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Hofbauer

(54) A THERMALLY-DRIVEN HEAT PUMP HAVING A HEAT EXCHANGER LOCATED BETWEEN DISPLACERS

(71) Applicant: **ThermoLift, Inc.**, Stony Brook, NY (US)

(72) Inventor: **Peter Hofbauer**, West Bloomfield, MI (US)

(73) Assignee: **ThermoLift, Inc.**, Stony Brook, NY (US)

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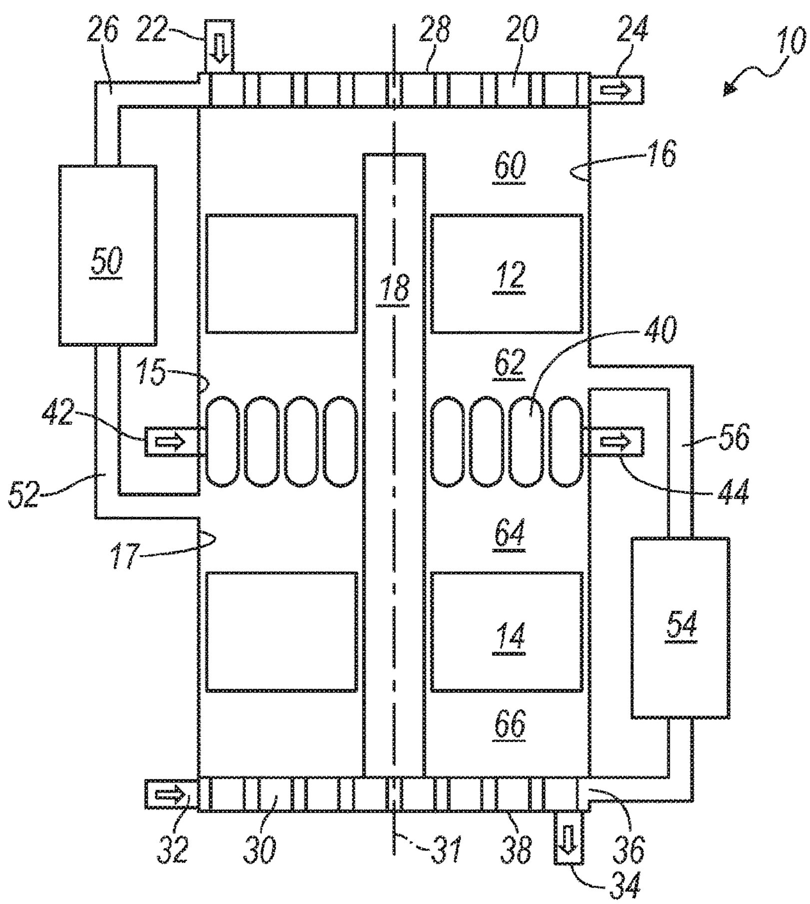
CPC ***F25B 9/14*** (2013.01); ***F25B 49/02*** (2013.01); *F25B 2309/003* (2013.01)

(57) **ABSTRACT**

A thermally driven heat pump is disclosed in which at least most of the warm heat exchanger is disposed within the cylinder between the hot and cold displacers. Such an arrangement is not suitable for a prior art heat pump in which movement of the displacers is based on a crank because it would lead to too much dead volume in the system. However, with mechatronically-controlled displacers in which the displacers are independently controlled, the displacers can reciprocate up to the heat exchanger. Such a configuration reduces dead volume compared to prior art Vuilleumier heat pumps in which the warm exchanger occupies a portion of an annular space between the cylinder in which the displacers move.



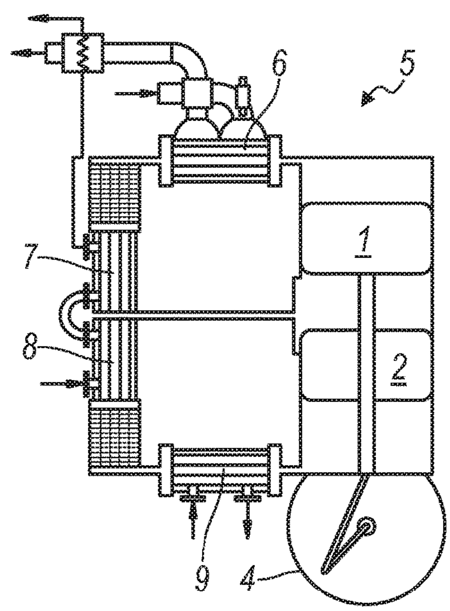


Fig. 1
(Prior Art)

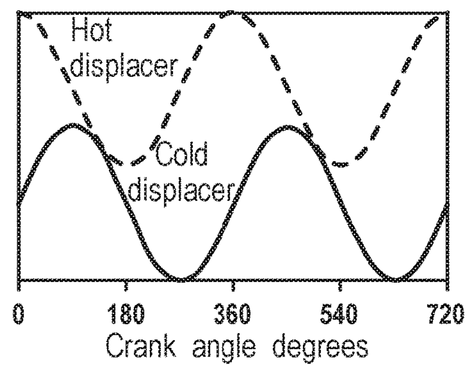


Fig. 2
(Prior Art)

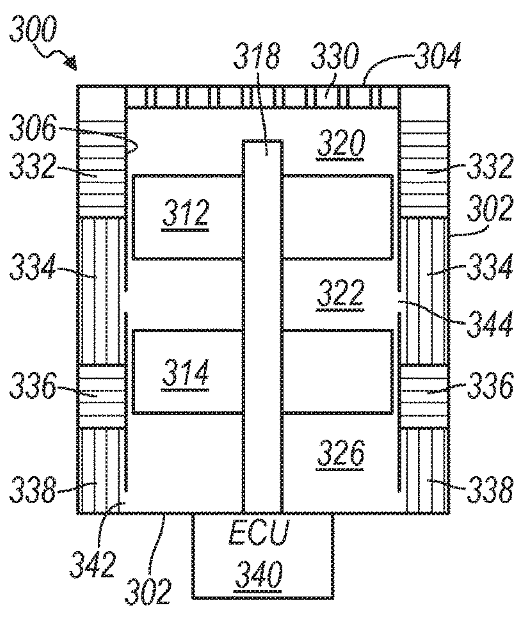


Fig. 3
(Prior Art)

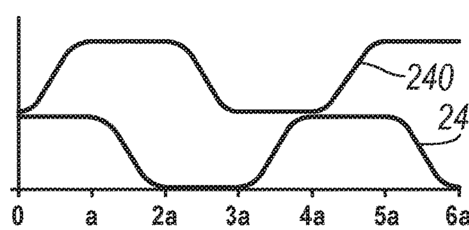


Fig. 4

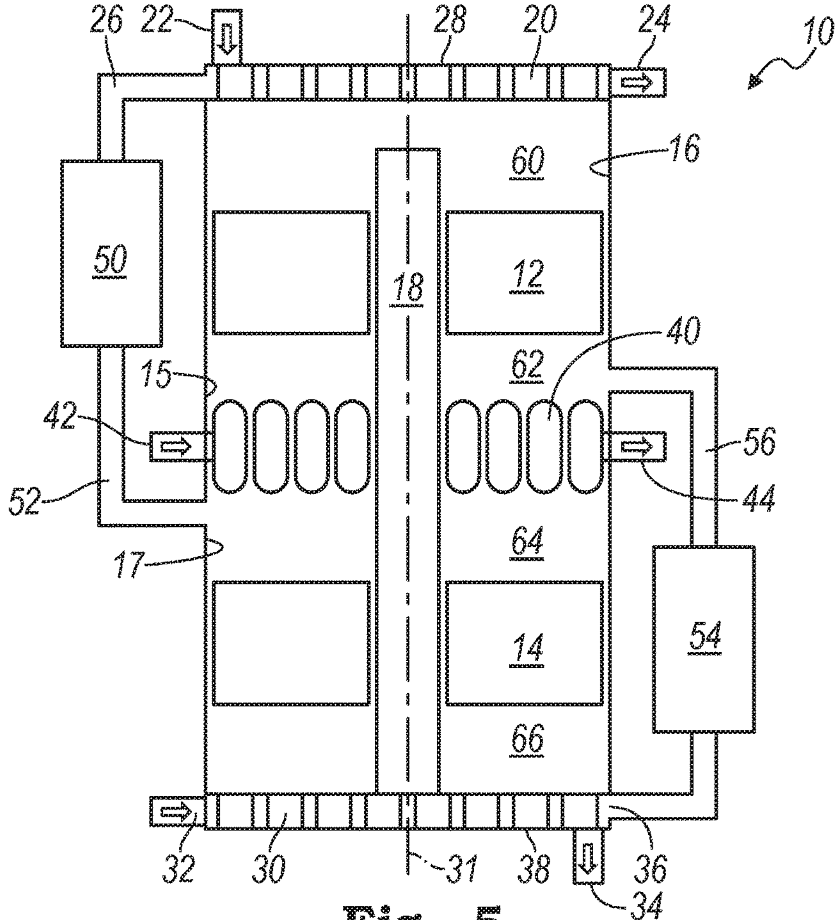

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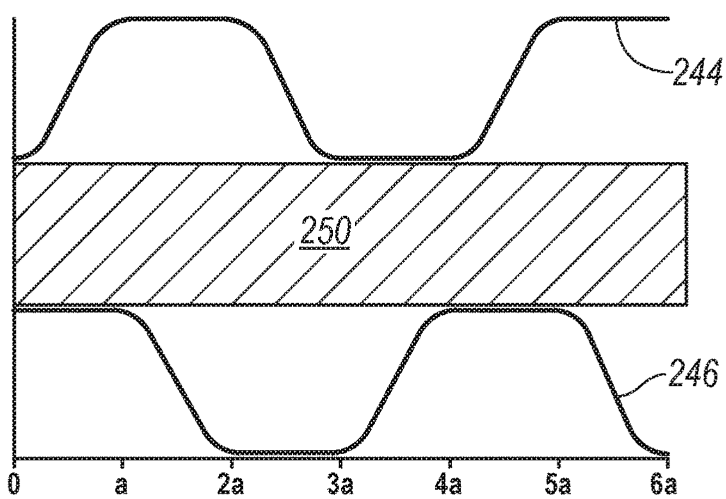
Fig. 5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5a
6a

Fig. 6

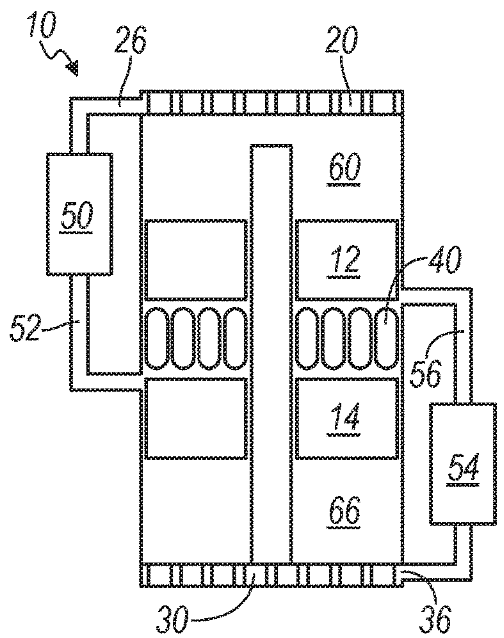

Fig. 7

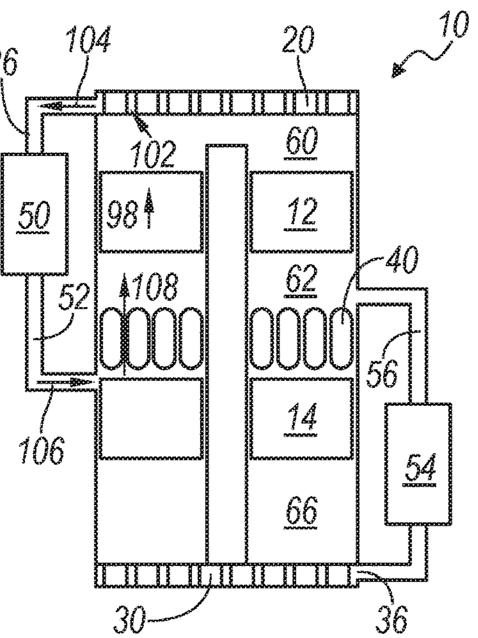

Fig. 8

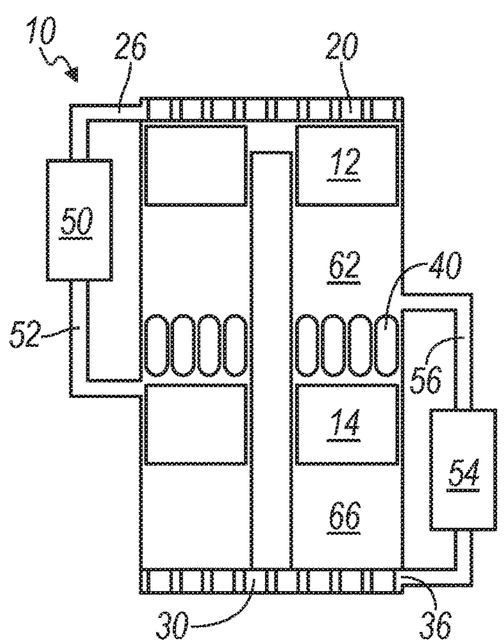

Fig. 9

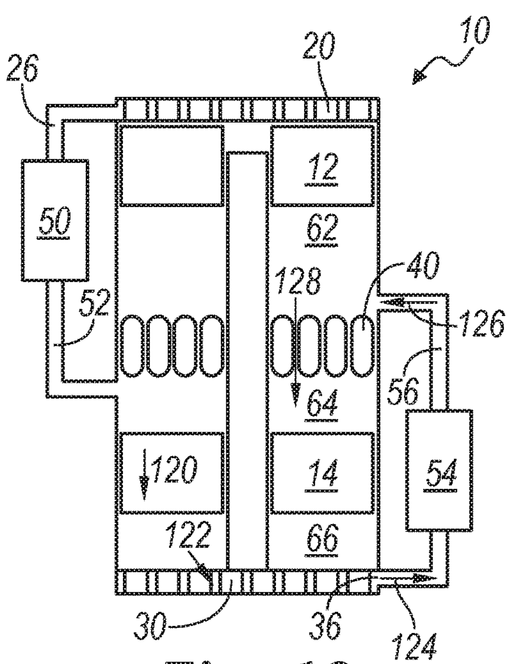

Fig. 10

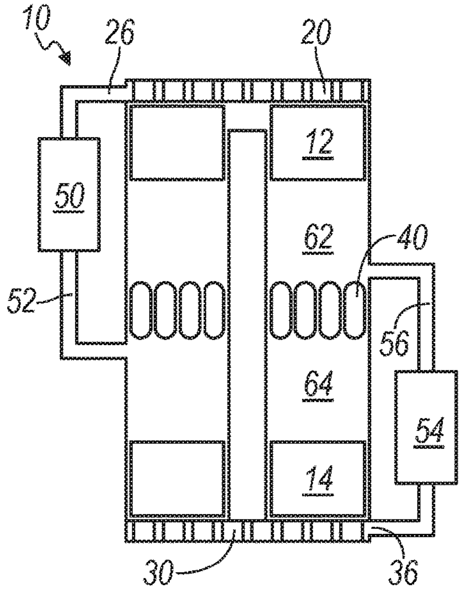

Fig. 11

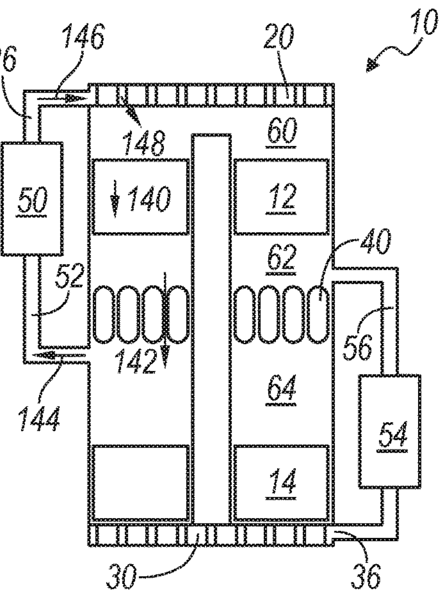

Fig. 12

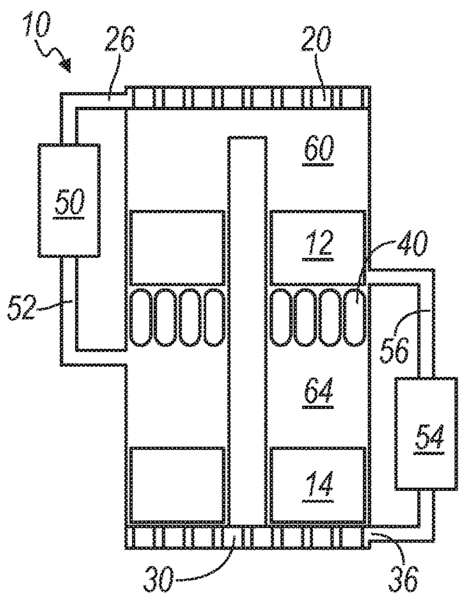

Fig. 13

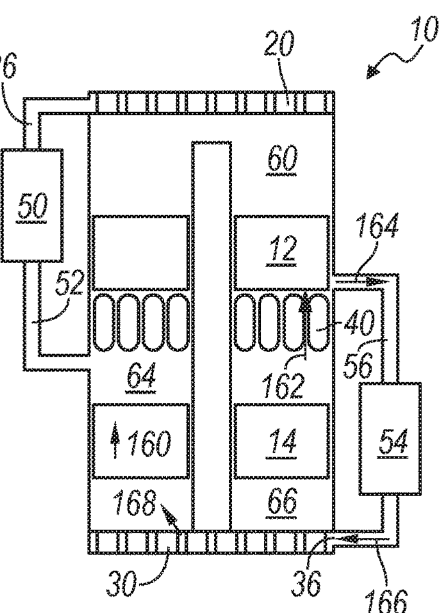

Fig. 14

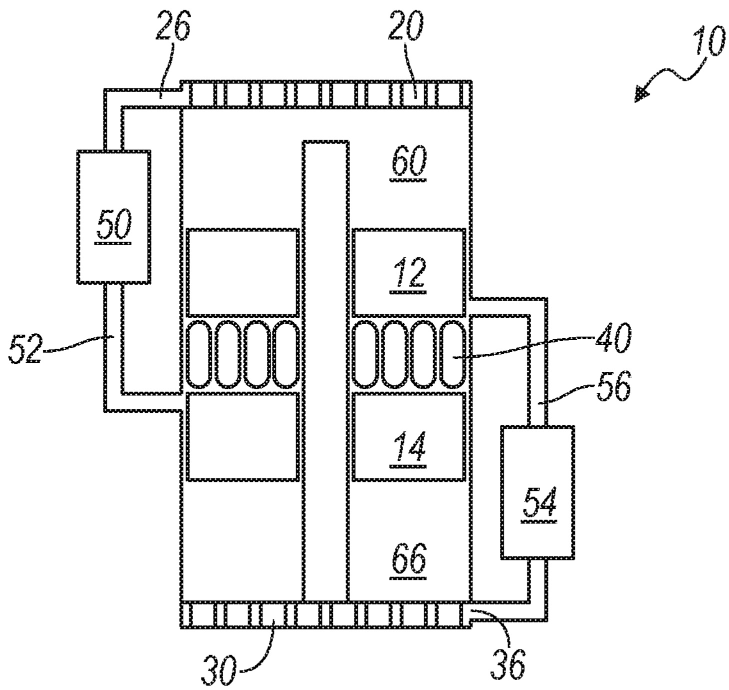
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Fig. 15

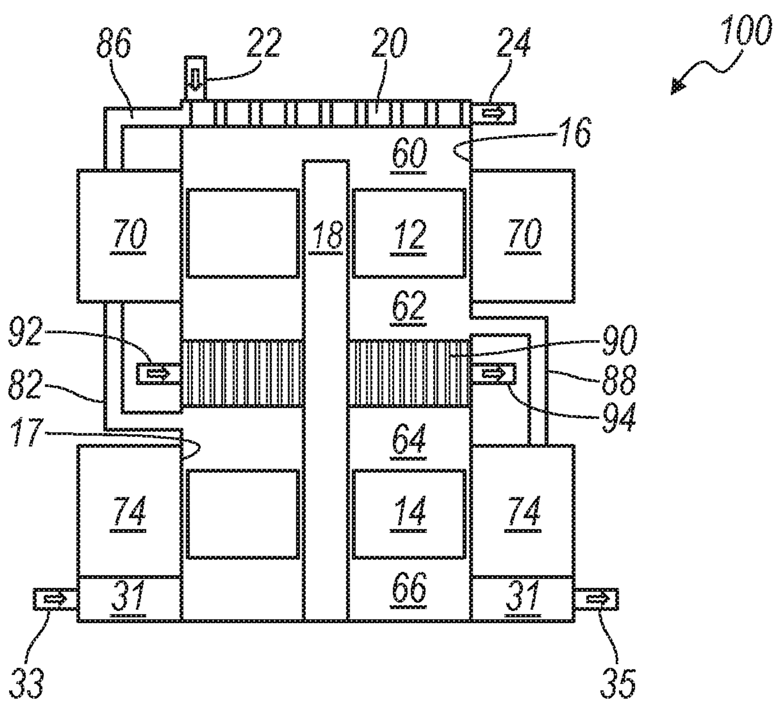
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Fig. 16

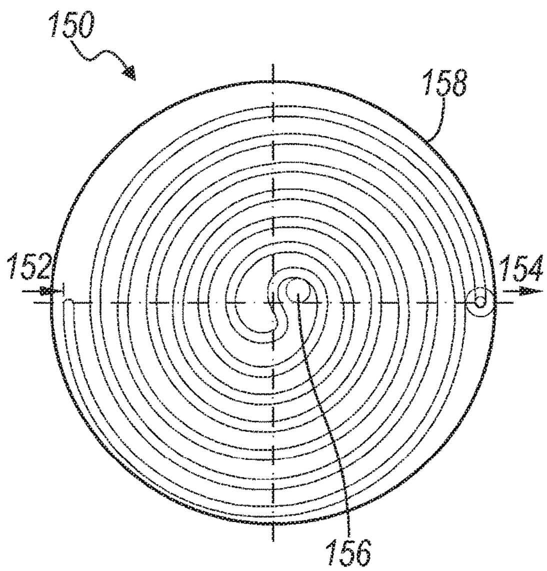

Fig. 17

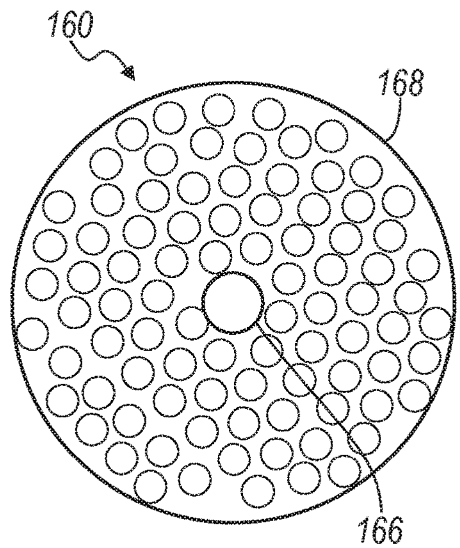

Fig. 18

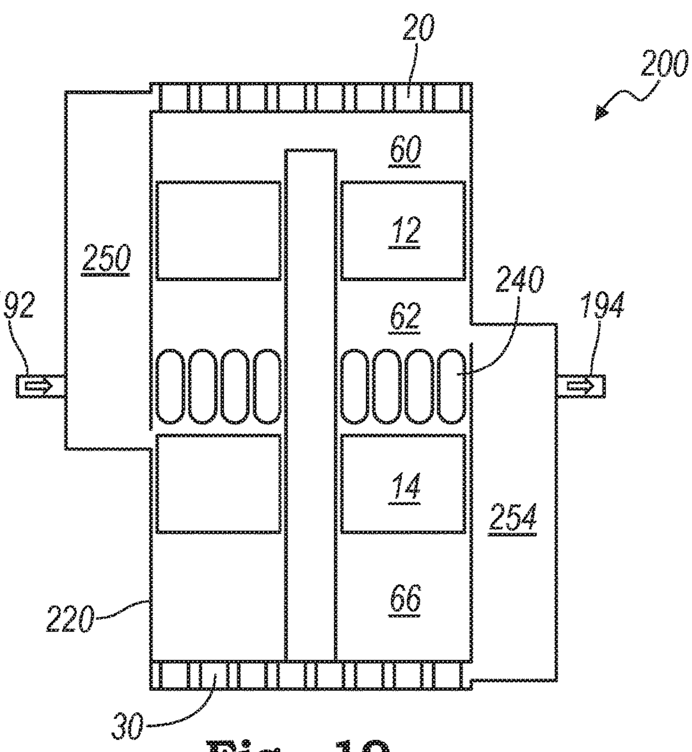

Fig. 19

A THERMALLY-DRIVEN HEAT PUMP HAVING A HEAT EXCHANGER LOCATED BETWEEN DISPLACERS

TECHNICAL FIELD

[0001] The present disclosure relates to arrangement of a heat exchanger in a thermally-driven heat pump.

[0002] BACKGROUND ART

[0003] A prior art Vuilleumier heat pump **5** is shown in FIG. **1**. A hot displacer **1** and a cold displacer **2** are driven by a crank **4**. In FIG. **2**, the upper end of cold displacer **2** and the lower end of hot displacer **1** are shown plotted in FIG. **2**, the two are out of phase by 90°. The paths of the two displacers overlap in the middle region of the cylinder in which the displacers reciprocate.

[0004] A thermally-driven heat pump in which the displacers are mechatronically actuated is disclosed in commonly-assigned patent application PCT/US13/36101 filed 11 Apr. 2013. The displacers are independently actuated such that one displacer may be held stationary while the other moves. In the heat pump disclosed in PCT/US13/36101, neither displacer reciprocates into the stroke of the other displacer, i.e., no overlap over in space of the two displacers. This is in contrast with the movement shown in FIG. **2** for a crank-driven Vuilleumier heat pump in which the displacers overlap in space, but not in time to prevent the displacers from colliding. A heat pump with independently-actuated displacers, such as disclosed in the PCT/US13/36101 application, presents opportunities not available in heat pumps in which the displacer movement is constrained by crank geometry.

DISCLOSURE

[0005] To exploit an opportunity provided by independent displacer operation over prior Vuilleumier heat pumps associated with crank movement, a heat pump is disclosed that includes a housing having: a hot cap, a cold cap, a hot cylinder portion proximate the hot cap, and a cold cylinder portion proximate the cold cap. The heat pump includes a cold displacer disposed within the cold cylinder portion, a hot displacer disposed within the hot cylinder portion, a post coupled to the cold cap and extending toward the hot cap along a centerline of the cold cylinder portion, and a substantially disk-shaped warm heat exchanger. The warm heat exchanger is located between the hot and cold displacers. An opening is defined in the warm heat exchanger to accommodate the post. A diameter of the opening in the warm heat exchanger is less than a diameter of the cold displacer. The warm heat exchanger is housed within a warm heat exchanger cylinder portion. In some embodiments, the hot cylinder portion, the cold cylinder portion, and the warm heat exchanger cylinder portion are of the same diameter.

[0006] The warm heat exchanger has an inlet that pierces the warm heat exchanger cylinder portion and an outlet that pierces the warm heat exchanger cylinder portion.

[0007] In one embodiment, the warm heat exchanger comprises at least one tube wrapped in a spiral with adjacent turns of the spiral separated by at most a predetermined distance. A working fluid within the hot and cold cylinder portions pass through the separations between adjacent turns of the spiral in response to movement of the displacers. Alternatively, the warm heat exchanger comprises a tube-and-shell heat exchanger with a working fluid within the hot and cold cylinder portions passing between the tubes in response to movement of the displacers. Alternatively, any suitable heat exchanger configuration may be provided for the warm heat exchanger.

[0008] The heat pump may further include a hot heat exchanger located proximate the hot cap and fluidly coupled to a chamber within the hot cylinder portion, a hot regenerator having one end fluidly coupled to the hot heat exchanger and one end fluidly coupled to a chamber within the cold cylinder portion, a cold heat exchanger fluidly coupled to a cold chamber within the cold cylinder portion, and a cold regenerator having one end fluidly coupled to the cold heat exchanger and one end fluidly coupled to a hot warm chamber within the hot cylinder portion.

[0009] The hot displacer reciprocation is limited by the hot cap and the warm heat exchanger. The cold displacer reciprocation is limited by the cold cap and the warm heat exchanger.

[0010] The heat pump may further include a hot heat exchanger proximate the hot cap and fluidly coupled to a hot chamber within the hot cylinder portion; a cold heat exchanger fluidly coupled to a cold chamber within the cold cylinder portion; an annular-shaped hot regenerator arranged outside the hot cylinder portion; and an annular-shaped cold regenerator arranged outside the cold cylinder portion. A first end of the hot regenerator is fluidly coupled to the hot heat exchanger and a second end of the hot regenerator is fluidly coupled to a cold warm chamber within the cold cylinder portion. A first end of the cold regenerator is fluidly coupled to the cold heat exchanger and a second end of the cold regenerator is fluidly coupled to a hot warm chamber within the hot cylinder portion.

[0011] The hot chamber is delimited by the hot cap, the hot cylinder portion, and the hot displacer. The cold chamber is delimited by the cold cap, the cold cylinder portion, and the cold displacer. The hot warm chamber is delimited by the warm heat exchanger, the hot cylinder portion, and the hot displacer. The cold warm chamber is delimited by the warm heat exchanger, the cold cylinder portion, and the cold displacer.

[0012] Also disclosed is a heat pump that includes a heat pump housing with: a hot cap, a cold cap, a hot cylinder portion near the hot cap, and a cold cylinder portion near the cold cap. The heat pump has a cold displacer disposed within the cold cylinder portion, a hot displacer disposed within the hot cylinder portion, and a substantially disk-shaped warm heat exchanger between the hot cylinder portion and the cold cylinder portion. The cold displacer reciprocates between the warm heat exchanger and the cold cap; and the hot displacer reciprocates between the warm heat exchanger and the hot cap.

[0013] The heat pump has a post coupled to the cold cap and extending toward the hot cap along a centerline of the cold cylinder portion. An opening is defined in the warm heat exchanger to accommodate the post. A diameter of the opening in the warm heat exchanger is less than a diameter of the cold displacer.

[0014] The heat pump further includes: a hot heat exchanger located proximate the hot cap and fluidly coupled to the hot cylinder portion, a hot regenerator having one end fluidly coupled to the hot heat exchanger and one end fluidly coupled to the cold cylinder portion, a cold heat exchanger fluidly coupled to the cold cylinder portion, and a cold regenerator having one end fluidly coupled to the cold heat exchanger and one end fluidly coupled to the hot cylinder portion.

[0015] The heat pump may include an annularly-shaped hot regenerator arranged outside the hot cylinder portion, an annularly-shaped cold regenerator arranged outside the cold cylinder portion, a hot chamber delimited by the hot cylinder portion, the hot displacer, and the hot cap, a hot warm chamber delimited by the hot cylinder portion, the hot displacer, and the warm heat exchanger, a cold warm chamber delimited by the cold cylinder portion, the cold displacer, and the warm heat exchanger, a cold chamber delimited by the cold cylinder portion, the cold displacer, and the cold cap, a hot heat exchanger fluidly coupled to the hot chamber and to the hot regenerator, and a cold heat exchanger fluidly coupled to the cold chamber and to the cold regenerator. The hot regenerator is fluidly coupled to the hot heat exchanger and the cold warm chamber. The cold regenerator is fluidly coupled to the cold heat exchanger and the hot warm chamber.

[0016] In some embodiments, the heat pump also has a hot heat exchanger disposed in the hot cap and a cold heat exchanger annularly arranged around the cold cylinder portion.

[0017] According to an embodiment of the present disclosure, a heat pump has a housing having a hot cap on one end of the housing and a cold cap on the other end of the housing, a cylinder within the housing, a substantially disk-shaped warm heat exchanger disposed within the housing and roughly centrally located between the hot cap and the cold cap, a hot displacer disposed in a portion of the cylinder between the warm heat exchanger and the hot cap, and a cold displacer disposed in a portion of the cylinder between the warm heat exchanger and the cold cap. The cylinder has a hot cylinder portion and a cold cylinder portion. A hot chamber is delimited by the hot cap, the hot cylinder portion, and the hot displacer. A cold chamber is delimited by the cold cap, the cold cylinder portion, and the cold displacer. A hot warm chamber is delimited by the warm heat exchanger, the hot cylinder portion, and the hot displacer. A cold warm chamber is delimited by the warm heat exchanger, the cold cylinder portion, and the cold displacer. The heat pump includes: a hot heat exchanger proximate fluidly coupled to the hot chamber, a cold heat exchanger fluidly coupled to the cold chamber, a hot regenerator, and a cold regenerator. A first end of the hot regenerator is fluidly coupled to the hot heat exchanger. A second end of the hot regenerator is fluidly coupled to a cold warm chamber. A first end of the cold regenerator is fluidly coupled to the cold heat exchanger. A second end of the cold regenerator is fluidly coupled to a hot warm chamber.

[0018] In some embodiments, the hot regenerator is annularly arranged outside the cylinder near the hot cap and the cold regenerator is annularly arranged outside the cylinder near the cold cap.

[0019] In heat pumps in which the displacers are driven by a crank arrangement, a warm heat exchanger cannot be placed within the cylinder unless the displacers were to be separated so that they do not overlap the same space. Such an arrangement would yield too much dead volume and would seriously impair thermal efficiency. The mechatronically-driven heat pump allows for the warm heat exchanger to be located within the cylinder without such a large dead volume. The gases in the cylinder readily flow over the warm heat exchanger compared with the prior-art configuration where the warm heat exchanger was in an annular volume outside the cylinder.

[0020] An advantage of the disclosed configuration is that the warm heat exchanger is more easily manufactured compared to a heat exchanger that resides in an annular volume. Another advantage of embodiments in which recuperators are disposed in the passages is that the recuperators are more easily formed in a circular or other simple cross-sectional shape compared with an annulus. Yet another advantage in some alternatives is a reduction in dead volume by obviating passages to and from the warm heat exchanger.

[0021] Vuilleumier heat pump **5** in FIG. **1** has four heat exchangers: a hot heat exchanger **6**, a warm-hot heat exchanger **7**, a warm-cold heat exchanger **8**, and a cold heat exchanger **9**. When hot displacer **1** moves downward and cold displacer **2** is mostly stationary (moving at its slowest near reversal at its lower position), or moving minimally, gases between displacers **1** and **2** are pushed through warm-hot heat exchanger **7** into a hot chamber (volume in cylinder above hot displacer **1**). When cold displacer **2** moves upward and hot displacer **1** is mostly stationary (moving at its slowest near reversal at its upper position) gases between displacers **1** and **2** are pushed through warm-cold heat exchanger **8** through a regenerator and a cold chamber (volume in cylinder below cold displacer **2**). There are times in the cycle in which gases are pulled into the space between the displacers from warm-hot displacer **7** and other times from warm-cold displacer **8**. This present inefficiencies in there being more dead space than if a single heat exchanger could be used, simply the fact that there are two heat exchangers and the cost and complication, and the extra plumbing for the two heat exchangers. Yet other advantages according to embodiments of the present disclosure include: a single warm heat exchanger and the lack of plumbing from the space between the displacers to the warm heat exchanger. Instead, the gases flow directly from one side of the single warm heat exchanger.

BRIEF DESCRIPTION OF THE DRAWINGS

[0022] FIG. **1** is an illustration of a prior art Vuilleumier heat pump in which displacers are crank driven;

[0023] FIG. **2** is an illustration of displacer movement of the crank-driven displacers of FIG. **1**;

[0024] FIG. **3** is a heat pump with mechatronically-actuated displacers;

[0025] FIGS. **4** and **16** are illustrations of a heat pump according to embodiments of the present disclosure;

[0026] FIGS. **5**-**15** are illustrations of the heat pump of FIG. **4** in a range of displacer positions;

[0027] FIGS. **17** and **18** are plan views of warm heat exchanger embodiments; and

[0028] FIG. **19** is an illustration of a heat pump according to an embodiment of the disclosure.

DETAILED DESCRIPTION

[0029] As those of ordinary skill in the art will understand, various features of the embodiments illustrated and described with reference to any one of the Figures may be combined with features illustrated in one or more other Figures to produce alternative embodiments that are not explicitly illustrated or described. The combinations of features illustrated provide representative embodiments for typical applications. However, various combinations and modifications of the features consistent with the teachings of the present disclosure may be desired for particular applications or implementations. Those of ordinary skill in the art may recognize similar applications or implementations whether or not explicitly described or illustrated.

[0030] A thermally-driven heat pump **300** has a housing **302** which has a hot cap **304** on each end is shown in FIG. **3**. Inside housing **302** is a cylinder **306**. In the annular space between housing **302** and cylinder **306**, a hot regenerator **332**, a warm heat exchanger **334**, a cold regenerator **336**, and a cold heat exchanger **338** are arranged. A hot displacer **312** and a cold displacer **314** are disposed within cylinder **306** and delimit hot chamber **320**, warm chamber **322**, and cold chamber **326**. A post **318** is coupled to cold cap **302**. Displacers **312** and **314** reciprocate within cylinder **306** under control by an ECU **340**. Displacers **312** and **314** have springs (not shown) that cause them to oscillate between upper and lower positions, respectively. Also not shown are the electromagnets and ferromagnetic plates associated with displacers **312** and **314**. ECU **340** provides a signal to the electromagnets to attract the ferromagnetic plates to grab the displacer in one of its extreme positions. The electromagnet can hold its associated displacer until ECU **340** commands the electromagnet to de-energize to allow the displacer to act under spring control to travel to its other extreme position. More detail of mechatronic control of the displacers is found in: PCT/US13/36101 filed 11 Apr. 2013.

[0031] Continuing to refer to FIG. **3**, an energy source (not shown) provides energy to a working fluid within housing **302** via a hot heat exchanger **330**. When hot displacer **312** moves upward, gases flow from hot chamber **320** into hot heat exchanger **330** into hot regenerator **332** into warm heat exchanger **334** through openings **344** in cylinder **306** into the into warm chamber **322** and in the reverse order upon hot displacer **312** moving downward. Upon cold displacer **314** moving downward, the working fluid in cold chamber **326** moves through openings **342** in cylinder **316** into cold heat exchanger **338**, into cold regenerator **336**, into hot heat exchanger **334** into warm chamber **332** via openings **344** in cylinder **306** and in reverse order upon cold displacer **314** moving upward. Heat exchangers **334** and **338** have two fluids exchanging energy: the working fluid and a second fluid, such as a liquid. In one embodiment, the heat pump is providing domestic heating and the second fluid is water that is heated within warm heat exchanger **334**. Energy is extracted from a fluid provided to cold heat exchanger **338** in such an embodiment. In another embodiment, a second fluid is provided to cold heat exchanger **338** for cooling purposes. In such embodiment, energy is exhausted via another fluid provided to warm heat exchanger **334**. Provisions for inlets and outlets for a fluid other than the working fluid to heat exchangers **330**, **334**, and **338** are not shown in FIG. **3**.

[0032] One example of motion of the displacers of FIG. **3** is illustrated in FIG. **4**. Curve **240** is an illustration of the movement of the bottom edge of hot displacer (**312** in FIG. **3**) and line **242** shows motion of the upper edge of the cold displacer (**314** in FIG. **3**). At time **0**, the displacers are proximate each other. At time **0**, the electromagnet holding the hot displacer is de-energized to allow the hot displacer to travel toward its upper position. The motion is roughly sinusoidal. At time a, the upper electromagnet is energized to grab and hold the hot displacer. From time **0** to a, the cold displacer remains stationary at its upper position. At time a, the electromagnet grabbing the cold displacer is de-energized to allow the cold displacer to travel downward. At time **2***a*, the electromagnet associated with the cold displacer grabs the cold displacer. Electromagnets are energized and de-energized to complete a cycle is complete from time **0** to time **4***a* and continuing on. The dwell periods of the hot and cold displacers can be lengthened to alter the cycle to meet heating or cooling demand.

[0033] In FIG. **5**, an interior of a heat pump **10** having a hot displacer **12** which reciprocates within a hot cylinder portion **16** and a cold displacer **14** which reciprocates within a cold cylinder portion **17** is illustrated. The electronic controls to manage the electromagnets (not shown) are provided through post **18**. Post **18** extends from cold cap **38** toward hot cap **28** along centerline **31**. A hot chamber **60** is above hot displacer **12** and a hot warm chamber **62** is below hot displacer **12**. A cold chamber **66** is below cold displacer **14** and a cold warm chamber **64** is above cold displacer **14**. A hot heat exchanger **20** is proximate a hot cap **28** of heat pump **10**. Hot heat exchanger **20** may, in some embodiments, be in contact with a burner. Or, in other embodiments, another energy source, such as a solar collector is used. A warm heat exchanger **40** is within a warm heat exchanger cylinder portion **15** which is located between hot cylinder portion **16** and cold cylinder portion **17**. Warm heat exchanger **40** is substantially in a disk shape, although with an opening in the center to accommodate post **18**. A fluid passes inside the tubes of warm heat exchanger **40** with an inlet **42** and an exit **44**. The working fluid within heat pump **10** passes by warm heat exchanger **40** upon movement of displacers **12** and **14**. Energy is exchanged with a fluid provided to warm heat exchanger through inlet **42**. A cold heat exchanger **30** is proximate a cold cap **38** of heat pump **10**. A fluid passes inside the tubes of cold heat exchanger **30** with an inlet **32** and an outlet **34**. The working fluid passes on the outside of the tubes of cold heat exchanger **30** with the gases flowing from cold chamber **66** to passage **36** into a cold displacer **54**, into a passage **56** and exits hot warm chamber **62**, when displacer **14** moves downward; and in reverse when displacer **14** moves upward. A hot regenerator **50** is located outside of cylinder **16** in passages **26** and **52**. When hot displacer **12** moves upward, gases in hot chamber **60** flows on the outer surface of heat exchanger **20** into passage **26** through hot regenerator **50** through passage **52** and exits into lower warm exchanger **64**.

[0034] In the embodiment in FIG. **5**, cylinders **15**, **16**, and **17** are the same size. Alternatively, one of cylinders **16** and **17** has greater diameter than the other cylinder.

[0035] Movement of the displacers of FIG. **5** is shown in FIG. **6**. Movement of hot displacer **12** is shown by curve **244** and movement of cold displacer is shown by curve **246**. The movement of the displacers, curves **240** and **242**, is the same as the movement of the displacers, curves **244** and **246**, as shown in FIG. **4** except that the two, in FIG. **5**, are separated from each other by the height of a warm heat exchanger **250**.

[0036] In FIGS. **7-15**, a cycle in heat pump **10** is shown. Starting in FIG. **7**, hot displacer **12** is at its lower position and cold displacer **14** is at its upper position.

[0037] In FIG. **8**, hot displacer **12** is moving upward, as shown by arrow **98**. Movement of hot displacer **12** causes gas **102** in hot chamber **60** to pass through heat exchanger **20** into passage **26**, as shown by arrow **104**, through hot generator **50** into passage **52**, as shown by arrow **106**, and through warm exchanger **40** into hot warm chamber **62**, as shown by arrow **108**.

[0038] In FIG. **9**, hot displacer **12** has reached its upper position and cold displacer **14** is still in its upper position.

[0039] In FIG. **10**, cold displacer **14** is moving downwards, as indicated by arrow **120**. Gas is pushed out of cold chamber **66**, as shown by arrow **122**, into cold heat exchanger **30** into passage **36**, as shown by arrow **124**, into cold regenerator **54** into passages **56**, as shown by arrow **126**, into hot warm chamber **62**, through warm heat exchanger **40**, as illustrated by arrow **128**, and finally into cold warm chamber **64**.

[0040] In FIG. **11**, cold displacer has reached is lower position and hot displacer **12** is still in it upper position.

[0041] In FIG. **12**, cold displacer **12** moves downwardly, as indicated by arrow **140**. Gas is pushed out of hot warm chamber **62** through warm heat exchanger **40**, as indicated by arrow **142**, into passage **52**, as indicated by arrow **144**, into cold regenerator **50**, into passage **26**, as indicated by arrow **146**, into hot heat exchanger **20**, and into hot chamber **60**, as indicated by arrow **148**. In FIG. **13**, hot displacer **14** reaches its lower position and cold displacer **12** remains at its upper position.

[0042] In FIG. **14**, cold displacer **14** moves upwardly as indicated by arrow **160**. Gas from upper warm chamber **64** is forced through warm heat exchanger **40**, as indicated by arrow **162**, into passage **56**, as indicated by arrow **164**, into cold regenerator **54** into passage **36**, as indicated by arrow **166** through cold heat exchanger **30** into cold chamber **66**, as indicated by arrow **168**.

[0043] In FIG. **15**, cold displacer **14** has achieved it upper position while hot displacer remains in its lower position. The cycle is completed as the position of the displacers in FIG. **15** is the same as the start position shown in FIG. **5**.

[0044] The description of the gas movement implies that the gases make a complete loop. However, the gases move in the path described, but gases starting on one side of the displacer do not make the complete path to the other side of the displacer, but instead make travel through part of the loop.

[0045] An alternative heat pump **100** configuration is illustrated in FIG. **16** in which regenerators are integral with the housing. The configuration in FIG. **16** shows hot regenerator **70** annularly arranged outside of cylinder **16** and cold regenerator **74** annularly arrangement outside of cylinder **17**. Also shown in heat pump **100** is a tube and shell heat exchanger **90**. An inlet **92** allows a liquid, as an example, to travel through the shell of heat exchanger **90**. The fluid exits at **94**. The working fluid within heat pump **100** passes within the tubes of heat exchanger **90**. In FIG. **16**, a cold heat exchanger **31** is annularly arranged around cylinder **17**. Cold heat exchanger **31** is fluidly coupled to cold regenerator **74** and to cold chamber **66**. The other fluid provided to cold heat exchanger **31** has an inlet **33** and an outlet **35**.

[0046] A view down the cylinder of the two warm heat exchanger alternatives previously illustrated is shown in FIGS. **17** and **18**. In FIG. **17**, a spiral heat exchanger **150** similar to that illustrated in FIGS. **4-15** is shown within a cylinder portion **158**. Due to the reversal in the center of the spiral, both an inlet **152** and an outlet **154** are on the periphery of the spiral. An opening **156** is provided through spiral heat exchanger **150** to accommodate a post that carries electrical conductors (element **18** shown in FIG. **4**).

[0047] A shell-and-tube heat exchanger **160** similar to that illustrated in FIG. **16** is shown in FIG. **18**. Heat exchanger **160** is contained within a cylinder **168**. An opening **166** is provided through spiral heat exchanger **150** to accommodate the post.

[0048] In the embodiment of heat pump **200** in FIG. **19**, regenerators **250** and **254** are placed along cylinder wall **220** in which displacers **12** and **14** reciprocate. A heat exchanger **240** is located between displacers **12** and **14**. An opening through cylinder wall **220** fluidly connects hot regenerator **250** with the chamber **62**, but on the lower side of heat exchanger **240**. In regards to cold regenerator **254**, there is an opening in cylinder wall **220** to fluidly connect cold regenerator **254** with chamber **62**, on the upper side of heat exchanger **240**. Water or other fluid to be heated is provided to heat exchanger **240** through inlet **192** that goes through hot regenerator **250** and exits through outlet **194**, which goes through cold regenerator **254**. In other embodiments, the lower portion of the space for hot regenerator **250** and the upper portion of the space for cold regenerator **254** is actually an extension of heat exchanger **240**. In such embodiment, part of heat exchanger **240** is within cylinder wall **220** and part of heat exchanger **240** is outside cylinder wall **220**.

[0049] While the best mode has been described in detail with respect to particular embodiments, those familiar with the art will recognize various alternative designs and embodiments within the scope of the following claims. While various embodiments may have been described as providing advantages or being preferred over other embodiments with respect to one or more desired characteristics, as one skilled in the art is aware, one or more characteristics may be compromised to achieve desired system attributes, which depend on the specific application and implementation. These attributes include, but are not limited to: cost, strength, durability, life cycle cost, marketability, appearance, packaging, size, serviceability, weight, manufacturability, ease of assembly, etc. The embodiments described herein that are characterized as less desirable than other embodiments or prior art implementations with respect to one or more characteristics are not outside the scope of the disclosure and may be desirable for particular applications.

1. A heat pump, comprising:

a heat pump housing having: a hot cap, a cold cap, a hot cylinder portion proximate the hot cap, and a cold cylinder portion proximate the cold cap;

a cold displacer disposed within the cold cylinder portion;

a hot displacer disposed within the hot cylinder portion; and

a substantially disk-shaped warm heat exchanger between the hot cylinder portion and the cold cylinder portion wherein:

the cold displacer reciprocates between the warm heat exchanger and the cold cap; and

the hot displacer reciprocates between the warm heat exchanger and the hot cap.

2. The heat pump of claim **1**, further comprising:

a post coupled to the cold cap and extending toward the hot cap along a centerline of the cold cylinder portion wherein:

an opening is defined in the warm heat exchanger to accommodate the post; and

a diameter of the opening in the warm heat exchanger is less than a diameter of the cold displacer.

3. The heat pump of claim 1, further comprising:
a hot heat exchanger located proximate the hot cap and fluidly coupled to the hot cylinder portion; and
a hot regenerator having one end fluidly coupled to the hot heat exchanger and one end fluidly coupled to the cold cylinder portion.
4. The heat pump of claim 1, further comprising:
a cold heat exchanger fluidly coupled to the cold cylinder portion; and
a cold regenerator having one end fluidly coupled to the cold heat exchanger and one end fluidly coupled to the hot cylinder portion.
5. The heat pump of claim 1, further comprising:
a hot regenerator arranged outside the hot cylinder portion; and
a cold regenerator arranged outside the cold cylinder portion.
6. The heat pump of claim 5, further comprising:
a hot chamber delimited by the hot cylinder portion, the hot displacer, and the hot cap;
a hot warm chamber delimited by the hot cylinder portion, the hot displacer, and the warm heat exchanger;
a cold warm chamber delimited by the cold cylinder portion, the cold displacer, and the warm heat exchanger;
a cold chamber delimited by the cold cylinder portion, the cold displacer, and the cold cap; and
a hot heat exchanger fluidly coupled to the hot chamber and to the hot regenerator;
a cold heat exchanger fluidly coupled to the cold chamber and to the cold regenerator, wherein:
the hot regenerator is fluidly coupled to the hot heat exchanger and the cold warm chamber; and
the cold regenerator is fluidly coupled to the cold heat exchanger and the hot warm chamber.
7. The heat pump of claim 1, further comprising:
a hot heat exchanger disposed in the hot cap; and
a cold heat exchanger annularly arranged around the cold cylinder portion.
8. The heat pump of claim 1 wherein:
the warm heat exchanger comprises at least one tube wrapped in a spiral;
adjacent turns of the spiral are separated by at most a predetermined distance; and
a working fluid within the hot and cold cylinder portions pass through the separations between adjacent turns of the spiral in response to movement of the displacers.
9. The heat pump of claim 1, further comprising:
a hot heat exchanger proximate the hot cap and fluidly coupled to a hot chamber within the hot cylinder portion;
a cold heat exchanger fluidly coupled to a cold chamber within the cold cylinder portion;
an annular-shaped hot regenerator arranged outside the hot cylinder portion; and
an annular-shaped cold regenerator arranged outside the cold cylinder portion wherein:
a first end of the hot regenerator is fluidly coupled to the hot heat exchanger;
a second end of the hot regenerator is fluidly coupled to a cold warm chamber within the cold cylinder portion;
a first end of the cold regenerator is fluidly coupled to the cold heat exchanger; and
a second end of the cold regenerator is fluidly coupled to a hot warm chamber within the hot cylinder portion.
10. The heat pump of claim 1 wherein the warm heat exchanger is housed within a warm heat exchanger cylinder portion; and the hot cylinder portion, the cold cylinder portion, and the warm heat exchanger cylinder portion are of the same diameter.
11. The heat pump of claim 1 wherein the warm heat exchanger is housed within a warm heat exchanger portion; and the warm heat exchanger has an inlet that pierces the warm heat exchanger cylinder portion and an outlet that pierces the warm heat exchanger cylinder portion.
12. A heat pump, comprising:
a housing having a hot cap on one end of the housing and a cold cap on the other end of the housing;
a cylinder within the housing;
a substantially disk-shaped warm heat exchanger disposed within the housing and roughly centrally located between the hot cap and the cold cap;
a hot displacer disposed in a portion of the cylinder between the warm heat exchanger and the hot cap; and
a cold displacer disposed in a portion of the cylinder between the warm heat exchanger and the cold cap.
13. The heat pump of claim 12 wherein the cylinder has a hot cylinder portion and a cold cylinder portion, the heat pump further comprising:
a hot chamber delimited by the hot cap, the hot cylinder portion, and the hot displacer;
a cold chamber delimited by the cold cap, the cold cylinder portion, and the cold displacer;
a hot warm chamber delimited by the warm heat exchanger, the hot cylinder portion, and the hot displacer;
a cold warm chamber delimited by the warm heat exchanger, the cold cylinder portion, and the cold displacer;
a hot heat exchanger proximate fluidly coupled to the hot chamber;
a cold heat exchanger fluidly coupled to the cold chamber;
a hot regenerator; and
a cold regenerator, wherein:
a first end of the hot regenerator is fluidly coupled to the hot heat exchanger;
a second end of the hot regenerator is fluidly coupled to a cold warm chamber;
a first end of the cold regenerator is fluidly coupled to the cold heat exchanger; and
a second end of the cold regenerator is fluidly coupled to a hot warm chamber.
14. The heat pump of claim 13 wherein:
the hot regenerator is annularly arranged outside the cylinder near the hot cap; and
the cold regenerator is annularly arranged outside the cylinder near the cold cap.
15. A heat pump, comprising:
a heat pump housing having: a hot cap, a cold cap, a hot cylinder portion proximate the hot cap, and a cold cylinder portion proximate the cold cap;
a cold displacer disposed within the cold cylinder portion;
a hot displacer disposed within the hot cylinder portion; and

a substantially disk-shaped warm heat exchanger wherein:

the warm heat exchanger is located between the hot and cold displacers.

16. The heat pump of claim **1.5** wherein:

the warm heat exchanger is housed within a warm heat exchanger cylinder portion; and

the hot cylinder portion, the cold cylinder portion, and the warm heat exchanger cylinder portion are of the same diameter.

17. The heat pump of claim **15** wherein the warm heat exchanger has an inlet that pierces the warm heat exchanger cylinder portion and an outlet that pierces the warm heat exchanger cylinder portion.

18. The heat pump of claim **15** wherein:

the warm heat exchanger comprises at least one tube wrapped in a spiral;

adjacent turns of the spiral are separated by at most a predetermined distance; and

a working fluid within the hot and cold cylinder portions pass through the separations between adjacent turns of the spiral in response to movement of the displacers.

19. The heat pump of claim **15**, further comprising:

a hot heat exchanger located proximate the hot cap and fluidly coupled to a chamber within the hot cylinder portion;

a hot regenerator having one end fluidly coupled to the hot heat exchanger and one end fluidly coupled to a chamber within the cold cylinder portion.

20. The heat pump of claim **15**, further comprising:

a hot heat exchanger proximate the hot cap and fluidly coupled to a hot chamber within the hot cylinder portion;

a cold heat exchanger fluidly coupled to a cold chamber within the cold cylinder portion;

an annular-shaped hot regenerator arranged outside the hot cylinder portion; and

an annular-shaped cold regenerator arranged outside the cold cylinder portion wherein:

a first end of the hot regenerator is fluidly coupled to the hot heat exchanger;

a second end of the hot regenerator is fluidly coupled to a cold warm chamber within the cold cylinder portion;

a first end of the cold regenerator is fluidly coupled to the cold heat exchanger; and

a second end of the cold regenerator is fluidly coupled to a hot warm chamber within the hot cylinder portion.

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