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(54) Title: FIELD-ACTIVE HEAT PUMPING USING LIQUID MATERIALS

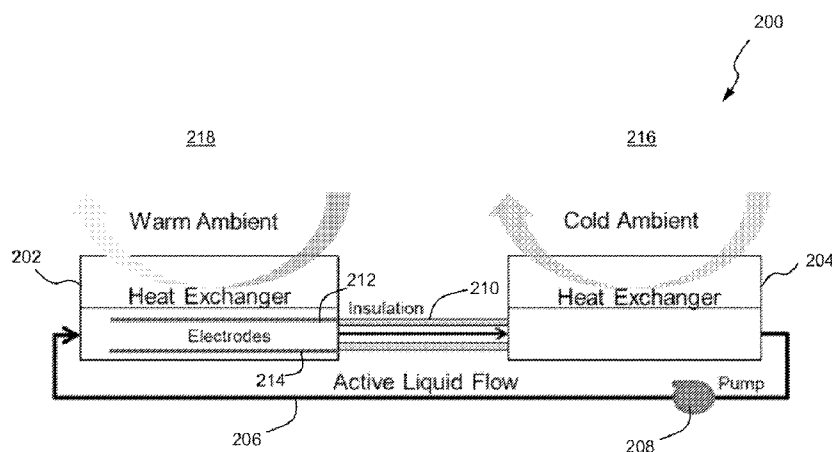


FIG. 2

(57) Abstract: Heat pump cycle provided with a fluidic loop connecting two heat exchangers. The fluidic loop is filled with an electro-caloric liquid as a heat transfer medium. Applying electric field in one of the heat exchangers the temperature of the electro-caloric liquid is changed.

FIELD-ACTIVE HEAT PUMPING USING LIQUID MATERIALS

FIELD OF THE INVENTION

[0001] The subject matter disclosed herein relates generally to the field of electrocaloric materials and, more particularly, to a heat pump system that uses liquid-phase electrocaloric materials.

BACKGROUND OF THE INVENTION

[0002] Typical heating, ventilation, and air conditioning functionality ("HVAC") is provided by vapor compression, or reverse Rankine, cycles. These devices use two-phase fluorinated refrigerants which are under high pressure and exhibit significant global warming potential when they inevitably leak into the atmosphere. Also, the compression process cannot be efficiently scaled to small sizes restricting energy savings achievable through distributed heat pumping. Finally, such compressors tend to be noisy. A scalable, quiet, and environmentally friendly alternative is desired.

[0003] Materials that exhibit adiabatic temperature change when subject to mechanical strain, magnetic fields, or electrical fields have been used to create heat pump cycles. For example, field-active materials can include electrocaloric and magnetocaloric materials. Electrocaloric materials exhibit large entropy changes when an electric field is applied to their structure. A basic heat pump cycle that implements an electrocaloric material is shown in FIG. 1. At state 1, a material is at steady temperature and is subject to a steady field applied directly to the material. An increase in the applied field strength increases material temperature at state 2. Heat is rejected to a hot ambient bringing the material temperature down near the hot ambient value in state 3. This is best accomplished through direct contact of the ambient air and the active material. Reduction of the field strength reduces material temperature at state 4. The cycle is then completed by absorbing heat from a cold ambient, again preferably through direct contact, causing the material temperature to rise back to the temperature value at state 1. This cycle may approximate ideal Carnot, Brayton, or Ericsson cycles depending on the timing of field actuation in relation to heat rejection.

[0004] The adiabatic temperature lift available with known electrocaloric or magnetocaloric materials is typically lower than the lift required for most commercial heat pump applications such as environmental control. One well-known means of increasing temperature lift (at the expense of capacity) is thermal regeneration. A typical regenerative heat exchanger depends on thermal storage and reciprocating fluid motion to develop an axial temperature gradient and thus multiply temperature lift. Regenerative heat exchangers are

common in cycles that use fluid compression rather than field-active materials to provide heat pumping. For example, Stirling cycle coolers, and thermoacoustic coolers that apply a modified Stirling cycle, use regenerative heat exchangers as common practice. In these regenerative heat exchangers, the work for heat pumping comes from compression/expansion of the fluid within the regenerator and the solid material of the regenerator provides the heat capacity for regeneration. Also, in a thermoacoustic or other pressure-based regenerative cooling cycle, it is necessary to use a heat exchanger to separate the pressurized working fluid from the ambient air resulting in a significant loss in performance. Regenerative heat exchanger use has also been reported in field-active magnetocaloric cooler prototypes.

BRIEF SUMMARY OF THE INVENTION

[0005] In accordance with an embodiment, a heat pump cycle includes providing a fluidic loop between two heat exchangers in fluidic communication with each other; energizing at least a first heat exchanger of the two heat exchangers to generate an electric field in the first heat exchanger; advecting a field-active liquid through the fluidic loop; changing an entropy of the field-active liquid in response to advecting into the electric field of the at least first heat exchanger; and exchanging heat between the field-active liquid and the two heat exchangers in response to the changing of the entropy of the field-active liquid.

[0006] In accordance with another embodiment a regenerative field-active heat pump cycle for heat transport having a regenerator and secondary heat exchanger elements includes energizing the regenerator and a first heat exchanger of the secondary heat exchanger elements to apply an intermittent electric field; changing an entropy of the field-active liquid resident in the regenerator and a first heat exchanger of the secondary heat exchanger elements in response to the electric field; advecting the field-active liquid from the regenerator into the first heat exchanger of the secondary heat exchanger elements while maintaining the electric field; transferring heat from the first heat exchanger to a hot ambient temperature in response to advecting the hot energized field-active liquid into the heat exchanger; releasing the field in the regenerator and a first heat exchanger of the secondary heat exchanger elements; changing an entropy of the field-active liquid resident in the regenerator and a first heat exchanger of the secondary heat exchanger elements in response to releasing the electric field; advecting the cold field-active liquid from the regenerator into the second heat exchanger of the secondary heat exchanger elements while maintaining the electric field; and transferring heat from the second heat exchanger to a cold ambient

temperature in response to advecting the cold de-energized field-active liquid into the heat exchanger.

[0007] Technical function of the one or more claims described above provides heat transfer through a field-active liquid that heats or cools upon application of a field, and heat transfer occurs in a heat exchanger with the associated hot or cool environment until the liquid comes into near-equilibrium with the environs while remaining in the field.

[0008] Other aspects, features, and techniques of the invention will become more apparent from the following description taken in conjunction with the drawings.

BRIEF DESCRIPTION OF THE SEVERAL VIEWS OF THE DRAWING

[0009] The subject matter, which is regarded as the invention, is particularly pointed out and distinctly claimed in the claims at the conclusion of the specification. The foregoing and other features, and advantages of the invention are apparent from the following detailed description taken in conjunction with the accompanying drawings in which like elements are numbered alike in the several FIGURES:

[0010] FIG. 1 is a diagram of a field-activated heat pump cycle in accordance with the prior art;

[0011] FIG. 2 is an exemplary system diagram for a heat pump cycle that utilizes a field-active liquid in accordance with an embodiment of the invention;

[0012] FIG. 3A is a general perspective view of an exemplary heat exchanger that has multiple flow tubes and electrodes in accordance with an embodiment of the invention;

[0013] FIG. 3B is a side elevation view of an exemplary heat exchanger of FIG. 3A that has multiple flow tubes and electrodes in accordance with an embodiment of the invention;

[0014] FIG. 4 is a front elevation view of an exemplary regenerator in accordance with an embodiment of the invention;

[0015] FIG. 5 illustrates an exemplary hybridized regenerator system for use in accordance with embodiments of the invention; and

[0016] FIGS. 6A-6C illustrates a cascade regenerator system that integrates multiple electrocaloric loops in accordance with an embodiment of the invention.

DETAILED DESCRIPTION OF THE INVENTION

[0017] Embodiments of the invention described below include using liquid-based electrocaloric materials as the working fluids for heat pumping in heating, ventilation, and air conditioning ("HVAC") and refrigeration systems, as well as in hybrid systems containing

field-active liquid and solid materials. In embodiments, the field-active liquid is circulated through at least two heat exchanger elements, wherein a heat transfer process occurs in the presence of an electric field in one and in the absence of field in the other. The field causes the field-active liquid to either heat or cool (depending on the specific liquid composition), and heat transfer occurs in the heat exchanger with the associated hot or cool environment until the liquid comes into near-equilibrium with the environs while remaining in the field. As the liquid leaves the field it cools or heats (respectively) and the fluid enters a de-energized heat exchanger to once again transfer heat to the cool/hot environment.

[0018] Referring to FIG. 2, a basic system 200 for a heat pump cycle is illustrated in accordance with an embodiment of the invention. System 200 includes a plurality of heat exchangers 202 and 204 that are in fluidic communication with each other through a flow tube or passage 206. Heat exchanger 202 includes electrodes 212 and 214 in order to generate an electric field in the heat exchanger. Flow tube 206 contains a field-active liquid material that is circulated between heat exchangers 202 and 204 and through the flow tube 206 continuously. In an embodiment, flow tube 206 includes insulation 210 in order to prevent heat exchange between the field-active liquid material and an external environment. A pump 208 creates the pressure to advect or pump the field-active liquid material through the flow tube 206 and the heat exchangers 202 and 204. In some non-limiting examples, pump 206 can be a mechanical pump, an electrostatic electric field pump, an electrophoretic electric field pump, or the like. Also, the field-active liquid material exhibits temperature change when subject to the electrical field in heat exchanger 202 and can be an liquid electrocaloric material. Non-limiting examples of liquid electrocaloric materials can include liquid crystals, ionic liquids, or other similar liquids that can exhibit a temperature change in an electric field. It is to be appreciated that the field-active liquid material serves as the working fluid for the heat pumping cycle as well as enabling heat exchange between heat exchangers 202 and 204 and an external environment 216.

[0019] Field-active materials including liquid crystals respond to an applied electric field, creating internal order/disorder; and therefore are capable of storing or releasing energy in the form of caloric heat and electrical capacitive energy. The field-active material can alter its order parameter with the applied electric field. As the order parameter is directly related to the system entropy and free energy, cooling and heating are consequences of electric field release or application, or of advection of the field-active material through a localized continuous electric field.

[0020] In an exemplary operation for system 200, the field-active liquid material is circulated through heat exchanger elements 202 and 204, wherein an electric field is applied or not applied during a heat transfer process. Field-active liquid material is pumped into heat exchanger 202 where an electric field is applied. The electric field causes the field-active liquid material to transfer heat to the associated hot environment 218 (e.g., outdoors in cooling mode or indoors in heating mode) until the field-active liquid material comes into near-equilibrium with the environs while remaining in the electric field. As the field-active liquid material leaves the electric field it cools and the field-active liquid material enters a de-energized heat exchanger 204 to absorb heat from cold environment 216 (e.g., indoors in cooling mode or outdoors in heating mode). This cycle is repeated continuously. It is to be appreciated that, for maximizing performance of system 200, the field-active liquid material is energized in the same location that heat exchange occurs as any interruption of electric field will return the field-active liquid material to its original temperature. So, a heat exchanger integrated with electrodes that can apply the required uniform field can be used, for example, as heat exchanger 202.

[0021] FIG. 3A illustrates an exemplary heat exchanger that can be used with system 200 of FIG. 2 to provide an effective cooling device. Preferably, in embodiments, a multiple channel liquid-air heat exchanger with a counter flow configuration or a cross-counter flow configuration can be used, but other configurations of heat exchangers can also be used in accordance with embodiments of the invention. In other embodiments, liquid-gas heat exchangers or liquid-liquid heat exchangers in a counter flow or cross-counter flow configuration can also be used. An exemplary counter flow heat exchanger 300 is illustrated in FIG. 3A. Heat exchanger 300 is a tube-fin structure heat exchanger and includes a plurality of electrically conductive channels that serve as tubes or conduits 302 for a secondary heat exchange fluid. In one embodiment, this fluid is a liquid such as water or oil. In another embodiment, this fluid is air. Each fluid-containing tube 302 is separated by an insulating material 306 such that each tube 302 and its associated fins, if any, can be energized independently. The space 304 between any two tubes 302 contains field-active liquid material wherein a field can be applied to this liquid by applying a potential to the surrounding conductive tubes 302 without applying any field to the secondary heat transfer fluid. Each tube-fin structure of heat exchanger 300 serves as an electrode and will be energized with potential of opposing polarity. The liquid heat exchanger 300 can be made out of metal tubes but other materials could also be used given the low pressure of the process. Polymer or ceramic-walled heat exchangers with deposited electrodes can also be used. As shown in

FIG. 3B, positive electrodes 310a-310e and negative electrodes 312a-312e are placed with opposing polarity to create an electrical field in the flowing field-active liquid material, but are placed with similar polarity surrounding the secondary fluid to avoid any electrical discharge through this fluid. In embodiments, the walls of the heat exchanger could be made of a solid field-active ceramic or polymer such as PZT ceramic or PVDF polymer. One set of electrodes can now energize both active liquid and active solid material simultaneously, increasing the specific capacity of the overall device. The heat exchanger 300 serves a function of a heat transport fluid, enabling a continually flowing pumped loop with continuously applied electric fields.

[0022] It is to be appreciated that performance of the field-active liquid material can be increased by utilizing a mixture of dielectric constituents; both liquid and solid, to improve entropy change and/or extend operating temperature range. For example, particles of an electrocaloric ceramic with large pyroelectric effect can be mixed into an active electrocaloric liquid crystal with lower performance to create a slurry, gaining the performance advantage of the solid material while retaining the system flexibility advantage of using a liquid. In addition to the features of a slurry of an electrocaloric ceramic with an active electrocaloric liquid, other embodiments can include an inactive liquid dielectric material that is added to a solid electrocaloric material for the purpose of creating a flowable mixture. As an additional example, two or more different liquid crystals with different active temperature ranges may be mixed to broaden the temperature response of the liquid mixture in the system. As an additional example, additives may be used to lower input requirements for entropy change, such as nanoparticles to lower required field strength. Also, solid-state pumping technology such as electrophoretic pumping could be used to create an entirely solid-state cooling device.

[0023] FIG. 4 illustrates an exemplary variation of a system 400 that uses a regenerative heat exchanger to achieve higher temperature lift than that enabled by the physical properties of the field-active liquid material. System 400 includes a regenerative heat exchanger 402 (or regenerator 402) that includes a regenerative matrix made from a solid material that stores heat and acts as an electrode, imposing an electric field on the field-active liquid. A field active liquid reciprocates back-and-forth between bracketed respective hot and cold heat exchangers 404 and 406 and through the regenerative heat exchanger 402 in synchronization with the applied electric field to develop a temperature gradient in the regenerator and thus increase the temperature difference between heat exchangers 404 and 406. The field-active liquid material can be translated back and forth through the regenerator 402 by an imposed pressure field generated by a mechanical or electrostatic pump or linear actuator.

[0024] Heat exchangers 404 and 406 can include electrodes to apply an electric field to the field-active liquid material. Unlike any other regenerative cycle, the reciprocating field-active liquid is best maintained under constant field, either on or off, when the liquid is reciprocated from regenerator 402 toward either heat exchangers 404 and 406. When the regenerator is energized and the liquid is translated toward one heat exchanger, that heat exchanger will also be energized. This requires integration of the three heat exchangers 402, 404, and 406 and specific spatial-temporal synchronization of the applied field.

[0025] In operation, application of the field through intimate contact to the field-active liquid in regenerator 402 may increase the material entropy (e.g., temperature). Advecting the now hot field-active liquid into the hot heat exchanger 404 while also maintaining the field in the heat exchanger 404 causes it to reject heat to the hot ambient 408. Once the heat exchanger 404 cools to the hot ambient 408 temperature, the field in the regenerator 402 is released causing the field-active liquid to cool. The field in hot heat exchanger 404 is also de-energized causing the field-active material inside to cool. Advecting the now cooled field-active material from the hot exchanger 404 toward the cold heat exchanger 406 causes the field-active material to absorb heat from the cold ambient 410 and complete the cycle. The performance of the system 400 may depend on timing and synchronization of the applied field and flow, and that such timing may change with thermal properties of the material, the load, and the temperature lift desired, so careful control of this process may be needed to achieve satisfactory performance.

[0026] The regenerator matrix can be made with field-active materials to create a hybrid liquid-solid matrix, increasing the heat pumping capacity and power density. In one embodiment the regenerator matrix 402 is made from electrically insulating electroactive ceramic or polymer with electrodes on each side and the field-active liquid between the layers. Energizing these electrodes activate both liquid and solid field-active material simultaneously for increased capacity. In another embodiment the regenerator matrix 402 can be made from active solid magnetocaloric materials, elastocaloric materials, or optocaloric materials. Electric field applied to activate the electroactive liquid material is synchronized with a separately applied magnetic, strain, or light field, respectively, to the solid matrix to produce additional capacity. In another embodiment, heat exchangers 404 and 406 can also be made from solid field-active material and energized with the field-active regenerator matrix and field-active liquid to further increase capacity.

[0027] FIG. 5 illustrates an exemplary hybridized system 500 for use in accordance with embodiments of the invention. System 500 illustrates two repeating elements 502 and 504 of

a multi-channel regenerative heat exchanger that utilizes combinations of liquid and solid electrocaloric materials as well as materials sensitive to other fields such as magnetic, strain, pressure or radiation fields. In an example for regenerator element 502, a solid matrix 503 of the regenerator 502 can be made of electrocaloric material such as ferroelectric ceramics or polymers. This material provides thermal storage needed for regeneration as well as providing support for the electrodes 506 and 508. A pair of electrodes 506 and 508 can energize the electrocaloric solid. A pair of electrodes 508 and 510 can energize the electrocaloric liquid 512 flowing between a pair of solid matrices in regenerator elements 502 and 504. These electrodes, e.g., electrodes 506, 508, and 510 can simultaneously energize both the field-active liquid (e.g., electrocaloric liquid) and the field-active solid material of the regenerator matrix, in effect offsetting the parasitic thermal dilutive effect of the regenerator material and thus increasing the specific capacity of the device. In another embodiment, the electrode pairs 506/508 and 508/510 can be energized in sequence to provide additional temperature lift.

[0028] In order to use the principle of offsetting parasitic loss of the regenerator matrix, a solid material can be used which exhibits entropy change in fields other than electric for the regenerator matrix. Use of a magnetocaloric material or material that changes entropy when exposed to strain, pressure, or radiation (including light) as the regenerator matrix and electrode support, combined with the imposition of the respective field synchronized with the electric field imposed on the liquid electrocaloric material, can also increase specific capacity of the device. Similarly, an electrocaloric solid material could be superposed with an optically energized liquid material.

[0029] Using a field-active liquid material serves a function of a heat transport fluid, enabling a continually flowing pumped loop with continuously applied electric fields as described in the embodiments described above in FIGS. 2-3. However, using regeneration to multiply temperature lift as described in the embodiments described above in FIGS. 4-5 requires a less efficient reciprocating fluid motion as well as potentially inefficient temporal variation of the electric field. To achieve high temperature lift with continuous fluid flow and electric field, and thus improved efficiency, a cascaded cycle concept with appropriately integrated heat exchangers is used as is described in FIG. 6.

[0030] FIGS. 6A-6C illustrate an exemplary regenerator system 600 that integrates multiple electrocaloric loops through coupling heat transfer in accordance with an embodiment of the invention. System 600 integrates many individual electrocaloric loops through coupling heat transfers using an electrocaloric liquid crystal but, in embodiments,

other field-active liquid materials may also be utilized. As seen in FIG. 6A, a first electrocaloric loop is illustrated where a cold secondary fluid or ambient is connected through a heat exchanger 604 with the de-energized end 608 of an electrocaloric loop 602 which is driven by a liquid pump 606. In some non-limiting examples, pump 606 can be a mechanical pump, an electrostatic electric field pump, an electrophoretic electric field pump, or the like. The electrocaloric loop 602 will continually transport heat from the low ambient to a higher temperature. The energized (or hot) end 610 of the loop 602 is in a heat exchange relationship with another heat exchange element 612 to the cold end of another independent loop 614 to pump heat to an even higher temperature as illustrated in FIG. 6B. Similarly, as illustrated in FIG. 6C, an energized hot end 616 of loop 614 is in a heat exchange relationship through another heat exchange element 618 to the cold end of another independent loop 620 to pump heat to an even higher temperature. This process continues with another connection between low ambient to a higher temperature through an electrocaloric loop until adequate temperature lift is achieved and then the hot end of the last loop is connected to the hot secondary fluid or ambient through heat exchanger 622.

[0031] As shown in FIGS. 6A-6C, combination of electrocaloric loops 602, 614, and 620 is enabled by stacking layers of loops and heat exchangers and then using headers to connect the channels together such that many parallel loops can be driven by one pump, which is similar to brazed or welded plate-fin, minichannel, or compact heat exchanger fabrication known in the industry. In embodiments, a multichannel pump such as a peristaltic pump or other modular pump could be used to drive flow through multiple cascade elements using a single motor and speed control. The system 600 allows heat pumping while maintaining continuous active fluid and secondary fluid flows combined with steadily applied electric fields to avoid any wasteful reversal of flow or current. Again, many physical embodiments may provide the same functionality of bringing active primary and secondary fluids together at the appropriate temperatures for heat transfer resulting in additional lift.

[0032] The terminology used herein is for the purpose of describing particular embodiments only and is not intended to be limiting of the invention. While the description of the present invention has been presented for purposes of illustration and description, it is not intended to be exhaustive or limited to the invention in the form disclosed. Many modifications, variations, alterations, substitutions, or equivalent arrangement not hereto described will be apparent to those of ordinary skill in the art without departing from the scope and spirit of the invention. Additionally, while various embodiments of the invention have been described, it is to be understood that aspects of the invention may include only

some of the described embodiments. Accordingly, the invention is not to be seen as limited by the foregoing description, but is only limited by the scope of the appended claims.

CLAIMS

What is claimed is:

1. A heat pump cycle for heat exchange, comprising:
 - providing a fluidic loop between two heat exchangers in fluidic communication with each other;
 - energizing at least a first heat exchanger of the two heat exchangers to generate an electric field in the first heat exchanger;
 - advecting a field-active liquid through the fluidic loop;
 - changing an entropy of the field-active liquid in response to advecting into the electric field of the at least first heat exchanger; and
 - exchanging heat between the field-active liquid and the two heat exchangers in response to the changing of the entropy of the field-active liquid.
2. The heat pump cycle of claim 1, further comprising imposing an electric field in the first and the second heat exchangers.
3. The heat pump cycle of any preceding claim, further comprising at least one of rejecting or absorbing heat in the field-active liquid in response to the advecting of the field active liquid through the at least first heat exchanger.
4. The heat pump cycle of any of preceding claim, further comprising:
 - providing liquid-gas heat exchangers or liquid-liquid heat exchangers in a counter flow or cross-counter flow configuration; and
 - applying the electric field to one fluid stream of the liquid-gas heat exchangers or the liquid-liquid heat exchangers.
5. The heat pump cycle of any preceding claim, further comprising using an active electrocaloric liquid as the field-active liquid that is selected from one of a single component field-active liquid, a multi-component mixture of field-active liquids, a pumpable multi-component mixture including field-active liquid and field-active solid materials, or an inactive dielectric liquid added to a solid field-active material to enable pumping of the solid material field-active material.

6. The heat pump cycle of claim 5, further comprising using a liquid crystal as the field-active liquid.
7. The heat pump cycle of any preceding claim, further comprising energizing the at least first heat exchanger to continuously generate the electric field.
8. The heat pump cycle of any preceding claim, further comprising energizing the field-active liquid to change entropy of the field-active liquid.
9. The heat pump cycle of any preceding claim wherein at least the first heat exchanger of the two heat exchangers comprises two electrically conductive channels separated by an insulating material to define a flow channel for the field-active liquid between the two electrically conductive channels.
10. The heat pump cycle of any preceding claim wherein at least the first heat exchanger of the two heat exchangers comprises a polymer channel defining a flow channel for the field-active liquid, the polymer channel including a first electrode on one side and a second electrode on another side to generate the electric field.
11. The heat pump cycle of any preceding claim, further comprising:
 - providing a second fluidic loop between two additional heat exchangers in fluidic communication with each other;
 - placing the energized first heat exchanger in a heat exchanger relationship with a deenergized heat exchanger of the second fluidic loop.
12. The heat pump cycle of claim 11, further comprising:
 - energizing at least a first heat exchanger of the two additional heat exchangers.
13. The heat pump cycle of claim 12, further comprising:
 - providing a third fluidic loop between two further heat exchangers in fluidic communication with each other;
 - placing the energized first heat exchanger of the two additional heat exchangers in a heat exchanger relationship with a deenergized heat exchanger of the third fluidic loop.

14. The heat pump cycle of claim 13, wherein placing the energized first heat exchanger in a heat exchanger relationship with a deenergized heat exchanger of the second fluidic loop comprises physically stacking the energized first heat exchanger and the deenergized heat exchanger of the second fluidic loop.

15. A regenerative field-active heat pump cycle for heat transport having a regenerator and secondary heat exchanger elements, comprising:

- energizing the regenerator and a first heat exchanger of the secondary heat exchanger elements to apply an intermittent electric field;

- changing an entropy of the field-active liquid resident in the regenerator and a first heat exchanger of the secondary heat exchanger elements in response to the electric field;

- advecting the field-active liquid from the regenerator into the first heat exchanger of the secondary heat exchanger elements while maintaining the electric field;

- transferring heat from the first heat exchanger to a hot ambient temperature in response to advecting the hot energized field-active liquid into the heat exchanger;

- releasing the field in the regenerator and a first heat exchanger of the secondary heat exchanger elements;

- changing an entropy of the field-active liquid resident in the regenerator and a first heat exchanger of the secondary heat exchanger elements in response to releasing the electric field;

- advecting the cold field-active liquid from the regenerator into the second heat exchanger of the secondary heat exchanger elements while maintaining the electric field; and

- transferring heat from the second heat exchanger to a cold ambient temperature in response to advecting the cold de-energized field-active liquid into the heat exchanger.

16. The regenerative field-active heat pump cycle of claim 15, further comprising advecting the field-active liquid through the regenerator and the secondary heat exchanger elements by pumping using a linear actuator, a mechanical pump, an electrophoretic electric field pump, or an electrostatic electric field pump.

17. The regenerative field-active heat pump cycle of claim 15, wherein the field-active liquid is static in the regenerator and a secondary fluid is advected through the regenerator and the secondary heat exchanger elements.

18. The regenerative field-active heat pump cycle of claim 17, further comprising transferring heat from the field-active liquid and the secondary fluid in the regenerator.
19. The regenerative field-active heat pump cycle of claim 15, further comprising providing the regenerator with an active solid electrocaloric material.
20. The regenerative field-active heat pump cycle of claim 19, further comprising energizing the regenerator active solid structure and the field-active liquid with the same electrodes.
21. The regenerative field-active heat pump cycle of claim 15, further comprising providing the regenerator and at least the first of the secondary heat exchanger elements with an active solid electrocaloric material.
22. The regenerative field-active heat pump cycle of claim 21, further comprising energizing the at least first heat exchanger, the regenerator, and the field-active liquid with the same electrodes simultaneously or in sequence.
23. The regenerative field-active heat pump cycle of claim 15, further comprising:
 - providing at least one of the regenerator and the secondary heat exchanger elements from magnetocaloric materials, elastocaloric materials, or optocaloric materials; and
 - applying an electric field to the field-active liquid while energizing at least one of the regenerator and the secondary heat exchanger elements with an applied magnetic, strain, or light field, respectively in an advantageous phase relationship.

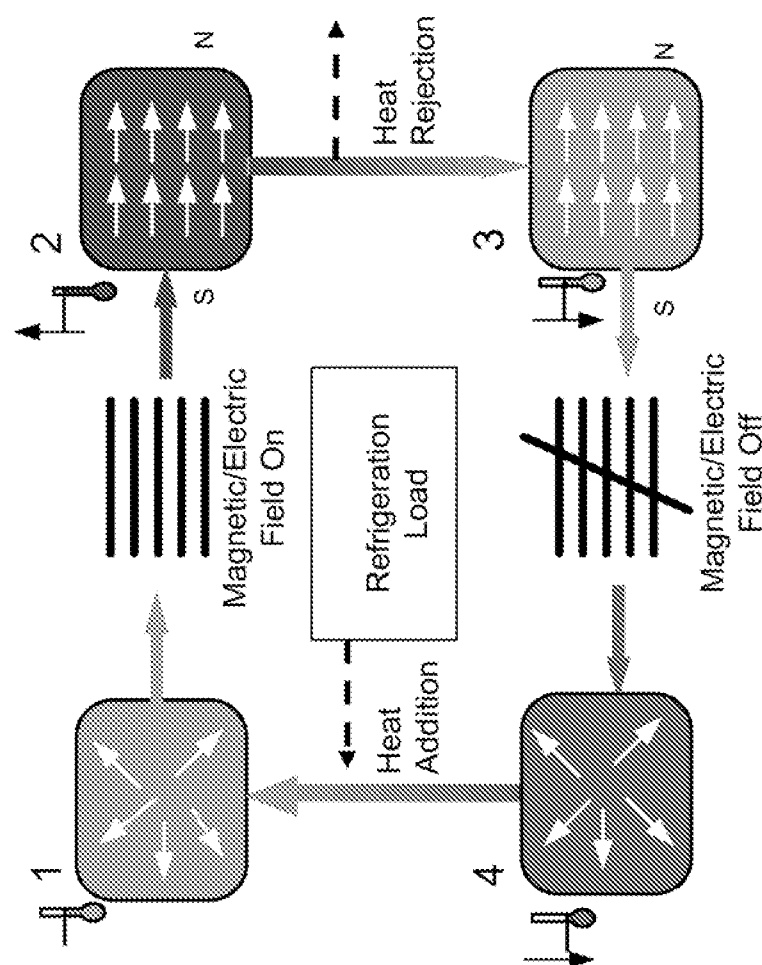


FIG. 1 (PRIOR ART)

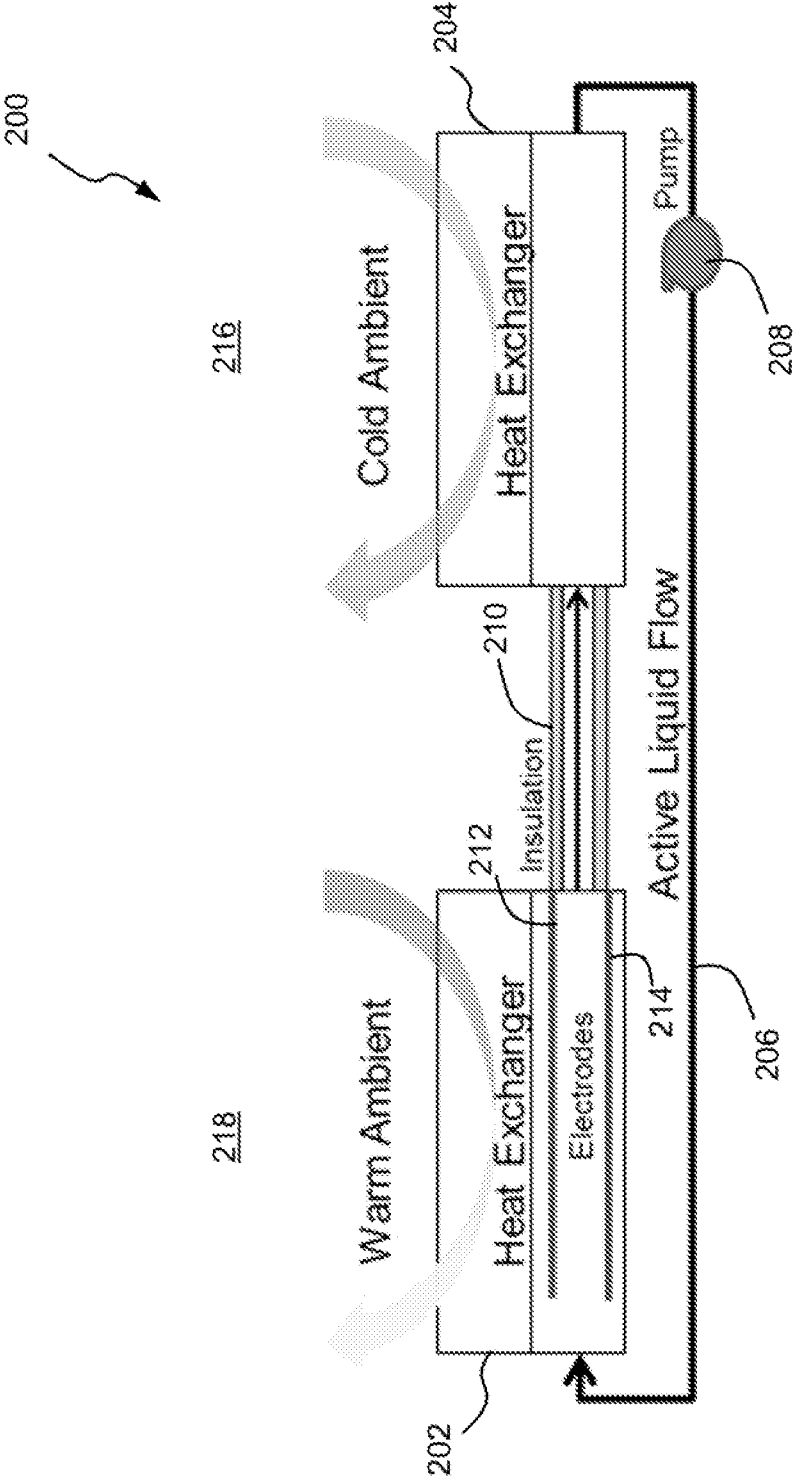
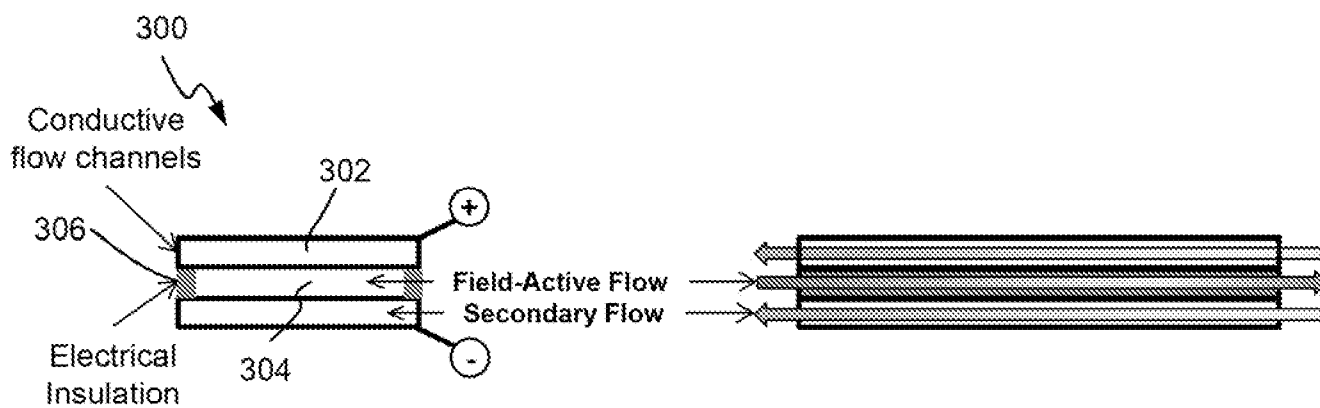
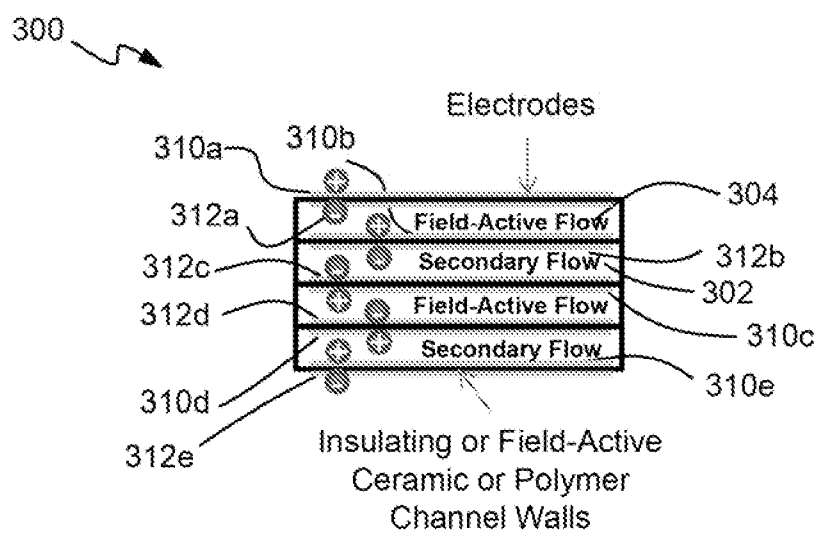
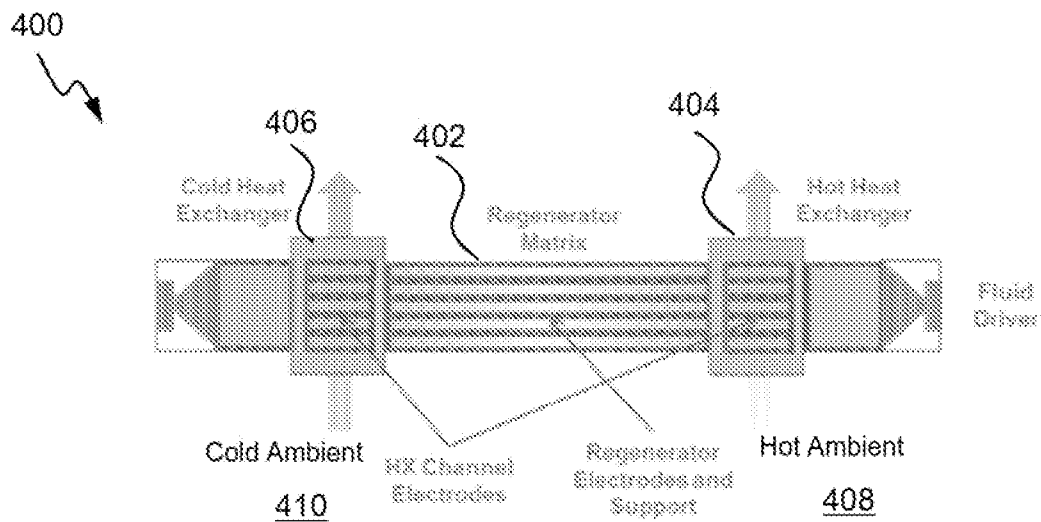
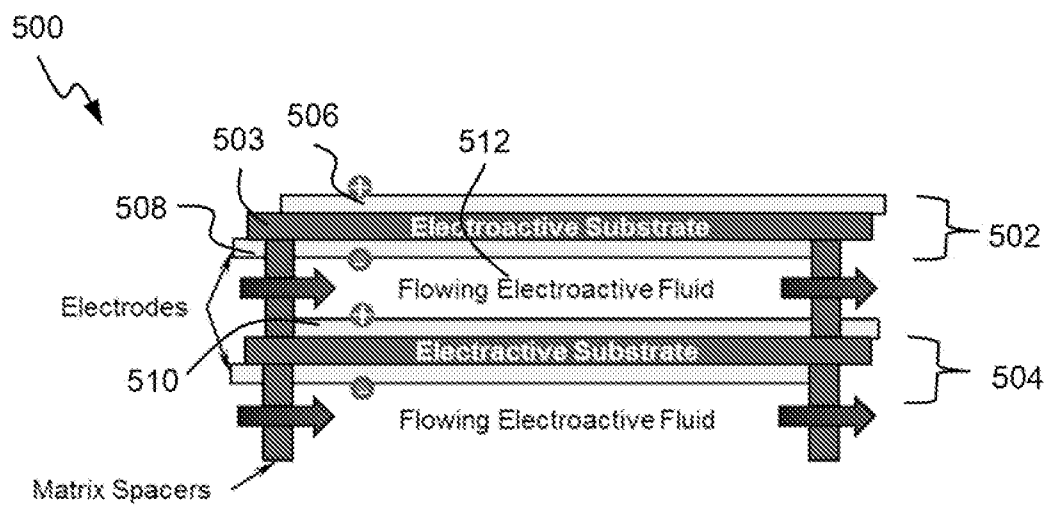


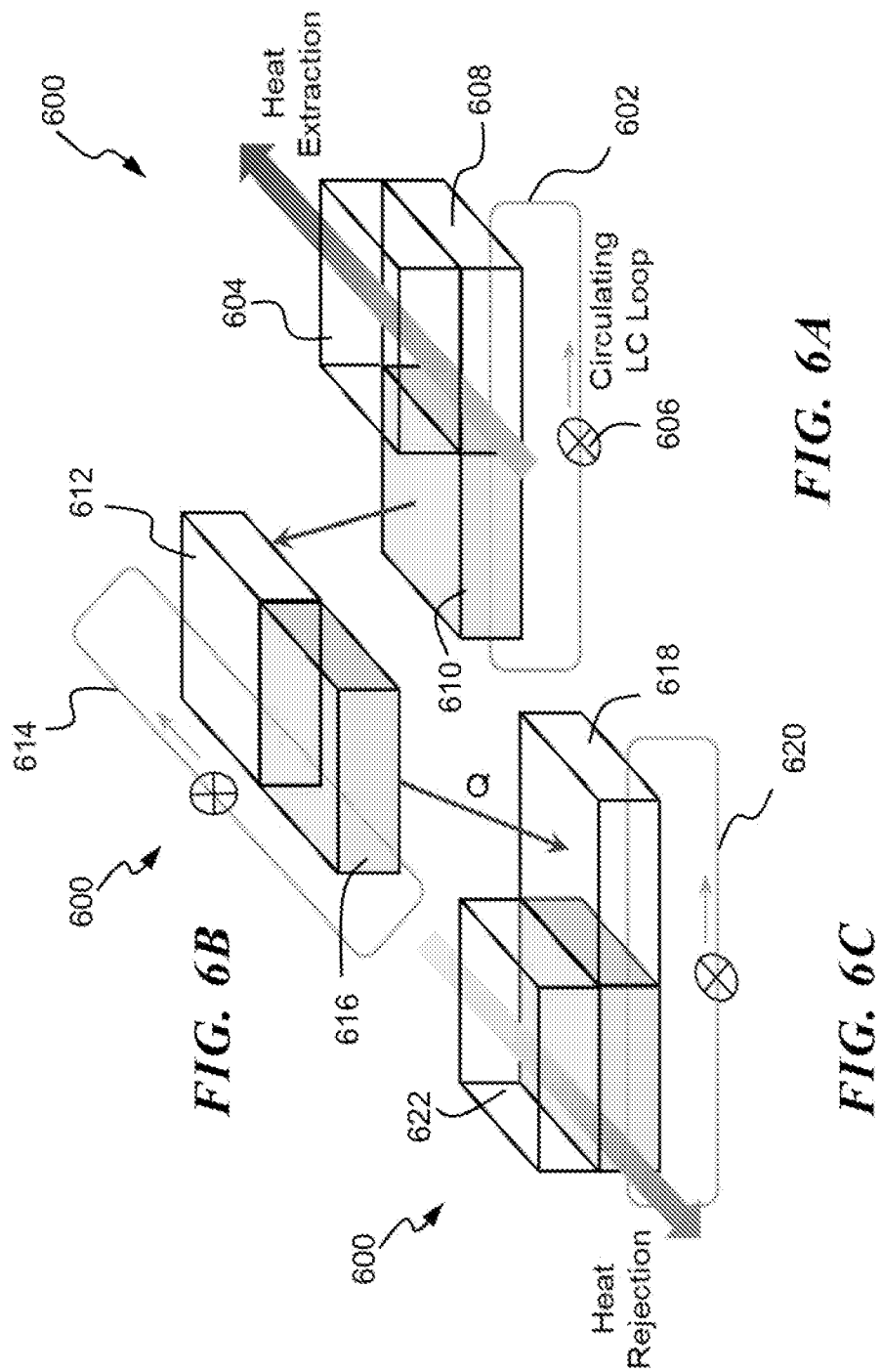
FIG. 2

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**FIG. 3A****FIG. 3B**

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**FIG. 4****FIG. 5**



INTERNATIONAL SEARCH REPORT

International application No

PCT/US2014/068497

A. CLASSIFICATION OF SUBJECT MATTER

INV. F25B21/00

ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

F25B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	DE 10 2008 021086 A1 (BSCHORR OSKAR [DE]) 29 October 2009 (2009-10-29)	1,15
A	paragraph [0015] - paragraph [0022]; figures 1-5	2-14, 16-23

A	EP 1 171 947 A1 (CORNWALL REMI OSERI [GB]) 16 January 2002 (2002-01-16)	1-23
	paragraph [0006] - paragraph [0104]; figures 1-27	



Further documents are listed in the continuation of Box C.



See patent family annex.

* Special categories of cited documents :

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Date of the actual completion of the international search

27 August 2015

Date of mailing of the international search report

04/09/2015

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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/US2014/068497

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
DE 102008021086 A1	29-10-2009	NONE	
EP 1171947 A1	16-01-2002	AT 415732 T	15-12-2008
		AU 4307100 A	02-11-2000
		CN 1376328 A	23-10-2002
		DK 1171947 T3	30-03-2009
		EP 1171947 A1	16-01-2002
		HK 1045413 A1	08-05-2009
		JP 2002542758 A	10-12-2002
		JP 2014014269 A	23-01-2014
		US 6725668 B1	27-04-2004
		WO 0064038 A1	26-10-2000