



US 20120060537A1

(19) **United States**(12) **Patent Application Publication**
Bolin(10) **Pub. No.: US 2012/0060537 A1**(43) **Pub. Date: Mar. 15, 2012**(54) **CHEMICAL HEAT PUMP COMPRISING AN ACTIVE SURFACE****Publication Classification**(75) Inventor: **Goran Bolin**, Taby (SE)(51) **Int. Cl.**
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Hagersten (SE)(52) **U.S. Cl.** **62/324.1**(21) Appl. No.: **13/319,485**(57) **ABSTRACT**(22) PCT Filed: **Apr. 18, 2011**(86) PCT No.: **PCT/SE2011/050471**

§ 371 (c)(1),

(2), (4) Date: **Nov. 29, 2011**

Chemical heat pump comprising an active surface. A chemical heat pump working according to the hybrid principle with an active substance and a volatile liquid whereby the active substance is in a reactor part 1 and the volatile liquid is in a condenser/evaporator part 3, while the volatile liquid is moving between these parts 1, 3 to be absorbed and desorbed by the active substance and be condensed and evaporated in the condenser/evaporator part. The reactor part may comprise a layer 12 for the active substance so that this at least in its liquid phase is retained in the layer and the condenser/evaporator part may comprise a layer 13 for the volatile liquid so that this in its liquid phase is retained in the layer. Advantages of a falling film process are combined with the advantages of a matrix material in a chemical heat pump.

(30) **Foreign Application Priority Data**

Apr. 21, 2010 (SE) 1000405-9

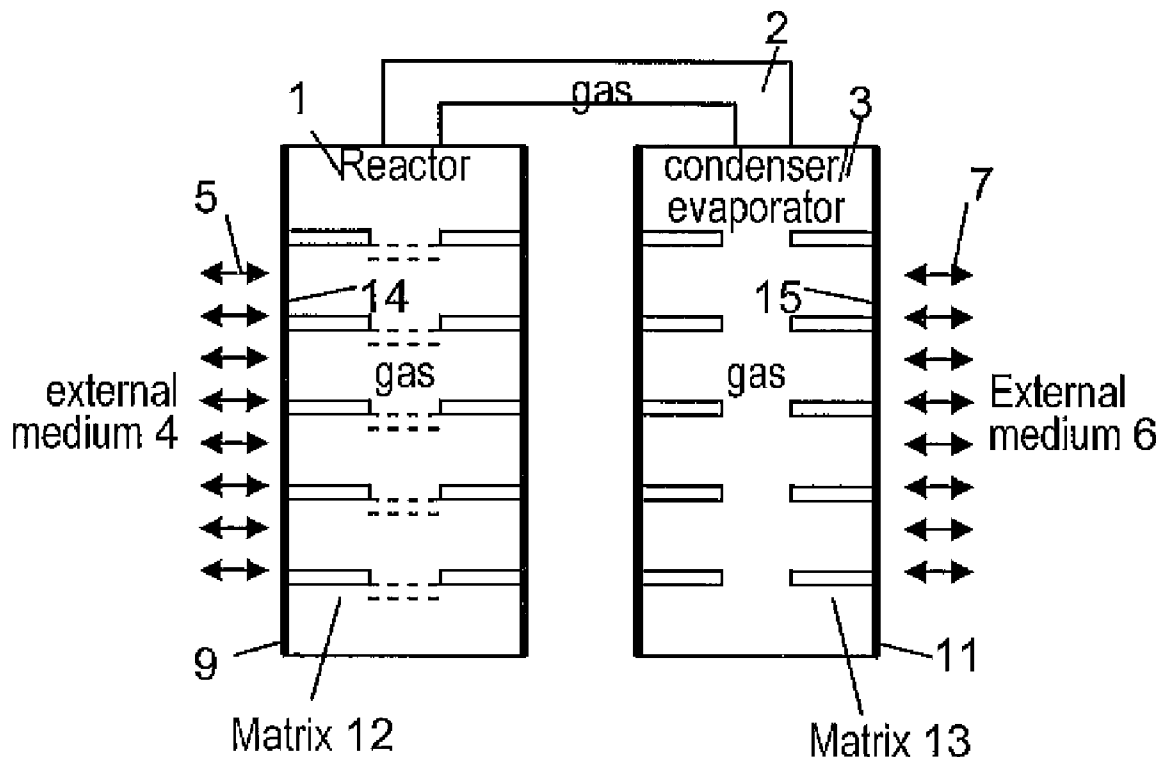


Fig. 1a
Prior art

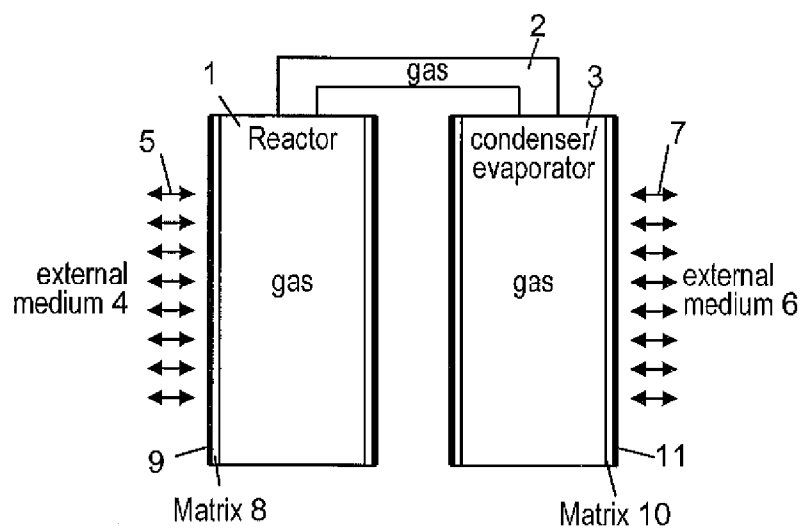


Fig. 1b

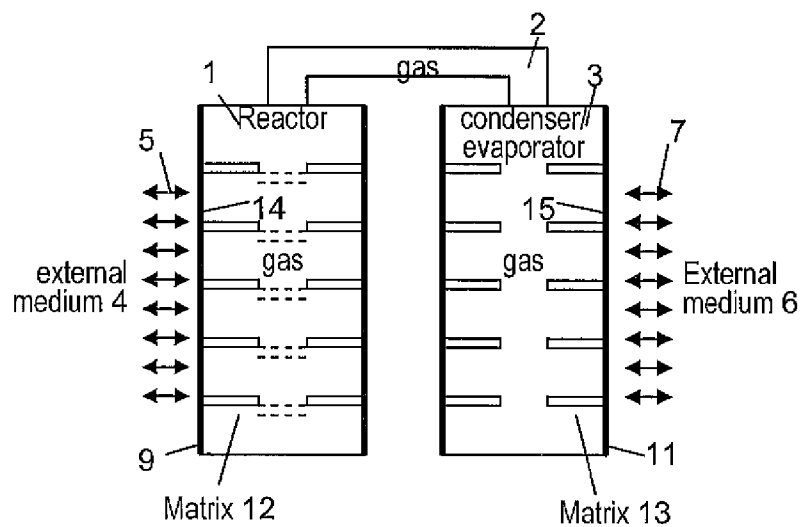


Fig. 2

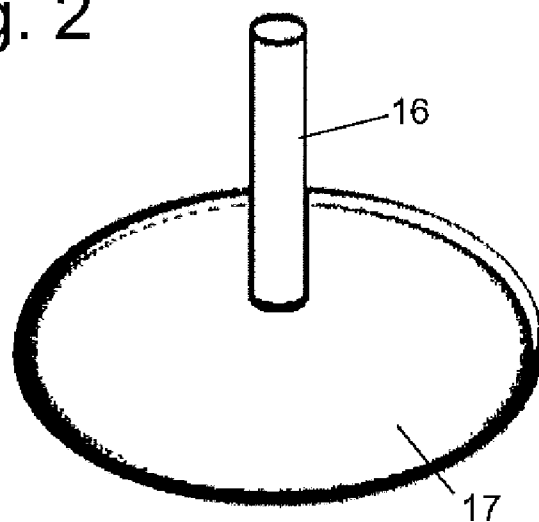
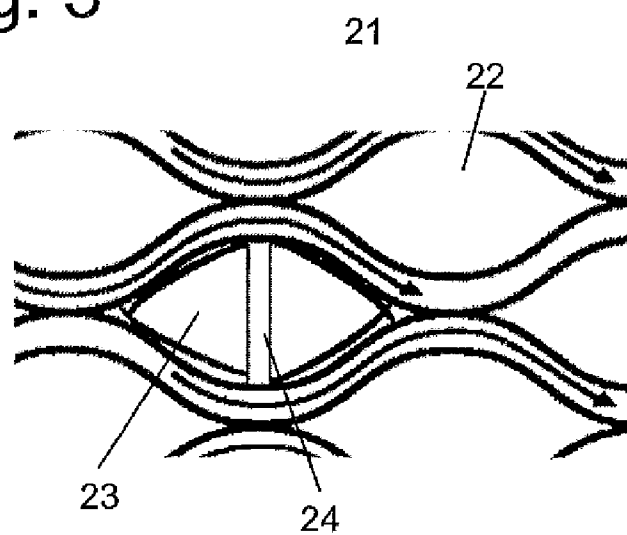


Fig. 3



CHEMICAL HEAT PUMP COMPRISING AN ACTIVE SURFACE

TECHNICAL FIELD

[0001] The present invention relates generally to a chemical heat pump with extended functionality. More in particular it relates to a chemical heat pump working according to the hybrid principle and wherein there is an active surface in the chemical heat pump.

BACKGROUND

[0002] In prior art chemical heat pumps working according to the hybrid principle are already known. In chemical heat pumps working according to the hybrid principle the active substance is in both solid and liquid phase during the process. These two phases are utilized to give an improved storage of energy. A volatile liquid such as water is absorbed by and then desorbed from the active substance. The liquid phase of the active substance is during charging spread out over a heat conducting material such as a heat exchange surface for exchange of heat in the reactor part of the chemical heat pump. The liquid phase is heated during charging and the liquid is desorbed from the active substance and moved in gas phase to a condenser/evaporator part of the chemical heat pump. In the condenser/evaporator the gas is condensed to liquid and collected. During discharge of the chemical heat pump the liquid is evaporated in the condenser/evaporator and moved to the reactor part, whereby the gas condenses to liquid and is absorbed by the active substance.

[0003] In earlier known chemical heat pumps working according to the hybrid principle the falling film process is for instance utilized. The liquid phase of the active substance and the liquid is sprayed by pumps over a heat conducting material at an upper level of the reactor and the condenser/evaporator part respectively, for exchange of heat during charging and discharging of the chemical heat pump. A thin film of liquid comprising the active substance in liquid phase in the reactor part and liquid in the condenser/evaporator part is spread out over the heat conducting material for exchange of heat and is falling down through the reactor part or condenser/evaporator part because of the gravity. The liquid phase and the liquid eventually reach the bottom level of the reactor part and the condenser/evaporator part respectively, whereby pumps again pump the liquid to the upper level of the chemical heat pump whereby the falling film process continues. An advantage of a falling film process is that the heat conductive material is completely exposed to the liquid phase and the liquid respectively, because the liquid film on the heat conducting material is thin. Condensation of gas and evaporation of liquid can thereby be efficient.

[0004] A problem with the falling film process is that particles of active substance in solid phase may form, and they may obstruct for instance in the pumps. In order to avoid this problem the formation of active substance in solid phase is normally avoided when using the falling film process.

[0005] A solution to the above described problem with the falling film process is disclosed in the Swedish patent SE 515 688, where a net is used to hold the active substance in its solid phase so that particles of solid active substance in the pumps can be avoided. When the formation of solid active substance can be allowed, it is possible to store more energy.

[0006] A development of the chemical heat pump according to the Swedish patent SE 515 688 is disclosed in the

Swedish patent SE 530 959. In this later patent there is disclosed a chemical heat pump which utilizes the same basic principle but where the net is exchanged with a layer in the form of a matrix. The matrix holds the active substance both in its liquid and solid phase and is distributed as a layer over the heat conductive material. The matrix is inert and permeable to the liquid phase. An advantage with such a chemical heat pump is that a large amount of active substance in solid or liquid phase can be bound to the matrix so that the chemical heat pump can contain a large amount of energy. The matrix has the property that it is able to absorb the liquid and the liquid phase of the active substance. With the matrix no pumps are required as in earlier falling film processes.

[0007] In certain cases there is a room for improvement regarding chemical heat pumps with a matrix. The matrix is in contact with the heat conductive material so that the heat conductive material is covered by the matrix. Evaporation of the volatile liquid and condensing of the gas phase may thereby take somewhat longer time compared to a case where the heat conductive material is directly exposed to the volatile liquid and the gas phase. The transport of gas to and from the heat conductive material and between the reactor part and the condenser/evaporator part may be somewhat impaired. Further the matrix causes a pressure drop when gas passes the matrix.

[0008] In the prior art there is thus a need for an improved chemical heat pump working according to the hybrid principle.

SUMMARY

[0009] It is an object of the present invention to obviate at least some of the disadvantages in the prior art and provide an improved chemical heat pump.

[0010] In a first aspect there is provided a chemical heat pump comprising an active substance and a volatile liquid, said volatile liquid being adapted to be absorbed by the active substance at a first temperature and said volatile liquid being adapted to be desorbed by the active substance at a second higher temperature, whereby the active substance at the first temperature has a solid phase, from which the active substance during uptake of the volatile liquid and its gas phase immediately transforms partially into liquid phase or liquid phase and whereby the active substance at the second higher temperature has a liquid phase or is in liquid phase, from which the active substance during desorption of the volatile liquid, in particular the gas phase of the volatile liquid, immediately transforms partially into solid phase, whereby the chemical heat pump comprises:

[0011] a reactor part **1** comprising active substance, whereby the reactor part **1** is adapted to exchange heat with an external medium **4** by exchange of heat through delimiting and heat conducting walls **9,11**,

[0012] a condenser/evaporator part **3** comprising a part of the volatile liquid, the condenser/evaporator part **3** being adapted to exchange heat with an external medium **6** by exchange of heat through delimiting and heat conducting walls **9,11**, and

[0013] a passage **2** for the gas phase of the volatile liquid, said passage connecting the reactor part **1** and the condenser/evaporator part **3** with each other,

[0014] whereby at least one of i the reactor part **1** and ii the condenser/evaporator part **3** comprises a layer **12, 13, 16**,

[0015] whereby a layer **12, 16** if present in the reactor part **1** is adapted to retain the active substance at least in its liquid

phase or its liquid phase, and whereby a layer **13**, **16** if present in the condenser/evaporator part **3** is adapted to retain the volatile liquid in its liquid phase,

[0016] wherein

[0017] the layer **12**, **13**, **16** is arranged as bodies with limited contact surfaces against the surface of one or more of the heat conducting walls **9**, **11** so that free areas **14**, **15** of the surfaces of the heat conducting walls **9**, **11** are between the contact surfaces,

[0018] that the free areas **14**, **15** of the surface of the heat conducting walls **9**, **11** are adapted to exert a net attractive force on the active substance in its liquid phase and the volatile liquid in its liquid phase respectively and that the net attractive force is adjusted with regard to net attractive force exerted by the layer **12**, **13**, **16** on the active substance in its liquid phase and the volatile liquid in its liquid phase respectively.

[0019] In one embodiment the layer **12**, **13**, **16** comprises a matrix and wherein the matrix comprises a porous material which is permeable to the gas phase of the volatile liquid.

[0020] In one embodiment said net attractive force exerted by the free areas **14**, **15** of the surface of the heat conducting walls **9**, **11** comprises capillary force.

[0021] In one embodiment the layer **12**, **13**, **16** comprises a material which has adjusted capillary properties with regard to the active substance in its liquid phase and the volatile liquid in its liquid phase respectively.

[0022] In one embodiment the layer **12**, **13**, **16** comprises surfaces which have adjusted wetting properties with regard to the active substance in its liquid phase and the volatile liquid in its liquid phase respectively.

[0023] In one embodiment the net attractive force exerted by the free areas **14**, **15** of the surface of the heat conducting walls **9**, **11** is adjusted so that the net attractive force exerted by the heat conducting walls **9**, **11** on the active substance in its liquid phase and the volatile liquid in its liquid phase respectively, is higher than the net attractive force exerted by the layer **12**, **13**, **16** on the active substance in its liquid phase and the volatile liquid in its liquid phase respectively.

[0024] In one embodiment the limited contact surfaces constitute maximum 10%, preferably maximum 5% of the area of the heat conducting walls **9**, **11**.

[0025] In one embodiment the bodies of matrix are designed as parallel discs with a through hole and the outer surfaces of the discs are in contact with the surface of a heat conducting wall.

[0026] In one embodiment the bodies of matrix are arranged as bodies which extend between opposite walls in parallel channels **22** in a plate heat exchanger, whereby other parallel channels **23** in the plate heat exchanger comprises a heat carrying medium.

[0027] The advantages of an exposed surface of a heat conducting material in a falling film process are combined with the advantages of a matrix for storage of active substance in solid and liquid phase.

[0028] One advantage is that the transport of gas to and from the heat conductive material is improved. The pressure drop caused when gas passes the matrix is reduced.

BRIEF DESCRIPTION OF THE DRAWINGS

[0029] The invention is now described, by way of example, with reference to the accompanying drawings, in which

[0030] FIG. **1a** is a schematic drawing of a known chemical heat pump working according to the hybrid principle with a matrix according to the state of the art,

[0031] FIG. **1b** is a schematic drawing similar to FIG. **1a**, in which the matrix is arranged in a different way compared to the relation between inner surfaces in the reactor part and condenser/evaporator part in the chemical heat pump,

[0032] FIG. **2** shows how the liquid phase of an active substance in a reactor or volatile liquid in a condenser/evaporator in a chemical heat pump is transported from an active surface to a layer and,

[0033] FIG. **3** is a sectional view of a heat exchanger with parallel channels, of which some channels are reactor or condenser/evaporator in a chemical heat pump and other channels are for circulation of an outer heat carrying medium.

DETAILED DESCRIPTION

[0034] Before the invention is disclosed and described in detail, it is to be understood that this invention is not limited to particular compounds, configurations, method steps, substrates, and materials disclosed herein as such compounds, configurations, method steps, substrates, and materials may vary somewhat. It is also to be understood that the terminology employed herein is used for the purpose of describing particular embodiments only and is not intended to be limiting since the scope of the present invention is limited only by the appended claims and equivalents thereof.

[0035] It must be noted that as used in this specification and the appended claims, the singular forms "a", "an" and "the" include plural referents unless the context clearly dictates otherwise.

[0036] If nothing else is defined, any terms and scientific terminology used herein are intended to have the meanings commonly understood by those of skill in the art to which this invention pertains.

[0037] The term "about" as used in connection with a numerical value throughout the description and the claims denotes an interval of accuracy, familiar and acceptable to a person skilled in the art. Said interval is $\pm 10\%$.

[0038] In a chemical heat pump working according to the hybrid principle there may be in one of or both of the reactor part and the condenser/evaporator part be collecting areas, denoted layers, which attract the active substance in its dissolved liquid phase and the volatile liquid respectively so that the layer can take up more or less of the active substance in its dissolved liquid phase and more or less of the volatile liquid in its liquid phase. The attraction is accomplished in a suitable way such as with the aid of a capillary force and/or wetting forces. These layers are arranged as delimited bodies with only such a limited contact with the outer wall in a reactor part and condenser/evaporator part respectively so that there between the contact surfaces are free areas of the inside of the outer wall. These free areas also have a capillary and/or wetting ability, which in a suitable way is adapted to the attractive capillary and wetting ability of the layers and constitute areas which may have heat exchange with an external medium across only the wall, which may be thin, and on the surface of which the free areas are situated. Such a nearly direct heat exchange is efficient and is relatively quick

[0039] The layers may be shaped as bodies of matrix material designed according to the above mentioned Swedish patent SE 530 959. In another case the layers comprise other suitable bodies with capillary suction and/or wetting inner surfaces, for instance two discs of ceramic material such as glass disks, which opposing surfaces are capillary and/or wetting for the active substance in its liquid phase and the volatile liquid and between which liquid can be sucked in.

[0040] With such a chemical heat pump comprising an exposed surface of a heat conducting wall combined with a layer for storage of for instance active substance in its liquid phase it is possible to achieve the same effect per surface area as for the falling film process without using mechanical pumps, such as electrical pumps. When using matrix material in the storage bodies it is possible to retain the large storage capacity of the matrix.

[0041] With the chemical heat pump a higher power per unit area may be reached. This can for instance be utilized so that a smaller amount of material may be used for manufacture of the chemical heat pump and so that its size thereby can be reduced. This may lead to lower manufacturing costs for the chemical heat pump. A chemical heat pump in which a higher power is reached per unit area may also open new possibilities for applications. Such a heat pump could for instance be used for fast processes, during which charging and discharging can be performed during minutes instead of hours as the heat pumps according to the prior art. In order to achieve this it is important that the surface of the heat conducting material is as well exposed as possible and at least partially not covered by a matrix.

[0042] The chemical heat pump thus has free exposed active surface areas of heat conducting walls and a layer for a liquid phase, whereby both the active surface and the layer have an ability to attract the liquid phase for instance by capillary action and/or wetting. The drawbacks of a matrix can thereby be eliminated and the advantage of a large storage can be maintained.

[0043] The disclosed heat pump is thus in general of the type with an active substance and a volatile liquid, whereby the liquid may be absorbed by the substance at a first temperature and desorbed by the substance at a second higher temperature. The active substance has at the first temperature a solid phase, from which it during uptake of the volatile liquid and its gas phase immediately transforms partially to a liquid phase or liquid phase. At the second temperature it has a liquid phase or is in liquid phase, from which it during desorption of the volatile liquid, in particular its gas phase, immediately transforms partially into solid phase. The chemical heat pump in general comprises the following parts:

[0044] A reactor part comprising the active substance and which is adapted to exchange heat, i.e. to be heated and/or cooled by an external medium by exchange of heat through one or more delimiting heat conducting walls.

[0045] A condenser/evaporator part comprising essentially the part of the volatile liquid which is in condensed form and which is designed to exchange heat, i.e. to be heated and cooled by an external medium by exchange of heat through one or more delimiting heat conducting walls.

[0046] A passage for the gas phase of the volatile liquid, which passage connects the reactor part and the condenser/evaporator part with each other.

[0047] The reactor part can comprise a layer intended for the active substance, which in one embodiment may comprise a matrix in the form of a porous material, so that the active substance at least in its liquid phase or in its liquid phase can be retained in and/or be bound to the matrix. Alternatively or in combination the condenser/evaporator part may comprise a layer for the volatile liquid, which may comprise a matrix in the form of a porous material, which material is permeable for the gas phase of the volatile liquid, so that the volatile liquid in its liquid phase can be retained in and/or be bound to the matrix.

[0048] The matrix can in one part or in both parts be arranged as bodies, which may be designed as discs or plates and have limited contact surfaces against the inner surface of the one or more heat conducting walls. In one embodiment the layer 12, 13, 16 is arranged as discs. In one embodiment the layer 12, 13, 16 is arranged as plates. In one embodiment the layer 12, 13, 16 is arranged as discs and plates. Free areas of the surfaces of the heat conducting walls then exist between the contact surfaces. These free surfaces of the heat conducting walls may have capillary properties and/or wetting properties for the active substance in its liquid phase and for the volatile liquid in its liquid phase respectively. In particular so that the free areas of the surfaces of the heat conducting walls have capillary properties or wetting properties for the active substance in its liquid phase and for the volatile liquid in its liquid phase respectively, which is larger than the capillary properties of the matrix with regard to the active substance in its liquid phase and the volatile liquid in its liquid phase respectively, i.e. so that the active substance in its liquid phase and the volatile liquid in its liquid phase is easier attracted, sucked into, and/or distributed and spread over the free areas of the surfaces of the heat conducting walls compared to the matrix.

[0049] The limited contact surfaces have in general a minimum or relative small area, so that they constitute a relatively small part of the surface of a heat conducting wall. They may for a heat conducting wall together constitute maximum 10%, or maximum 5% of the surface of the heat conducting wall.

[0050] In the chemical heat pump depicted schematically in FIG. 1a there are two compartments. A first compartment constitutes the reactor part 1, comprising an active substance, which in an exothermic reaction can absorb and in an endothermic reaction can desorb the vapor or gas phase of a volatile liquid. The reactor part 1 is via a tube or channel 2 connected to a second compartment, which constitutes a condenser/evaporator part 3. The second compartment 3 acts as a condenser for condensing the gas phase of the volatile liquid to its liquid phase and as an evaporator of the volatile liquid in its liquid phase to gas. The active substance in the reactor part 1 is in heat exchanging contact with an external heat carrying medium 4, which is shown by the arrows 5 for addition or removal of heat. The liquid in the condenser/evaporator part 3 is also in heat exchanging contact with a second external heat carrying medium 6, which is shown by the arrows 7, for addition or removal of heat.

[0051] According to the hybrid principle the active substance changes between solid phase and solution state. For the chemical heat pump to work according to the hybrid principle, the active substance has to remain in the reactor part 1. One way of accomplishing this is by using a net to limit the movements of the active substance in its solid phase. Another way is to use a matrix 8 which also may function as energy storage. Such a matrix holds the active substance both in its

liquid and solid phase and is inert with respect to the used active substance and the volatile liquid in their different phases. Further the matrix is permeable for the volatile liquid in its gas phase and may be arranged inside the reactor part **1** in the form of a layer **8** on an inner surface of one or several walls **9**. The inner surface of the walls **9** are in contact with the first outer heat carrying medium **4**. On the inner surfaces of walls **11** in the condenser/evaporator part **3** similar layers of matrix **10** may be arranged, which matrix is used to retain and bind the volatile liquid in its liquid phase.

[0052] In such a chemical heat pump a relatively large amount of active substance can be retained in the matrix **8**. The chemical heat pump can then contain a large energy storage. The matrix is of a material, which has the property the surface of the material can be wetted by volatile liquid, and thereby that it can bind to the volatile liquid in its liquid phase. The same is true for the liquid phase of the active substance.

[0053] In the prior art and as depicted in FIG. **1a** the matrix **8**, **10** is in contact with the heat conducting material in the walls **9**, **11**. The inner surface of the walls is thereby not directly exposed to the gas phase of the volatile liquid and the gas phase is thereby not in direct heat conducting contact with the wall material and can thus for instance not be cooled with maximum efficiency and not quickly. Similarly the active substance in its liquid phase or liquid phase is not in direct heat exchanging contact with the wall material, which does not give a completely efficient or at least not a quick heat transfer, for instance for evaporation of the liquid in the active substance in its active form. The corresponding is true for the condenser/evaporator part. The slow heat exchange can be said to correspond to a pressure drop accomplished by the matrix when vapor or gas is passing the matrix.

[0054] In order to achieve direct contact between the gas phase and the inner surfaces of the heat conducting walls **9**, **11**, large areas of those walls are left free from matrix whereas the matrix is arranged as a collection area or storage designed as one or more bodies **12**, **13**, which only have relatively limited contact area against the inner surfaces of the walls, see FIG. **1b**. It is desirable that the gas phase of the volatile liquid is able to pass these bodies and these can be made as relatively thin layers. Such layers of matrix can for instance and as indicated in FIG. **1b** be arranged as essentially parallel relatively thin discs with one or several holes such as a centered through hole to allow passage of gas between the different part of the compartment **1**, **3**.

[0055] liquid which has condensed or has formed in the surface of the free areas **14**, **15** of the heat exchanging walls **9**, **11**, shall be able to be retained in the storages, i.e. in the bodies **12**, **13**. This may be accomplished if the material in the bodies have a sucking or attractive force, for instance a capillary action on the liquid phase of the active substance and the volatile liquid respectively, which is adjusted to or in relation to the adhesion or wetting, which the liquid phase of the active substance and the volatile liquid respectively has to the surface of the free areas **14**, **15** of the inside of the walls. The adhesion or wetting which the liquid phase of the active substance and the volatile liquid respectively to the surface of the free areas of the inside of the walls, is suitably adapted in relation to the adhesion of the material in the bodies for the liquid phase of the active substance and the volatile liquid respectively.

[0056] When there is plenty of liquid phase of the active substance and volatile liquid respectively in the free areas **14**,

15 the liquid is affected by the attractive forces and sucked into the storages, i.e. the matrix in the bodies **12**, **13** and is temporarily retained there. On the contrary when there is plenty of liquid phase of the active substance and volatile liquid respectively in the bodies **12**, **13**, the liquid phase of the active substance and volatile liquid respectively is spread out as a layer on the surface of the free areas **14**, **15**, where it easily and quickly can be evaporated by the almost direct heat transfer, which is accomplished by heat transfer through the walls **9**, **11**.

[0057] The mentioned adhesion or wetting, i.e. attraction, which the active substance and volatile liquid respectively has for the surface or surface layer in the free areas **14**, **15** of the heat conducting walls, and which cause the active substance and volatile liquid respectively to spread out over these areas can be accomplished if desired by a surface treatment in order to achieve the desired properties. This can for instance be accomplished by coating the surface of the heat conducting material in the walls **9**, **11**, with a suitable capillary material or with a material with suitable wetting properties. The surface of the heat conducting wall may be treated mechanical, chemical or electrical.

[0058] When the surface of the free areas is coated with a capillary material the mentioned adhesion or wetting which the active substance and volatile liquid respectively has for the surface of the free areas **14**, **15** of the heat conducting walls **9**, **11**, is equivalent with that the surface has a capillary action for the active substance and volatile liquid respectively. Such layers with capillary material may have a thickness in the range **10** μm -**1** mm.

[0059] If the wetting or adhesive ability or the capillary properties of the active surface is adapted in a suitable way, it can to a large extent contribute to that the liquid phase can efficiently be spread out over the free areas **14**, **15** of the heat conducting wall material in the outer walls **9**, **11** for exchange of heat during charge and discharge respectively. The chemical heat pump can then be operated with high power.

[0060] The active surface can for instance comprise the capillary material Al_2O_3 . The capillary material can be bound together with SiO_2 but there are also other alternatives for adhesion of the capillary material to the heat conducting wall material. The active surface is preferably inert, i.e. the surface should not participate chemically in the chemical heat pump process. According to the teachings above the properties of the active surface are adapted so that the active surface obtains an ability to give the desired capillary or wetting attractive forces on the active substance and volatile liquid respectively, which are used in the chemical heat pump.

[0061] The storages i.e., the bodies **12**, **13** shall in general have properties so that they can attract and retain a certain amount of the active substance and volatile liquid respectively. It is then not entirely necessary that they are permeable to the gas phase of the volatile liquid. The storages can thus be designed as surface with suitably adapted wetting properties and/or be designed with capillaries, i.e. with capillary channels. Thus the material in a matrix may for instance, if such a matrix is used, comprise pores or capillaries with so small diameter that they act with capillary force on the respectively fluid.

[0062] In a chemical heat pump according to above no pump is utilized to spread out the liquid phase of the active substance and the volatile liquid respectively over the surface of the heat conducting wall material during charge and discharge. The liquid phase of the active substance and the

volatile liquid respectively is instead spread out over the surface of the heat conducting wall material through the capillary forces in the active surface. Thereby the chemical heat pump can be constructed with fewer number of parts and without mechanical pumps, often electrical driven pumps, which otherwise would decrease the total energy recovery due to their power consumption. In the chemical heat pump described herein the heat energy is utilized to accomplish the equivalent work, which in this chemical heat pump is attraction on molecular level, capillary and/or wetting.

[0063] In FIG. 2 there is shown the principles how the liquid phase of active substance in the reactor part 1 or volatile liquid in the condenser/evaporator part 3 is pumped from a storage 16 such as a matrix out and over an active surface 17 or alternatively how the liquid phase of active substance in the reactor part 1 or volatile liquid in the condenser/evaporator part 3 is pumped from the active surface 17 to the storage 16.

[0064] In contrast to the matrix described in the above mentioned Swedish patent 530 959, the matrix 12, 13 in the present chemical heat pump is arranged so that it only marginally affects evaporation and condensation, i.e. the matrix is arranged so that it only is in contact with a minimum of the surface of the heat conducting wall material, through which exchange of heat occurs, see FIG. 1b and FIG. 2. In some exceptional cases the energy storage 16 is not at all in contact with the surface 17. In contrast to the construction disclosed in the Swedish patent 530 959, essentially the entire surface, or at least 90% or at least 95% of the heat conducting material in the walls 9, 11 is directly accessible for evaporation/condensing, whereby this is accomplished without or essentially without or with only little pressure drop for the gas phase, moving between the different parts of the chemical heat pump. Since essentially or almost the entire inner surface of the heat conducting walls can be held free of matrix, an efficient gas transport and thereby a high output can be achieved. The amount of gas which can be transported to and from the heat conducting wall material in the walls 9, 10 is larger than in the known construction.

[0065] The storage 12, 13 for the liquid phase is arranged so that the liquid either by suitable forces such as capillary and/or wetting forces is pumped out of the storage or in the other process phase of the chemical heat pump by suitable forces such as capillary and/or wetting forces is pumped back to the storage. The storage is constructed so that it by aid of suitable forces is able to retain the active substance in its liquid phase in the reactor part 1 and in the condenser/evaporator part 3 retain the volatile liquid. The forces acting on the liquid phase or the volatile liquid in the storage 12, 13 is in one embodiment adjusted so that these net attractive forces are not as strong as the net attractive forces of the active surface in the free areas 14, 15, which act in a similar way on liquid phase of volatile liquid. The liquid phase or the volatile liquid can thereby be fed out from the storage 12, 13 on to the active surface in the free areas of the inner side of the outer walls 9, 11. For instance during charging of the chemical heat pump the liquid phase in the reactor part 1 is fed out onto the active surface as described below.

[0066] An example of an empiric formula for calculation of the capillary force in the active surface, if it is designed as a layer comprising particles is:

$$W_{a.s.} = k\sigma^2 \frac{\cos^2\theta \left(\frac{1}{d_{as}} - \frac{1}{d_s} \right)}{\rho g \mu L}$$

[0067] Wherein $W_{a.s.}$ is capillary average pump speed in the active surface for penetration length L, i.e. the length which the liquid phase travels in the capillary system.

[0068] K is a constant

[0069] σ is the surface tension of the liquid,

[0070] θ is the contact angle of a drop of the liquid against the active surface

[0071] ρ is the density of the liquid,

[0072] g is the gravity constant,

[0073] μ is the viscosity of the liquid,

[0074] L is the penetration length

[0075] $d_{a.s.}$ is the particle diameter in the capillary layer of the active surface, and

[0076] d_s is the particle diameter in the energy storage.

[0077] This formula is based on tests with an active surface and a layer 12, 13 comprising particles with different particle sizes. The formula is valid for penetration lengths L of about 5-40 mm. As seen from the formula the pump speed in the active surface has a meaningful value only when the condition $1/d_{as} > 1/d_s$ is fulfilled. The experimental measurements have shown that the optimum relation between d_{as} and d_s in one embodiment is about 1:3.

[0078] When the chemical heat pump is charged the reactor part 1 can be heated to a suitable temperature with a heat source, for instance the sun, which heats the first outer medium 4, or directly the outer surface of the heat conducting walls 9. During charging it is generally arranged so that the reactor part 1 because of external influence gets a higher temperature than the condenser/evaporator part. The active substance is during the initial part of the charge in liquid phase and retained in liquid phase in the storage 12 in the reactor part 1.

[0079] Because the material in the storage 12 and the active surface 14 are adjusted so that the capillary forces in the layer are not as strong as the capillary forces or the wetting forces in the heat conducting material of the active surface, the liquid phase can gradually be fed out and spread out over the active surface i.e. the inner free surface of the heat conducting wall material. Due to the properties of the active surface of the heat conductive material, the active substance in its liquid phase is fed out to and distributed over the surface of the heat conducting wall material. Finally the capillary system is saturated in the active surface by the liquid phase of the active substance, whereby further liquid in the liquid phase of the active substance can be evaporated from the active surface and travel to the condenser/evaporator part 3. Hereby more or less solid, active substance is formed on and in the active surface. When the liquid is evaporated from the active substance, new liquid liquid phase can by capillary forces be pumped out from the storage to the active surface and out over the heat conducting wall material. A continuous feed of liquid phase to the surface of the heat conducting wall material thus occurs.

[0080] In the condenser/evaporator part 3 the evaporated liquid is simultaneously condensed, when it comes into contact with the surface of the free areas 15 of the heat conducting wall material of the walls 11, which here are cooled by the second external medium 6. The liquid is pumped capillary into the matrix 13 and more steam can thereby continuously

be condensed and the process can continue. The condensed liquid can be pumped into the matrix even if the capillary forces are not as strong as the capillary forces or the wetting forces of the active surface, because the capillary system in the active surface becomes saturated and cannot retain more liquid, whereby the liquid flows on the active surface and can be sucked into the capillary system of the matrix.

[0081] In the beginning of the discharge of the present chemical heat pump the active substance is most often mainly in its solid phase on the active surface **14** in the reactor part **1** and the liquid is retained in the matrix **13** in the condenser/evaporator part **3**. The external heating and/or external cooling of the reactor part and the condenser/evaporator part ceases and can if required or if it is suitable with regard to the application area be replaced by external cooling and/or with external heating respectively. Liquid is pumped out from the matrix **13** by capillary forces in the condenser/evaporator part and out over the free areas **15** of the surfaces of the heat conducting material because these surfaces have a surface which is active according to the description above. The liquid on the active surface is evaporated and partially transferred to the reactor part **1**. This process occurs continuously because new liquid is pumped out on the surface of the heat conducting material when the liquid is evaporated. When the gas phase of the liquid reaches the reactor part **1** it is condensed and when it comes into contact with the inner surface of the heat conducting walls **9**. The active substance on the inner surface **14** absorbs the liquid and transforms into its liquid phase, whereby the liquid phase by capillary forces is distributed over the surface of the inner side of the heat conducting walls and finally are pumped into the storage **12** by capillary forces, as soon as there is a surplus of the liquid phase so that the capillary forces in the storage can act on the liquid. More gas from the condenser/evaporator part **3** can thereby continuously be condensed and absorbed by the active substance.

[0082] In one embodiment the reactor part and/or the condenser/evaporator part is arranged in a conventional plate heat exchanger. In one embodiment in a heat exchanger of cross flow type, see FIG. 3. In such a plate heat exchanger there are corrugated heat conducting walls **21**, which are arranged next to each other with different surface in close contact with each other. Between the heat conducting walls **21** there are first parallel channels **22**, in which the external medium **4**, **6** may be and be transported. Between the heat conducting walls **21** there are also second parallel channels **23**. These second channels **23**, which as shown may be arranged essentially perpendicular to the first channels, are spaces for the reactor and condenser/evaporator respectively in a chemical heat pump. In each such second channel **23**, which constitutes a space for the reactor or condenser/evaporator in a chemical heat pump as described above a stripe or disc **24** of matrix material may be arranged. The stripe or disc is placed so that it extends between opposing walls in the channel, for example centered in the channel.

[0083] The second channels **23** in a heat exchanger unit of the type shown in FIG. 3, can in a suitable way be connected to the second channels in a similar heat exchanger so that the second channels in the first heat exchanger form spaces for the reactor part in a chemical heat pump and the second channels in the second heat exchanger form space for the condenser/evaporator part.

[0084] The first channels **22** can for instance be more or less designed as ordinary conduits while the second channels **23** as shown can have a lens-shaped cross section. Of the walls **21**

are essentially horizontal, then the cross section of the second channels have a downwards bend bottom and an upwards bent upper part. The stripe or disc **24** of matrix material can as shown extend between the bent bottom surface and the bent upper part of the channel.

[0085] The heat conducting walls of both the reactor part **1** and the condenser/evaporator part may thus be bent. Such a bent shape at the bottom part of the second channels **23** may facilitate the transport of liquid over the surface of the walls **21**, so that when a surplus of liquid exists, it will gather in the bottom of the channel and be absorbed by the matrix material **24**.

[0086] Application areas for a chemical heat pump comprising an active surface and a layer as described above include but are not limited to all processes where heat energy is available continuously. In particular the chemical heat pump can be used in cases where energy does not have to be stored during extended periods, but where a lot of power has to be utilized and delivered respectively. Examples of such uses include but are not limited to more efficient use of an ordinary oil, wood, or gas heater. In one embodiment the heater can continuously deliver heat to the chemical heat pump and it is only desired to store energy for about 20-30 minutes. If the described chemical heat pump is used together with an existing heater, twice as much energy can be recovered from the heater in one embodiment, whereby about $\frac{3}{4}$ is heat and about $\frac{1}{4}$ is cooling in one embodiment.

[0087] Another example is air condition for vehicles, where continuous excess heat from the internal combustion engine can be transformed into cooling. This may in one embodiment reduce the fuel consumption with 5-25% for buses. Another example where electricity is generated from an internal combustion engine, because the excess heat which is cooled away in one embodiment constitutes about 70% of the fuel consumption. By using the described technology with the chemical heat pump comprising an active surface and storage more than half of this energy can be converted into heat or cooling, in one embodiment.

[0088] Other features and uses of the invention and their associated advantages will be evident to a person skilled in the art upon reading the description and the examples.

[0089] It is to be understood that this invention is not limited to the particular embodiments shown here. The following examples are provided for illustrative purposes and are not intended to limit the scope of the invention since the scope of the present invention is limited only by the appended claims and equivalents thereof.

1. A chemical heat pump comprising an active substance and a volatile liquid, said volatile liquid being adapted to be absorbed by the active substance at a first temperature and said volatile liquid being adapted to be desorbed by the active substance at a second higher temperature, whereby the active substance at the first temperature has a solid phase, from which the active substance during uptake of the volatile liquid and its gas phase immediately transforms partially into liquid phase or liquid phase and whereby the active substance at the second higher temperature has a liquid phase or is in liquid phase, from which the active substance during desorption of the volatile liquid, in particular the gas phase of the volatile liquid, in particular the gas phase of the volatile liquid, immediately transforms partially into solid phase, whereby the chemical heat pump comprises:

a reactor part comprising active substance, whereby the reactor part is adapted to exchange heat with an external medium by exchange of heat through delimiting and heat conducting walls,

a condenser/evaporator part comprising a part of the volatile liquid, the condenser/evaporator part being adapted to exchange heat with an external medium by exchange of heat through delimiting and heat conducting walls, and

a passage for the gas phase of the volatile liquid, said passage connecting the reactor part and the condenser/evaporator part with each other,

whereby at least one of (i) the reactor part and (ii) the condenser/evaporator part comprises a layer,

whereby a layer if present in the reactor part is adapted to retain the active substance at least in its liquid phase or its liquid phase, and

whereby a layer if present in the condenser/evaporator part is adapted to retain the volatile liquid in its liquid phase, that the layer is arranged as bodies with limited contact surfaces against the surface of one or more of the heat conducting walls so that free areas of the surfaces of the heat conducting walls are between the contact surfaces, that the free areas of the surface of the heat conducting walls are adapted to exert a net attractive force on the active substance in its liquid phase and the volatile liquid in its liquid phase respectively and that the net attractive force is adjusted with regard to net attractive force exerted by the layer on the active substance in its liquid phase and the volatile liquid in its liquid phase respectively.

2. The chemical heat pump according to claim 1, wherein the layer comprises a matrix and wherein the matrix comprises a porous material which is permeable to the gas phase of the volatile liquid.

3. The chemical heat pump according to claim 1, wherein said net attractive force exerted by the free areas of the surface of the heat conducting walls comprises capillary force.

4. The chemical heat pump according to claim 1, wherein the layer comprises a material which has adjusted capillary properties with regard to the active substance in its liquid phase and the volatile liquid in its liquid phase respectively.

5. The chemical heat pump according to claim 1 wherein the layer comprises surfaces which have adjusted wetting properties with regard to the active substance in its liquid phase and the volatile liquid in its liquid phase respectively.

6. The chemical heat pump according to claim 1, wherein the net attractive force exerted by the free areas of the surface of the heat conducting walls is adjusted so that the net attractive force exerted by the heat conducting walls on the active substance in its liquid phase and the volatile liquid in its liquid phase respectively, is higher than the net attractive force exerted by the layer on the active substance in its liquid phase and the volatile liquid in its liquid phase respectively.

7. The chemical heat pump according to claim 1, wherein the limited contact surfaces constitute maximum 10%, preferably maximum 5% of the area of the heat conducting walls 0414.

8. The chemical heat pump according to claim 1, wherein the bodies of matrix are designed as parallel discs with a through hole and the outer surfaces of the discs are in contact with the surface of a heat conducting wall.

9. The chemical heat pump according to claim 1, wherein the bodies of matrix are arranged as bodies which extend between opposite walls in parallel channels in a plate heat exchanger, whereby other parallel channels in the plate heat exchanger comprises a heat carrying medium.

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