A tube and fin arrangement of an evaporator for an air conditioning system for a vehicle having a first row of tubes disposed within a flow of air having at least two refrigerant tubes and at least two thermal storage tubes in thermal communication with the at least two refrigerant tubes, each of the thermal storage tubes containing a phase change material. The tube and fin arrangement further includes a fin in thermal communication with the first row of tubes and configured to receive a flow of air therethrough.
TUBE-FIN THERMAL STORAGE EVAPORATOR

FIELD OF THE INVENTION

[0001] The present invention relates to a thermal storage evaporator for use in vehicle air conditioning circuits, and more particularly to an arrangement of refrigerant tubes and thermal storage tubes in the evaporator.

BACKGROUND OF THE INVENTION

[0002] As commonly known, an air conditioning system for a vehicle is driven by engine power of the vehicle. In operation, a refrigerant receives heat from warm air to cool the air and sends cooled or dehumidified air to a passenger cabin of the vehicle. For conventional air conditioning systems, a manual compressor of the air conditioning system runs while the engine of the vehicle is operating. To enhance fuel efficiency, stop-start engine systems can be employed with vehicles that include an internal combustion engine. Additionally, the stop-start engine systems are also employed with vehicles including mild hybrid systems. Mild hybrid systems have a combination of the internal combustion engine and an electric motor. In stop-start engine systems, the engine stops operating during vehicle stops or idle mode, such as during a traffic light stop, for example. When the engine stops operating, the manual compressor of the air conditioning system also stops operating. Accordingly, stoppage of the engine, which stops the operation of the compressor of the air conditioning system, affects a temperature of the passenger cabin, especially when the ambient temperature is higher, causing thermal discomfort.

[0003] In order to address the thermal discomfort while maintaining efficiency, certain air conditioning systems employ an evaporator, such as an evaporator with phase change material (PCM), to provide residual cooling during engine stop conditions. The PCM stores and releases thermal energy when melting or solidifying at certain temperatures. When the PCM reaches a temperature at which it changes phase from solid to liquid, the PCM absorbs heat. When the temperature falls, the PCM solidifies and releases stored heat. Therefore, while the engine is operating, thermal energy is removed from the PCM, and alternatively, when the engine is not operating, the PCM changes phases and absorbs heat from the air.

[0004] For example, in U.S. Pat. Appl. Pub. No. 2012/0272679 to Vreeland et al., an evaporator phase change thermal siphon is disclosed. The evaporator includes a manifold and a plurality of refrigerant tubes extending downwardly from the manifold. A PCM housing engages an upper portion of the refrigerant tubes and the manifold. In operation, heat is transferred from the refrigerant to the solidified PCM to cool and condense the refrigerant. The condensed refrigerant then receives heat from the flow of air to cool the flow of air and to warm and evaporate the refrigerant. The evaporated refrigerant rises upwardly to the manifold where it dispenses heat to the phase change material.

[0005] However, these evaporators are not optimal for providing rapid recharging times and longer discharging times, where recharging is the state of the evaporator when the engine is operating (i.e. energy is removed from the PCM) and discharging is the state of the evaporator when the engine is in stop or idle mode (i.e. heat is absorbed by PCM). The known evaporators include the PCM; however, the PCM is disposed in the upper portion of the evaporator, rather than directly within the flow of air through the evaporator. By disposing the PCM in the upper portion of the evaporator, optimal recharging and discharging times of the PCM are not achieved. For example, a residual cooling of the air by existing evaporators with PCM during an engine off-time may only continue for a limited period of time before the evaporator no longer provides a desired discharge temperature. Subsequently, after the engine begins operating again, the vehicle may approach another stop or idle shortly after a prior stop or idle without allowing sufficient recharge time for the PCM, thus also resulting in a shorter residual cooling time.

[0006] Furthermore, the greater the amount of PCM, the longer the residual cooling time. However, the structure of the evaporator is typically limited in size to particular air conditioning package requirements based on installation space in the vehicle. Thus, incorporating additional elements with the evaporator may not be feasible. Also, the additional elements may delimit efficient operability of the air conditioning system such as by not maintaining a low pressure drop across the evaporator and providing optimal air stratification for the passenger cabin of the vehicle. Therefore, there is a continuing need for a thermal storage evaporator that provides longer residual cooling while meeting optimal package, cost, efficiency, and manufacturing requirements. It would be advantageous if a thermal storage evaporator could be improved.

SUMMARY OF THE INVENTION

[0007] Concordant and congruous with the present invention, an improvement of a thermal storage evaporator has surprisingly been discovered.

[0008] According to an embodiment of the invention, a tube and fin arrangement an air conditioning system for a vehicle is disclosed. The tube and fin arrangement includes a first row of tubes disposed within a flow of air having at least two refrigerant tubes and at least two thermal storage tubes in thermal communication with the at least two refrigerant tubes, each of the thermal storage tubes containing a phase change material. The tube and fin arrangement further includes a fin in thermal communication with the first row of tubes and configured to receive a flow of air therethrough.

[0009] According to another embodiment of the invention, a tube and fin arrangement of an evaporator for an air conditioning system for a vehicle is disclosed. The tube and fin arrangement includes a plurality of rows of tubes disposed within a flow of air, each of the rows of tubes having at least one thermal storage tube disposed intermediate at least two refrigerant tubes, each of the thermal storage tubes containing a phase change material. The tube and fin arrangement further includes a plurality of fins interposed between and in thermal communication with the rows of tubes.

[0010] According to a further embodiment of the invention an evaporator for an air conditioning system for a vehicle includes a plurality of headers containing at least one of a refrigerant and a phase change material (PCM). The evaporator further includes a plurality of substantially parallel rows of tubes extending from and in fluid communication with the headers and disposed within a flow of air, each of the rows of tubes having at least two refrigerant tubes and at least two thermal storage tubes in thermal communication with the at least two refrigerant tubes, each of the thermal storage tubes containing a phase change material. A fin assembly having a plurality of parallel fins is interposed between and in thermal
communication with the rows of tubes and configured for receiving a flow of air therethrough.

**BRIEF DESCRIPTION OF THE DRAWINGS**

**[0011]** The above, as well as other advantages of the present invention, will become readily apparent to those skilled in the art from the following detailed description of a preferred embodiment when considered in the light of the accompanying drawings in which:

**[0012]** FIG. 1 is a top perspective view of an evaporator according to an embodiment of the invention;

**[0013]** FIG. 2 is a top perspective view of a tube and fin arrangement of the evaporator shown in FIG. 1;

**[0014]** FIG. 3A is a cross-sectional view of a tube for a refrigerant or a phase change material (PCM) according to an embodiment of the invention;

**[0015]** FIG. 3B is a cross-sectional view of a tube for a refrigerant or phase change material (PCM) according to another embodiment of the invention; and

**[0016]** FIG. 3C is a cross-sectional view of a tube for a refrigerant or phase change material (PCM) according to another embodiment of the invention.

**DETAILED DESCRIPTION OF EXEMPLARY EMBODIMENTS OF THE INVENTION**

**[0017]** The following detailed description and appended drawings describe and illustrate various exemplary embodiments of the invention. The description and drawings serve to enable one skilled in the art to make and use the invention, and are not intended to limit the scope of the invention in any manner. The terms upper, lower, horizontal, and vertical are used with respect to the direction of gravity.

**[0018]** FIG. 1 illustrates an evaporator 10 of an air conditioning system according to an embodiment of the invention. In the embodiment shown, the evaporator 10 is configured to be a component of a refrigerant system of a motor vehicle (not shown) that includes a compressor that is operably connected to an engine of the motor vehicle. Accordingly, when the engine of the motor vehicle is not operating, the compressor is not operating. It is understood that the evaporator 10 could be used in other systems such as an air conditioning system for a building or an air conditioning system for a vehicle with an electrically driven compressor, for example.

**[0019]** The evaporator 10 includes a plurality of upper headers 12 and a lower header 14. The upper headers 12 are elongated conduits arranged substantially horizontally and in a substantially parallel relationship to each other. In the embodiment illustrated, four headers 12a, 12b, 12c, 12d are shown. Two of the headers 12a, 12c convey a flow of refrigerant such as an inlet flow of refrigerant and outlet flow of refrigerant. Another two of the headers 12b, 12d are configured to contain a thermal storage material or a phase change material (PCM). The headers 12a, 12b, 12c, 12d can be integrally or separately formed. Additionally, the evaporator 10 can have any number of headers 12a, 12b, 12c, 12d containing refrigerant and any number of headers 12a, 12b, 12c, 12d containing the PCM, as desired, and the headers 12a, 12b, 12c, 12d can be arranged in any order with respect to a direction of a flow of air 16 through the evaporator 10.

**[0020]** The evaporator 10 further includes a tube and fin arrangement 18. The tube and fin arrangement 18 includes a plurality of substantially parallel rows of tubes 20 extending from and in fluid communication with the headers 12a, 12b, 12c, 12d and configured to contain a material to facilitate heat transfer. The rows of tubes 20 are arranged transversely to the direction of the flow of air 16 through the evaporator 10. Each of the rows of tubes 20 can include elongate refrigerant tubes 22 and elongate thermal storage tubes 24 containing the PCM, wherein the refrigerant tubes 22 extend from headers 12a, 12c containing refrigerant and the thermal storage tubes 24 extend from headers 12b, 12d containing the PCM. The evaporator 10 further includes a plurality of fins 30 arranged substantially parallel with each other and interposed between the rows of tubes 20. The fins 30 are configured to receive the flow of air 16.

**[0021]** FIG. 2 shows the tube and fin arrangement 18 of the evaporator 10. The tube and fin arrangement 18 has an air inlet side 26 and an air outlet side 28. Each of the rows of tubes 20 can includes the refrigerant tubes 22 for conveying a flow of refrigerant and the thermal storage tubes 24 for containing PCM. Each of the refrigerant tubes 22 extends longitudinally from and is in fluid communication with one of the corresponding headers 12a, 12c containing refrigerant. Further, the refrigerant tubes 22 extend substantially perpendicular relative to the headers 12a, 12c. The refrigerant tubes 22 extend between each of the headers 12a, 12c and the lower header 14. Each of the refrigerant tubes 22 is in fluid communication with the lower header 14 so each of the upper headers 12a, 12c containing refrigerant are fluidly connected to the lower header 14. In the embodiment shown, one of the refrigerant tubes 22 is an inlet refrigerant tube and one of the refrigerant tubes 22 is an outlet refrigerant tube. As shown, the lower header 14 is a single conduit. However, the lower header 14 can be any number of conduits. The conduits can then be fluidly connected. For example, where two refrigerant tubes 22 are provided in each of the rows of tubes 20, the lower header 14 may include two lower conduits, one for each of the refrigerant tubes 22 and the two lower conduits can be fluidly connected by means of a conduit. Two refrigerant tubes 22 are shown in FIG. 2. However, it is understood that more or fewer refrigerant tubes 22 can be provided in each of the rows of tubes 20.

**[0022]** Each of the thermal storage tubes 24 extends from and is in fluid communication with one of the corresponding headers 12b, 12d containing the PCM. Each of the thermal storage tubes 24 extends substantially perpendicular relative to the headers 12b, 12d. In FIG. 2, two thermal storage tubes 24 are shown. However, there can be any number of thermal storage tubes 24 in each of the rows of tubes 20 such as one thermal storage tube, three thermal storage tubes, four thermal storage tubes, or any other number as desired. The PCM is a latent heat storage substance that absorbs and stores the heat when changing from a solid phase to a liquid phase and releases the stored heat when changing from a liquid phase to a solid phase. The PCM can be any substance having the required thermodynamic properties needed for vehicle air conditioning systems such as organic and inorganic eutectic materials, hydrated salts, paraffins and fatty acids, or any other substance capable of high latent heat storage as well as high thermal conductivity, for example. The PCM in each of the thermal storage tubes 24 can be any PCM having the required phase change temperatures dependent on the constraints of the evaporator 10. Further, the PCM in each of the thermal storage tubes 24 can be the same or the PCM in each of the thermal storage tubes 24 can be different.

**[0023]** The refrigerant tubes 22 and the thermal storage tubes 24 can be arranged in an order in each of the rows of
tubes 20 to facilitate thermal conductivity to the PCM contained in the thermal storage tubes 24 while maintaining efficiency of the refrigerant tubes 22. In the embodiment shown in FIG. 2, there can be four tubes 20a, 20b, 20c, 20d in each of the rows of tubes 20. One of the refrigerant tubes 22 can be arranged as the first tube 20a in each of the rows of tubes 20, where the first tube 20a is the tube in each of the rows of tubes 20 adjacent the air inlet side 26. One of the thermal storage tubes 24 can be arranged as the second tube 20b in the rows of tubes 20, where the second tube 20b is adjacent the first tube 20a and the third tube 20c in each of the rows of tubes 20. Another one of the refrigerant tubes 22 can be arranged as the third tube 20c in the rows of tubes 20, where the third tube 20c is adjacent the second tube 20b and the fourth tube 20d in each of the rows of tubes 20. Another one of the thermal storage tubes 24 can be arranged as the fourth tube 20d in the rows of tubes 20, where the fourth tube 20d is arranged between the third tube 20c in each of the rows of tubes 20 and the air outlet side 28.

[0024] The refrigerant tubes 22 and the thermal storage tubes 24 in each of the rows of tubes 20 can be arranged in any manner as desired. In one non-limiting example, each of the rows of tubes 20 can have one refrigerant tube 22 arranged as the first tube 20a adjacent the air inlet side 26 and another refrigerant tube 22 arranged as the fourth tube 20d adjacent the air outlet side 28. Two thermal storage tubes 24 can be disposed between the refrigerant tubes 22 arranged as the second tube 20b and the third tube 20c. Additionally, in another non-limiting example, two refrigerant tubes 22 can be arranged as the first tube 20a and the second tube 20b in each of the rows of tubes 20 and two thermal storage tubes 24 can be arranged as the third tube 20c and fourth tube 20d in each of the rows of tubes 20. It is understood that each of the thermal storage tubes 24 can contain a PCM with varying phase changes properties. For example, one thermal storage tube 24 can contain a PCM with a higher melting point temperature than the other thermal storage tubes 24 in each of the rows of tubes 20.

[0025] The fins 30 are disposed between each of the rows of tubes 20. The fins 30 are substantially parallel with the rows of tubes 20. Each of the fins 30 extends between the air inlet side 26 of the evaporator 10 and the air outlet side 28 of the evaporator 10. A first side 31 of each of the fins 30 is in thermal communication with each of the tubes 20a, 20b, 20c, 20d in one of the rows of tubes 20 and a second side 32 of each of the fins 30 is in thermal communication with each of the tubes 20a, 20b, 20c, 20d in another row of tubes 20. The fins 30 have an upper end 33 adjacent the upper headers 12 and a spaced apart lower end 34 adjacent the lower header 14. As shown, each of the fins 30 is formed as part of a continuous corrugated sheet to maximize heat transfer from the refrigerant in the evaporator 10 to the flow of air 16. Louvers 36 can be formed on corrugated walls 38 of each of the fins 30 to maximize thermal efficiency.

[0026] Each of the tubes 20a, 20b, 20c, 20d in each of the rows of tubes 20 can have equal widths. Alternatively, each of the tubes 20a, 20b, 20c, 20d in each of the rows of tubes 20 can have different widths. For example, one of the refrigerant tubes 22 such as the refrigerant tube 22 arranged as the first tube 20a in each of the rows of tubes 20 can have a width greater than each of the widths of the thermal storage tubes 24 and the width of the other refrigerant tubes 22 in each of the rows of tubes 20. The refrigerant tube 22 having the greater width creates a larger surface area to transfer heat to or from the flow of air 16 as the air flows through the evaporator 10. In another example, each of the refrigerant tubes 22 can have widths greater that the thermal storage tubes 24. Additionally, one of the thermal storage tubes 24 arranged as the second tube 20b in the rows of tubes 20 can have a width greater than the width of the other thermal storage tubes 24. The tubes 20a, 20b, 20c, 20d of the rows of tubes 20 can have any widths as desired to conform to the space requirements of the evaporator 10 and to maximize heat transfer within the evaporator 10.

[0027] In the embodiment illustrated in FIG. 2, each of the refrigerant tubes 22 and the thermal storage tubes 24 has an obround, oblong, or substantially oval shaped cross-section having two substantially planar sides 40 interconnected by arcuate ends 42. In another embodiment, as shown in FIG. 3a, the refrigerant tubes 22 and the thermal storage tubes 24 can have an obround, oblong, or substantially oval shaped cross-section with two substantially planar sides 40 interconnected by arcuate ends 42 with a partition 44 formed therein between the substantially planar sides 40. The partition 44 further enhances conduction of heat between the tubes 22, 24 and the fins 30. As shown, the partition 44 extends from a center of each of the opposing substantially planar sides 40, although other configurations can be used as desired. Any process such as an extrusion process can be used to form the tubes 22, 24. Another embodiment of the tubes 22, 24 is shown in FIG. 3b, wherein the refrigerant tubes 22 and the thermal storage tubes 24 include protuberances 46 extending outwardly from an inner surface thereof. As shown in FIG. 3b, the tubes 22, 24 can have four protuberances 46 that are integrally formed therewith. As shown, each of the protuberances 46 has a substantially T-shaped cross-section, although other cross-sectional shapes can be used as desired. Two of the protuberances 46 extend from the opposing substantially planar sides 40 and two protuberances 46 extend from the opposing arcuate ends 42. The protuberances 46 can be formed with the same material as the tubes 22, 24 or with any conductive material as desired. The protuberances 46 can have any cross-sectional shape as desired such as rectangular, triangular, serpentine, parabolic, ogival, or arch-shaped, for example. Any process such as an extrusion process can be used to form the tubes 22, 24.

[0028] In the embodiment shown in FIG. 3c, the tubes 22, 24 can be formed as an integral tube 50 having an obround, oblong, or substantially oval shape cross-section having two substantially planar sides 52 interconnected by arcuate ends 54. The integral tube 50 has conduits 48 formed therein. Each of the conduits 48 is configured to convey a refrigerant therethrough between the upper headers 12 and the lower header 14 or contain a PCM. The conduits 48 are separated by partitions 44 extending between substantially planar sides 52 of the integral tube 50. The integral tube 50 extends laterally from the air inlet side 26 to the air outlet side 28 of the evaporator 10. The integral tube 50 can also include protuberances formed therein as described hereinabove. Additionally, it is understood that the tubes 22, 24 can have any cross-sectional shape as desired such as circular, ovular, rectangular or any other shape as desired to facilitate heat transfer to cause the PCM to change phases.

[0029] Each of the refrigerant tubes 22 and the thermal storage tubes 24 can have any cross-sectional shape and dimension configured for an evaporator 10 with dimensional constraints such as an evaporator 10 with a depth of 50 to 70 mm. The refrigerant tubes 22 and the thermal storage tubes 24
in each of the rows of tubes 20 can be produced as desired such as by extrusion, 3-D printing, folding of a sheet of heat conductive material, or assembling two half plates having stamped features defining flow spaces, for example. Additionally, the PCM can be combined with another thermally conductive structure such as a metal mesh, metallic particles, and metallic fibers, for example.

[0030] In operation, during a recharging period of the PCM such as when the engine of the vehicle is operating, the cold refrigerant and air at lower temperatures cause thermal energy to be removed from the PCM, which causes the PCM to freeze or solidify. During a discharging period of the PCM such as when a vehicle engine is in a stopped or idle mode, the compressor is not operating and warm air flows through the evaporator 10. The PCM reaches a predetermined temperature at which the PCM gradually liquefies or melts. During this phase change, the PCM absorbs heat. The PCM continues to absorb heat without a substantial rise in temperature until all the PCM is liquefied. Therefore, the refrigerant tubes 22 and thermal storage tubes 24 can be arranged to facilitate conduction and convection to maximize the discharging period and minimize the recharging period. The refrigerant tubes 22 and thermal storage tubes 24 are arranged within the flow of air 16 to facilitate the transfer of thermal energy directly between the PCM and the air. The tube and fin arrangement 18 can be configured to receive a flow of air 16 at a flow rate of about 200 to 300 cfm with a temperature of about 20–40 degrees Celsius. However, the tube and fin arrangement 18 can be configured to receive any flow rate of a flow of air and any temperature of air as desired. The arrangement of the refrigerant tubes 22 and thermal storage tubes 24 within the flow of air 16 can facilitate providing a discharge time of about 20 to 60 seconds and a recharge time of less than 30 seconds, although the refrigerant tubes 22 and the thermal storage tubes 24 may be arranged as desired to facilitate other recharge times.

[0031] From the foregoing description, one ordinarily skilled in the art can easily ascertain the essential characteristics of this invention and, without departing from the spirit and scope thereof, can make various changes and modifications to the invention to adapt it to various usages and conditions.

1. A tube and fin arrangement of an evaporator for an air conditioning system for a vehicle, comprising:
   a first row of tubes disposed within a flow of air having at least two refrigerant tubes and at least two thermal storage tubes in thermal communication with the at least two refrigerant tubes, each of the thermal storage tubes containing a phase change material; and
   a fin in thermal communication with the first row of tubes and configured to receive a flow of air therethrough.

2. The tube and fin arrangement of claim 1, wherein at least one of the refrigerant tubes has a width greater than a width of at least one of the thermal storage tubes.

3. The tube and fin arrangement of claim 1, wherein each of the thermal storage tubes and each of the refrigerant tubes have opposing substantially planar surfaces.

4. The tube and fin arrangement of claim 1, wherein at least one of the thermal storage tubes and the refrigerant tubes includes a partition formed therein to facilitate heat transfer.

5. The tube and fin arrangement of claim 1, wherein the refrigerant tubes are integrally formed with the thermal storage tubes.
a fin assembly having a plurality of parallel fins interposed between and in thermal communication with the rows of tubes and configured for receiving a flow of air there-through.

18. The evaporator of claim 17, wherein each of the rows of tubes has two refrigerant tubes and two thermal storage tubes, one of the refrigerant tubes disposed adjacent an air inlet side of the evaporator, and one of the thermal storage tubes disposed adjacent an air outlet side of the evaporator.

19. The evaporator of claim 18, wherein at least one of the refrigerant tubes has a width greater than a width of at least one of the thermal storage tubes.

20. The evaporator of claim 17, wherein the headers include at least two refrigerant headers and at least two thermal storage headers, each of the refrigerant headers in fluid communication with at least one of the refrigerant tubes in each of the rows of tubes, and each of the thermal storage headers in fluid communication with at least one of the thermal storage tubes in each of the rows of tubes.

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