirror an arrangement of the first plurality of plates about the second opening.

6. The liquid ring rotor of any preceding claim, wherein the first plurality of plates includes at least three plates, and a first spacing between a first plate of the first plurality of plates and a second plate of the first plurality of plates is different to a second spacing between the second plate of the first plurality of plates and a third plate of the first plurality of plates.

7. The liquid ring rotor of any preceding claim, wherein the vanes of each vane set are connected to the adjacent plates and the shaft to prevent the working fluid from bypassing said connections.

8. The liquid ring rotor of any preceding claim, comprising a heat exchanger with a first port arranged to exchange the working fluid with the first opening of the shaft, such that in use the working fluid is able to pass between the hollow interior portion of the shaft and the heat exchanger, and wherein the heat exchanger is fixedly connected to the shaft to rotate with the shaft in use.

9. The liquid ring rotor of claim 8, the rotor further comprising:

a companion shaft with a companion hollow interior portion, the companion hollow interior portion having a companion first opening and a companion second opening, the companion second opening disposed in a surface that extends along a length of the companion shaft and spaced apart from the companion first opening in the length of the companion shaft, wherein the companion shaft is configured to enable the working fluid to pass along the companion shaft through the companion hollow interior portion between the openings, and wherein the companion first opening is arranged to exchange working fluid with a second port of the heat exchanger that is in fluid communication with the first port of the heat exchanger, such that in use the working fluid is able to pass between the companion hollow interior portion and the heat exchanger, and wherein the heat exchanger is fixedly connected to the companion shaft to rotate with the companion shaft in use;

a companion first plurality of plates, each extending at least partially radially from the companion shaft and fixedly attached to the companion shaft between the companion first opening and the companion second opening, wherein each plate of the companion first plurality of plates includes at least one plate opening therethrough, and wherein each plate of the companion first plurality of plates is spaced apart from other plates of the companion first plurality of plates and each plate opening of the companion first plurality of plates has an overlapping area of zero with the plate openings of another plate of the companion first plurality of plates; and

a companion first vane set comprising one or more vanes, wherein each vane of the companion first vane set is impermeable to the working fluid, and wherein each vane of the companion first vane set extends between adjacent plates of the companion first plurality of plates and the shaft.

10. The liquid ring rotor of claim 9, the rotor further comprising:

a companion second plurality of plates, each extending at least partially radially from the companion shaft and fixedly attached to the companion shaft in positions further from the companion first opening than the companion second opening is from the companion first opening, wherein each plate of the companion second plurality of plates includes at least one plate opening therethrough, and wherein each plate of the companion second plurality of plates is spaced apart from other plates of the companion second plurality of plates and each plate opening of the companion second plurality of plates has an overlapping area of zero with the plate openings of another plate of the companion second plurality of plates, and wherein the companion second plurality of plates is arranged to mirror an arrangement of the companion first plurality of plates about the companion second opening;

a companion second vane set comprising one or more vanes, wherein each vane of the companion second vane set is impermeable to the working fluid, and wherein each vane of the companion second vane set extends between adjacent plates of the companion second plurality of plates and the companion shaft; and/or

wherein the companion first plurality of plates includes at least three plates, and a first spacing between a first plate of the companion first plurality of plates and a second plate of the companion first plurality of plates is different to a second spacing between the second plate of the companion first plurality of plates and a third plate of the companion first plurality of plates.

11. A liquid ring system arrangement, the arrangement comprising:

the liquid ring rotor of claim 10;

a vessel configured to enclose a container and a companion container;

the container disposed inside the vessel and arranged to surround each edge of the plates of the first plurality of plates and each edge of the plates of the second plurality of plates, and wherein the container is configured to retain a sealing liquid;

the companion container disposed inside the vessel and arranged to surround each edge of the plates of the companion first plurality of plates and each edge of the plates of the companion second plurality of plates, and wherein the companion container is configured to retain a sealing liquid; and

an insulation wall disposed inside the vessel between the container and the companion container to reduce the direct flow of working fluid and/or thermal energy therebetween, such that a majority of working fluid and/or thermal energy passed between the container and the companion container is passed via the heat exchanger.

12. The liquid ring system arrangement of claim 11, wherein the vessel encloses one or more reservoirs to collect sealing liquid spillages from the container and/or companion container in use, and wherein a sealing liquid return system is configured to transport the spillage into the container and/or companion container.

13. A method for operating a liquid ring rotor comprising:

providing the liquid ring rotor of one of claims 1 to 10; and

causing the liquid ring rotor to rotate about the shaft using a drive system.

14. A method for operating a liquid ring system arrangement comprising:

providing the liquid ring system arrangement of one of claims 11 or 12; and causing the liquid ring rotor to rotate about the shaft using a drive system.

Amendments to the claims have been filed as follows:

CLAIMS

1. A liquid ring rotor, for a liquid ring system, comprising:

a shaft with a hollow interior portion, the hollow interior portion having a first opening and a second opening that is spaced apart from the first opening in a length of the shaft, the second opening disposed in a surface that extends along the length of the shaft , wherein the shaft is configured to enable a working fluid to pass along the shaft through the hollow interior portion between the openings; and

plurality of fluid diverting members extending at least partially radially from the shaft and fixedly attached thereto, wherein the plurality of fluid diverting members are configured to divert fluid along the shaft with one or more helical flow paths around the shaft when rotated about the shaft in use, and wherein the fluid diverting members comprise a first set of fluid diverting members and a second set of fluid diverting members, the first set of fluid diverting members configured to divert a working fluid with a first helical flow path, and the second set of fluid diverting members configured to divert the working fluid with a second helical flow path that mirrors the rotational direction and/or direction of propagation of the first helical flow path.

2. The liquid ring rotor of claim 1,

wherein the first and second sets of fluid diverting members are configured to divert the working fluid toward the second opening or the first and second sets of fluid diverting members are configured to divert the working fluid away from the second opening.

3. The liquid ring rotor of any preceding claim, wherein the plurality of fluid diverting members comprise:

a first plurality of plates, each extending at least partially radially from the shaft and fixedly attached to the shaft between the first opening and the second opening, wherein each plate of the first plurality of plates includes at least one plate opening therethrough, and wherein each plate of the first plurality of plates is spaced apart from other plates of the first plurality of plates;

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a first vane set comprising one or more vanes disposed between adjacent plates of the first plurality of plates; and

a first chamber set comprising at least one chamber, wherein a first chamber of the chamber set is bounded at least by a pair of adjacent plates of the first plurality of plates and one or more vanes of the first vane set, the first chamber configured to admit liquid through a first chamber opening disposed further from the shaft than the at least one plate opening of each plate, and wherein a plate opening of the at least one plate opening of each of the pair of adjacent plates opens into the first chamber.

4. The liquid ring rotor of claim 3, wherein the plurality of fluid diverting members comprise:

a second plurality of plates, each extending at least partially radially from the shaft and fixedly attached to the shaft in positions further from the first opening than the second opening is from the first opening, wherein each plate of the second plurality of plates includes at least one plate opening therethrough, and wherein each plate of the second plurality of plates is spaced apart from other plates of the second plurality of plates; and

a second vane set comprising one or more vanes, wherein each vane of the second vane set is impermeable to the working fluid, and wherein each vane of the second vane set extends between adjacent plates of the second plurality of plates and the shaft; and/or

wherein the at least one plate opening of the first plurality of plates has an overlapping area of zero with the at least one plate opening of another plate of the first plurality of plates and the at least one plate opening of the second plurality of plates has an overlapping area of zero with the at least one plate opening of another plate of the second plurality of plates.

5. The liquid ring rotor of claim 4, wherein the second plurality of plates is arranged to mirror an arrangement of the first plurality of plates about the second opening.

6. The liquid ring rotor of one of claims 4 or 5, wherein the first plurality of plates includes at least three plates, and a first spacing between a first plate of the first

plurality of plates and a second plate of the first plurality of plates is different to a second spacing between the second plate of the first plurality of plates and a third plate of the first plurality of plates.

7. The liquid ring rotor of one of claims 4, 5, or 6, wherein the vanes of each vane set are connected to the adjacent plates and the shaft to prevent the working fluid from bypassing said connections.

8. The liquid ring rotor of any preceding claim, comprising a heat exchanger with a first port arranged to exchange the working fluid with the first opening of the shaft, such that in use the working fluid is able to pass between the hollow interior portion of the shaft and the heat exchanger, and wherein the heat exchanger is fixedly connected to the shaft to rotate with the shaft in use.

9. The liquid ring rotor of claim 8, the rotor further comprising:

a companion shaft with a companion hollow interior portion, the companion hollow interior portion having a companion first opening and a companion second opening, the companion second opening disposed in a surface that extends along a length of the companion shaft and spaced apart from the companion first opening in the length of the companion shaft, wherein the companion shaft is configured to enable the working fluid to pass along the companion shaft through the companion hollow interior portion between the openings, and wherein the companion first opening is arranged to exchange working fluid with a second port of the heat exchanger that is in fluid communication with the first port of the heat exchanger, such that in use the working fluid is able to pass between the companion hollow interior portion and the heat exchanger, and wherein the heat exchanger is fixedly connected to the companion shaft to rotate with the companion shaft in use;

a companion first plurality of plates, each extending at least partially radially from the companion shaft and fixedly attached to the companion shaft between the companion first opening and the companion second opening, wherein each plate of the companion first plurality of plates includes at least one plate opening therethrough, and wherein each plate of the companion first plurality of plates is spaced apart from other plates of the companion first plurality of plates and each plate opening of the companion first plurality of plates has an overlapping area of zero with the plate openings of another plate of the companion first plurality of plates; and

a companion first vane set comprising one or more vanes, wherein each vane of the companion first vane set is impermeable to the working fluid, and wherein each vane of the companion first vane set extends between adjacent plates of the companion first plurality of plates and the shaft.

10. The liquid ring rotor of claim 9, the rotor further comprising:

a companion second plurality of plates, each extending at least partially radially from the companion shaft and fixedly attached to the companion shaft in positions further from the companion first opening than the companion second opening is from the companion first opening, wherein each plate of the companion second plurality of plates includes at least one plate opening therethrough, and wherein each plate of the companion second plurality of plates is spaced apart from other plates of the companion second plurality of plates and each plate opening of the companion second plurality of plates has an overlapping area of zero with the plate openings of another plate of the companion second plurality of plates, and wherein the companion second plurality of plates is arranged to mirror an arrangement of the companion first plurality of plates about the companion second opening;

a companion second vane set comprising one or more vanes, wherein each vane of the companion second vane set is impermeable to the working fluid, and wherein each vane of the companion second vane set extends between adjacent plates of the companion second plurality of plates and the companion shaft;

11. The liquid ring rotor of one of claims 9 or 10, wherein the companion first plurality of plates includes at least three plates, and a first spacing between a first plate of the companion first plurality of plates and a second plate of the companion first plurality of plates is different to a second spacing between the

second plate of the companion first plurality of plates and a third plate of the companion first plurality of plates.

12. A liquid ring system arrangement, the arrangement comprising:

the liquid ring rotor of one of claims 10 or 11;

a vessel configured to enclose a container and a companion container;

the container disposed inside the vessel and arranged to surround each edge of the plates of the first plurality of plates and each edge of the plates of the second plurality of plates, and wherein the container is configured to retain a sealing liquid;

the companion container disposed inside the vessel and arranged to surround each edge of the plates of the companion first plurality of plates and each edge of the plates of the companion second plurality of plates, and wherein the companion container is configured to retain a sealing liquid; and

an insulation wall disposed inside the vessel between the container and the companion container to reduce the direct flow of working fluid and/or thermal energy therebetween, such that a majority of working fluid and/or thermal energy passed between the container and the companion container is passed via the heat exchanger.

13. The liquid ring system arrangement of claim 12, wherein the vessel encloses one or more reservoirs to collect sealing liquid spillages from the container and/or companion container in use, and wherein a sealing liquid return system is configured to transport the spillage into the container and/or companion container.

14. A method for operating a liquid ring rotor comprising:

providing the liquid ring rotor of one of claims 1 to 11; and

causing the liquid ring rotor to rotate about the shaft using a drive system.

15. A method for operating a liquid ring system arrangement comprising:

providing the liquid ring system arrangement of one of claims 12 or 13; and causing the liquid ring rotor to rotate about the shaft using a drive system.

Intellectual Property Office

Application No:	GB2215704.4	**Examiner:**	Rachel Smith
Claims searched:	1-14	**Date of search:**	12 December 2022

Patents Act 1977: Search Report under Section 17

Documents considered to be relevant:

Category	Relevant to claims	Identity of document and passage or figure of particular relevance
X	1, 2, 8, 13	DE 102018212088 B3 (ITTNER) See figures and paragraphs 34-40.
X	1, 13	EP 2439412 A2 (GEN ELECTRIC) See figures and paragraphs 19-21.
X	1, 13	WO 2006/134590 A1 (AGAM ENERGY SYSTEMS LTD) See figures and pages 3 & 4.
X	1, 2, 13	US 1831336 A (ABBOTT) See figure 1 and page 2 lines 12-75.
X	1, 13	US 2937499 A (INST SCHIENENFAHRZEUGE) See figures 1 & 2 and column 4 lines 40-64.

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X	Document indicating lack of novelty or inventive step	A	Document indicating technological background and/or state of the art.
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Field of Search:

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F01C; F04C; F25B

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International Classification:

Subclass	Subgroup	Valid From
F04C	0019/00	01/01/2006
F25B	0030/02	01/01/2006