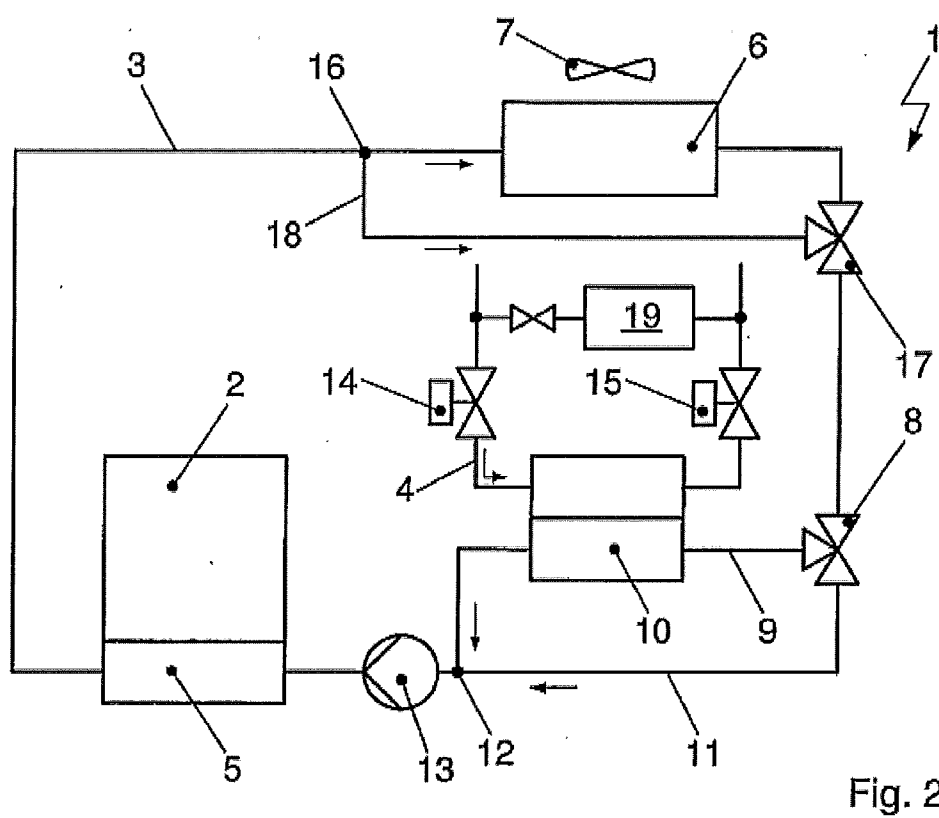
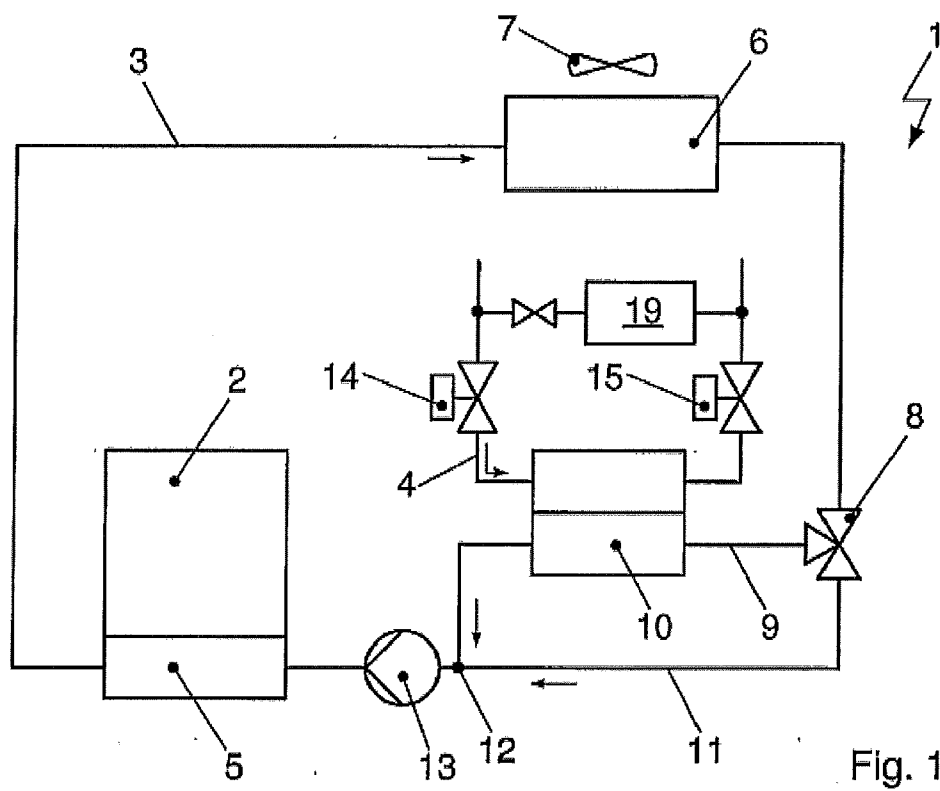




VEHICLE COOLING SYSTEM

CROSS-REFERENCE TO RELATED APPLICATION

[0001] This application claims the benefit of priority of German Patent Application Serial No. DE 10 2010 042 122. 7-45 filed on Oct. 7, 2010, hereby incorporated herein by reference in its entirety.

FIELD OF THE INVENTION

[0002] The invention relates to a cooling system for cooling the battery of a vehicle, and, more particularly, to a cooling system for cooling the battery of an electric vehicle or hybrid vehicle using a coolant circuit. The invention further relates to a method for operating the cooling system.

BACKGROUND OF THE INVENTION

[0003] High-capacity batteries used in electric or hybrid vehicles are used to store electrical energy. The energy is supplied to the battery by connecting the battery to a power supply source. With hybrid vehicles, energy can also be recovered during the braking processes of the vehicle.

[0004] During operation, both the battery cells of the battery as well as other components of the electrical drive train, such as the electric motor and the power electronics, heat up. The battery should be operated at an optimal temperature, especially during discharging and charging. Any heat generated and liberated in the process must be dissipated, because an elevated operating temperature can result in very high thermal loading on the battery cells. Due to the limited temperature resistance of batteries, they must be actively cooled. Suitable media for cooling the battery and other electronic components of the drive train are the ambient air, the air of the vehicle interior, refrigerants and coolants. Water and/or glycol, for example, may be used as a coolant.

[0005] Cooling the battery will increase its lifespan and should be performed so that the temperature of the cooled battery varies only within a limited range.

[0006] However, to operate the batteries of the electric vehicles at an optimal operating temperature, the generated heat must be dissipated, and heat must be supplied to the cold battery if the ambient temperature is too low, for example, when starting the vehicle.

[0007] The lithium-ion batteries used in electric or hybrid vehicles have a narrow temperature range in which operation is possible. At low temperatures of the battery cells, particularly at temperatures up to 0° C., the electrical output of the battery must be reduced to prevent damaging the cells. The batteries also cannot be charged in a temperature range below 0° C.

[0008] As the operating temperature increases, the electrical efficiency of the lithium-ion batteries increases. At temperatures above 40° C., however, increased aging of the battery cells occurs, which can result in damage to the cells if the temperature is higher than 50° C.

[0009] In the case of lithium-ion batteries which exhibit limited performance above approximately 40° C., cooling using ambient air is not feasible in all environmental conditions. The outside air temperature can reach or exceed values of 40° C. on a hot summer day, so that cooling using untreated ambient or outside air is not feasible. At these temperatures,

the output of the battery may be reduced in order to limit the heat generated. However, the battery may not provide the necessary maximum output.

[0010] A user could also withdraw cooling air from the air-conditioned vehicle interior and direct it to the battery.

[0011] While the use of cooling air from the vehicle interior permits a narrower temperature range than the use of ambient air, the withdrawal of air from the vehicle interior produces increased noise in the vehicle and therefore reduces the comfort for a user.

[0012] Moreover, using air cooling for batteries, which at temperature differences in the range of 0 to 5 K is rather demanding with regard to temperature distribution homogeneity, the temperature spread between the individual battery cells may become too great. In order to reduce the temperature spread, cooling must be performed using a very large air mass flow rate. In addition to the aforementioned high level of flow noise and the cooling capacity which depends on the ambient conditions, it must also be ensured that a large installation space is available for air routing when employing an air cooling system, using large-size blowers and large flow cross-sections.

[0013] In addition to cooling the battery air from the vehicle interior cooled by the air-conditioning system, other methods are known for connecting the battery cooling system to the air-conditioning system of the vehicle. It is possible to cool the battery directly using a refrigerant and a secondary circuit of the air-conditioning system. With direct cooling, refrigerant is supplied to the heat exchanger to absorb the heat developing inside the battery. When cooling by means of a secondary circuit, the heat from the battery absorbed in the heat exchanger is dissipated in a second heat exchanger to the air-conditioning system of the vehicle. Water or glycol, for example, may be used as a heat transfer medium to be recirculated within the secondary circuit.

[0014] When cooling the battery by way of refrigerant, the refrigerant circuit of the vehicle air-conditioning system must also be operated, even if the ambient conditions do not require air-conditioning of the vehicle interior, so that electrical energy is used to operate the compressor.

[0015] Electrical energy is also necessary for cooling the battery using a coolant. However, the power for delivering the coolant is significantly less than the required compressor power for operating the coolant circuit. Within a low-temperature circuit, the coolant will dissipate the heat absorbed from the battery to the surroundings, which is only possible at ambient temperatures below 40° C. because the temperature of the battery should not exceed 40° C.

[0016] When the ambient air temperatures are above 40° C., the coolant is cooled to below the ambient temperature using the refrigerant circuit of the vehicle air-conditioning system. The refrigerant/coolant heat exchanger is also referred to as a chiller and operates as an evaporator with respect to the refrigerant. The refrigerant, which largely includes a two-phase upon entering the evaporator, is evaporated and superheated, if necessary.

[0017] According to prior art, it is known to connect a thermostatic expansion valve upstream of the chiller to control constant superheating at the outlet of the chiller. A shut-off function is integrated in the thermostatic expansion valve for the operating state in which no refrigerating capacity is required at the chiller. The shut-off function is implemented using a solenoid valve or a stepping motor valve.

[0018] When the temperature of the battery exceeds an upper switching limit, the battery must be cooled. The solenoid valve is opened and the refrigerating capacity adjusts “automatically” via the thermostatic expansion valve, cooling the battery. When dropping below a lower switching limit, the solenoid valve will close and the temperature of the battery slowly rises. Since the thermostatic expansion valve control is mechanical, the appropriate refrigerating capacity for cooling the battery cannot be provided, which reduces the efficiency of the battery cooling process. The battery is cooled more than necessary and is therefore operated less efficiently. As the required cooling capacity increases, the electrical power generated for operating the battery cooling increases as well.

[0019] DE 10 2009 035 329 A1 describes a device and a method for operating a vehicle with a battery comprising a plurality of single cells. A coolant, which is delivered from a pump unit within the coolant circuit, flows through the housing of the battery. The coolant circuit is thermally coupled to a refrigerant circuit by means of a heat exchanger. Depending upon the ambient temperature and/or the speed of the vehicle, the rotational speed of a compressor arranged in the refrigerant circuit varies. The compressor is thermally coupled to the coolant circuit via the heat exchanger, which is designed as a chiller. The chiller, which can be hydraulically isolated from the refrigerant circuit by means of a shutoff valve, is operated in a pulse mode and/or intermittently. The evaporator and the chiller can therefore be operated independently or simultaneously, but only at the same pressure level as the refrigerant.

[0020] DE 10 2007 012 893 A1 describes a cooling system for cooling batteries that are made up from storage cells. The battery is housed within a battery case. In order to provide cooling, the cooling system has a coolant circuit with an air heat exchanger for the transfer of heat into the ambient air, a liquid cooler for the transfer of heat to a cooling liquid, preferably refrigerant in the refrigerant circuit of an air-conditioning system, and a three-way valve for switching between the two heat exchangers connected in parallel. When a permissible temperature of the battery cell casing is exceeded, the external air heat exchanger with axial fans is closed via the three-way valve, and the liquid cooler directly connected to the air-conditioning system of the vehicle is enabled.

[0021] A similar cooling system as that of DE 10 2007 012 893 A1 is disclosed in US Patent Application Publication No. 2009/0321532 A1. The cooling system has a coolant circuit with an air heat exchanger and a heat exchanger for transferring heat from the coolant to the refrigerant of the air-conditioning system of the vehicle. The heat exchangers are connected in parallel and by a three-way valve. Accordingly, the flow can occur through both heat exchangers at the same time, and, depending upon the power to be dissipated from the coolant, one of the heat exchangers may be deactivated so that the flow only passes through as a bypass. The demand for cooling capacity of the battery and of the heat exchanger connected to the battery is established by sensors that determine the temperatures of the battery and the surroundings.

[0022] Known devices from the prior art inherently operate the chillers in parallel with the evaporator when conditioning the air of the vehicle interior. Since the refrigerant lines are connected to each other downstream of the respective evaporator and chiller, the refrigerant has the same pressure, and therefore the same evaporation temperature level, in both components. The pressure and temperature level in the chiller

cannot be controlled independent of the evaporator of the vehicle air-conditioning system.

[0023] The object of the present invention is to provide a system and a method for the combined cooling of the battery of a vehicle, in particular, an electric or hybrid vehicle, and the conditioning of the air supplied to the vehicle interior. The cooling system must be designed such that a minimum amount of electrical energy must be generated for cooling the battery in order to maximize the efficiency of the drive system and the air-conditioning system of the vehicle.

[0024] The disclosure teaches that this is achieved using a cooling system for the combined cooling of the battery and the conditioning of the air supplied to the interior of a vehicle. The cooling system has a coolant circuit with a pump device, a heat exchanger for transferring heat between a coolant and the battery, a heat exchanger for transferring heat between the coolant and the surroundings, and a heat exchanger for transferring heat between the coolant and a refrigerant recirculating in a refrigerant circuit of the vehicle air-conditioning system. The heat exchanger for transferring heat between the coolant and the refrigerant is designed as an evaporator on the refrigerant side and is referred to hereafter as a chiller.

[0025] According to one embodiment of the invention, the coolant circuit is designed with two expansion elements. The first expansion element is arranged directly upstream of the chiller, and the second expansion element is arranged directly downstream of the chiller, with regard to the direction of the refrigerant flow. ‘Directly’ shall be understood to mean that the first expansion element and chiller as well as the chiller and second expansion element, follow each other in direct succession without, except for connecting lines, additional components of the refrigerant circuit being arranged in-between. The chiller, serving as the heat exchanger for transferring heat between the coolant and the refrigerant, represents a thermal coupling of the coolant circuit and the refrigerant circuit.

[0026] The refrigerant circuit is typically a component of an air-conditioning system for conditioning the incoming air supplied to a vehicle interior. In addition to the heat exchanger for transferring heat between the coolant and the refrigerant of the cooling system, the refrigerant circuit comprises an additional heat exchanger designed as an air/refrigerant heat exchanger, which also operates as an evaporator of the refrigerant.

[0027] The closed refrigerant circuit also includes a refrigerant compressor, a condenser, and an expansion element that is associated with the air/refrigerant heat exchanger designed as an evaporator.

[0028] It would be desirable to develop a cooling system for cooling the battery of a vehicle that enables the battery to operate at optimal temperature, maximum efficiency and minimum battery power loss, minimum electrical power consumption, maximum efficiency of the overall system, and maximum operating range of the vehicle.

SUMMARY OF THE INVENTION

[0029] Consonant with the present invention, a cooling system for cooling the battery of a vehicle that enables the battery to operate at optimal temperature, maximum efficiency and minimum battery power loss, minimum electrical power consumption, maximum efficiency of the overall system, and maximum operating range of the vehicle, has surprisingly been discovered.

[0030] According to one embodiment of the disclosure, a heat exchanger for transferring heat between a coolant and a refrigerant within a refrigerant circuit is connected in parallel to an air/refrigerant heat exchanger designed as an evaporator of the vehicle air-conditioning system.

[0031] According to another embodiment, a chiller is integrated upstream or downstream of the air/refrigerant heat exchanger of the vehicle air-conditioning system in series and/or as a series connection, rather than in parallel, and in the direction of refrigerant flow.

[0032] The expansion elements disposed around the chiller on the refrigerant side are typically adjustable expansion valves. The refrigerant circuit on the chiller may be operated with a two-stage expansion, so that the temperature level of the heat transfer between the coolant and the refrigerant is adjustable independent of the temperature level of the heat transfer within the air/refrigerant heat exchanger.

[0033] The adjustable expansion valves are thermostatic expansion valves, which are typically designed so that they can be activated externally.

[0034] A further embodiment of the disclosure includes a fan associated with the heat exchanger for transferring heat between the coolant and the surroundings as an air/coolant heat exchanger. The fan may be speed-controllable. The mass flow of the ambient air across the heat transfer surfaces of the air/coolant heat exchanger is adjustable, so that the heat to be transferred from the coolant to the air can be varied.

[0035] According to one method for operating a cooling system for cooling the battery of a vehicle, the heat to be dissipated from the battery is transferred to a coolant in a heat exchanger, also referred to as a battery cooler. The coolant re-circulated by a pump device within a closed coolant circuit is thermally coupled to a refrigerant via a heat exchanger, also referred to as a chiller. The refrigerant in turn circulates within a closed refrigerant circuit.

[0036] The heat transferred from the battery to the coolant and then dissipated from the coolant is controlled based on the inlet temperature of the coolant in the heat exchanger/battery cooler and, the temperature of the ambient air. The heat is transferred from the coolant in a heat exchanger to the ambient air and/or to the refrigerant in the chiller.

[0037] The chiller within the refrigerant circuit is operated as an evaporator with a first expansion element upstream, and a second expansion element downstream, with regard to the direction of the refrigerant flow. At the same time, an air/refrigerant heat exchanger, which is integrated in the refrigerant circuit and also works as an evaporator is operated. Accordingly, the temperature level of the evaporation of the refrigerant in the chiller is controlled independent of the temperature level of the evaporation in the air/refrigerant heat exchanger.

[0038] The mass flow of the refrigerant through the chiller is adjusted by means of the expansion elements.

[0039] According to another method as taught by the disclosure, the air/refrigerant heat exchanger of the air conditioning system of the vehicle is designed as an evaporator for transferring heat between the coolant and the refrigerant and includes a first expansion element upstream, and a second expansion element downstream, with regard to the direction of refrigerant flow. The first and second expansion elements are operated in a parallel connection with respect to each other in the refrigerant circuit.

[0040] Accordingly, the expansion valves, which may be designed as controllable expansion valves, and, more particu-

larly, as thermostatic expansion valves, are actuated externally. Before flowing into the chiller, and, if required, after flowing out of the chiller, the refrigerant is decompressed. In order to accommodate the process of decompressing the refrigerant upstream and downstream of the chiller, the refrigerant circuit is operated with a two-stage expansion. During the operation of the cooling system, the intermediate pressure level of the refrigerant within the chiller which is generated by means of the two-stage expansion is adjusted to various temperature levels of the evaporation based on the cooling demand of the battery and the ambient temperature. The intermediate pressure level is the pressure after the first expansion in the first expansion element, or, the pressure level within the chiller.

[0041] The temperature level of the heat transfer between the coolant and the refrigerant within the refrigerant/coolant heat exchanger can therefore be controlled independent of the evaporator of the vehicle air-conditioning system.

[0042] The heat to be dissipated from the battery is continuously controlled by the flow rate of the coolant through the battery cooler using an electrically driven pump device. With the aid of the coolant pump, the coolant is re-circulated in the coolant circuit.

[0043] According to another method as taught by the disclosure, the heat transferred to the coolant during the flow through the battery cooler is released to the ambient air in a heat exchanger at low ambient temperatures. Low ambient temperatures are present at ambient air temperature values of up to 30° C.

[0044] The mass flow of ambient air conducted through the air/coolant heat exchanger is controlled by the rotational speed of a fan associated with the heat exchanger. The chiller for transferring heat from the coolant to the refrigerant is deactivated. After exiting the air/coolant heat exchanger, the coolant flows either through a bypass around the chiller and/or no flow passes through the refrigerant side of the chiller. Under both control variants, no heat is transferred from the coolant to the refrigerant.

[0045] If the inlet temperature of the coolant entering the battery cooler exceeds a permissible temperature, the heat to be dissipated from the coolant is transferred to the ambient air in the air/coolant heat exchanger and also to the refrigerant in the chiller and the chiller transferring the heat to the refrigerant is activated. The coolant flows through the chiller, and not through the bypass around the chiller. At the same time, flow passes through the refrigerant side of the chiller. The temperature level of the evaporation of the refrigerant in the chiller and the refrigerating capacity are controlled by varying the cross-sections of the upstream and downstream expansion valves. The simultaneous and/or combined use of the chiller and air/coolant heat exchanger is typically operated at intermediate ambient air temperatures between 30° C. and 40° C.

[0046] At high ambient temperatures, the heat to be dissipated from the coolant is transferred to the refrigerant in the chiller. High ambient temperatures are present at ambient air temperature values of 40° C. and above. The temperature level of the evaporation of the refrigerant in the chiller and the refrigerating capacity are controlled by varying the cross-sections of the upstream and downstream expansion valves. The air/coolant heat exchanger transferring heat to the ambient air is deactivated. Accordingly, the fan of the heat exchanger is shut down, the air side of the heat exchanger is blocked off, or, depending on the configuration of the coolant

circuit, the coolant is conducted around the heat exchanger through a bypass so that no coolant flows through the heat exchanger, and the air/coolant heat exchanger is shut off on the coolant side and/or hydraulically isolated from the coolant circuit. In both cases, no heat is transferred to the ambient air in the air/coolant heat exchanger.

[0047] When the coolant circuit of the air-conditioning system of the vehicle is operated as an air heat pump, ambient air flows around the air/refrigerant heat exchanger of the refrigerant circuit designed as an evaporator. The ambient air is used as a heat source. At ambient temperatures, which are lower than the inlet temperature of the coolant into the battery cooler, the temperature level of the evaporation of the refrigerant in the chiller and the refrigerating capacity are controlled by varying the cross-sections of the expansion valves as necessary for the coolant in the battery cooler.

[0048] The solution taught by the disclosure for continuously controlling the temperature of the battery enables operation of the battery at optimal temperature, maximum efficiency and minimum battery power loss, minimum electrical power consumption for conditioning the battery, maximum efficiency of the overall system and the drive system, and maximum operating range of the vehicle.

[0049] Moreover, the coolant circuit is thermally coupled to the refrigerant circuit of the air-conditioning system and the refrigerant circuit is designed so that the vehicle interior is conditioned independently of the cooling of the battery because both systems may be operated at different temperature levels.

BRIEF DESCRIPTION OF THE DRAWINGS

[0050] 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 the preferred embodiment when considered in the light of the accompanying drawings in which:

[0051] FIG. 1 shows a schematic drawing of a cooling system including a coolant circuit having air and/or refrigerant of a vehicle air-conditioning system as a heat sink; and

[0052] FIG. 2 is a schematic drawing of a cooling system including a bypass around an air/coolant heat exchanger according to another embodiment.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

[0053] FIG. 1 shows a cooling system 1 comprising a coolant circuit 3, which is designed to cool and/or dissipate heat from a chemical energy storage device 2. In place of the energy storage device 2, which hereinafter is also referred to as a battery 2, it is also possible to thermally couple other components of the drive train of the vehicle, such as the engine of power electronics, to the cooling system 1.

[0054] The following detailed description and appended drawings describe and illustrate various 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.

[0055] The coolant circuit 3 has a pump device 13 for delivering the coolant. In the direction of flow of the coolant, a heat exchanger 5 is arranged downstream of the coolant pump, and is thermally coupled to the battery 2. Accordingly, several types of heat transfer are conceivable. The coolant

flows directly through the interspaces formed between the battery cells and has direct contact with the surfaces of the battery cells.

[0056] Alternatively, the heat is transferred to the coolant via a contact surface of the housing of the battery 2.

[0057] In the direction of flow of the coolant, an additional heat exchanger 6 is arranged downstream of the battery cooler 5, and dissipates the heat it absorbs from the battery cooler 5 to the surroundings, for example, the ambient air. For improved heat transfer, the heat exchanger 6, also referred to as a low-temperature cooler 6 or air/coolant heat exchanger 6 is designed with a fan 7, which delivers an air mass flow through the heat exchanger 6 and/or across its surface. By varying the mass flow of the coolant and therefore controlling the coolant flow rate by changing the output of the electrically driven coolant pump 13, both the heat absorption of the coolant within the battery cooler 5 and the heat dissipation within the heat exchanger 6 to the ambient air can be continuously controlled. Moreover, the heat transfer in the low-temperature cooler 6 can be varied using the air volume flowing through. The mass flow of air is varied by adjusting, shutting off, or changing the rotational speed of the blower 7.

[0058] After exiting the heat exchanger 6, the coolant flows to a junction 8, at which the mass flow of the coolant is divided into a flow path 9 and a bypass 11. Both the flow path 9 and the bypass 11 extend to a mouth point 12, which is designed as a T-piece 12. The coolant flows from the mouth point 12 to the pump device 13. The coolant circuit 3 is closed.

[0059] Between the junction 8 and the mouth point 12, the flow path 9 includes a heat exchanger 10, through which coolant flows on one side and refrigerant of the air-conditioning system of the vehicle flows on the other side. The coolant circuit 3 is thermally coupled to the refrigerant circuit 4 via the refrigerant/coolant heat exchanger 10. Inside the refrigerant/coolant heat exchanger 10, which is operated as an evaporator 10 with respect to the refrigerant circuit 4, the refrigerant is converted into the gaseous state and absorbs heat. Heat is withdrawn from the coolant and cooled. The bypass 11 allows for the conducting of the coolant past the heat exchanger 10, so that no heat transfer to the refrigerant occurs.

[0060] The junction 8 is designed as three-way valve and/or switching valve 8. On the one side, the coolant can be conducted along the flow path 9 using the evaporator 10, also referred to as the chiller 10, so that the coolant circuit 3 is connected directly to the refrigerant circuit 4. On the other side, the coolant can be conducted through the bypass 11 using the switching valve 8, and thus around the evaporator 10. The mass flow of the coolant can alternatively also be divided at the junction 8 to form the flow path 9 and the bypass 11.

[0061] The heat from the coolant is transferred to the refrigerant of the air-conditioning system of the vehicle in the chiller 10. The refrigerant circuit 4 includes conventional components (not shown) including a compressor, a heat exchanger for transferring heat to the surroundings, and an air/refrigerant heat exchanger 19 for conditioning the incoming air into the vehicle interior. The chiller 10 is connected in parallel to the air/refrigerant heat exchanger 19, which is designed as an evaporator 19, for conditioning the incoming air. The chiller 10 comprises two expansion elements 14, 15, which are designed as controllable expansion valves 14, 15 and/or thermostatic expansion valves. A first expansion valve 14 is arranged upstream and a second expansion valve 15 is

arranged downstream of the evaporator 10 with regard to the refrigerant flow direction. The coolant circuit 4 can be operated with a two-stage expansion at the chiller 10 by means of the expansion valves 14, 15 and the expansion valves 14, 15 can be actuated externally. Various evaporating pressures and/or evaporating temperatures of the refrigerant in the chiller 10 are adjustable on the refrigerant side due to the ability to operate using intermediate pressure, or decompress to the intermediate pressure level in the first expansion valve 14. The temperature level of the heat absorption by the refrigerant can also be varied in steps. Furthermore, the mass flow of the refrigerant through the chiller 10 may be adjusted with the aid of the adjustable expansion valves 14, 15.

[0062] Alternatively, the chiller 10 may be arranged in series upstream or downstream of the evaporator 19 in the refrigerant circuit 4 for conditioning the incoming air into the vehicle interior.

[0063] FIG. 2 shows the cooling system 1 from FIG. 1 with the expansion of bypass 18 around the low-temperature cooler 6. The bypass 18, which extends from a junction 16 to a mouth point 17, allows the coolant to be conducted around the cooler 6. The junction 16, designed as a T-piece 16, is arranged upstream of the heat exchanger 6, and the mouth point 17 is arranged downstream of the heat exchanger 6, with regard to the direction of the coolant flow. The mass flow of the refrigerant is controlled by a switching valve 17 and/or a three-way valve 17 serving as the mouth point 17. The mass flow of the coolant is conducted, either entirely through the cooler 6 or through the bypass 18 around the low-temperature cooler 6.

[0064] The inlet temperature of the coolant entering the battery 2 is controlled in different modes depending upon the ambient temperature.

[0065] At low ambient temperatures, such as at air temperatures of up to 30° C., the inlet temperature of the coolant into the battery 2 is controlled by means of the speed of the fan 7 conducting the mass flow of the ambient air across the low-temperature cooler 6. The coolant temperature is consequently controlled merely by means of the heat exchanger 6. The coolant, after passing through the heat exchanger 6, either flows through the bypass 11 around the chiller 10, or the coolant side of the chiller 10 is deactivated. No coolant flows through the evaporator 10, and the coolant releases no heat to the refrigerant in either of the two control variants of the switching valve 8.

[0066] The heat exchanger 6 is operated with the fan 7 up to ambient air temperatures of 30° C. Only when the temperature of the air-cooled coolant exceeds a permissible temperature for cooling of the battery 2 will the heat exchanger 10 of the coolant circuit 4 be also operating. The advantage of operating the low-temperature cooler 6 in the manner of exclusively cooling the coolant with air is in that the coolant circuit 4, and therefore the air-conditioning system of the vehicle, will be taken into operation only at ambient air temperatures above approximately 30° C. The air-conditioning system of the vehicle therefore does not need to be operated continuously, and energy that can be used to drive the vehicle is saved, thus maximizing the operating range of the vehicle.

[0067] During a combined operation of the chiller 10 and the low-temperature cooler 6, the temperature of the coolant entering the battery 2, the evaporation temperature, and the refrigerating capacity in the chiller 10, are controlled by the speed of the fan 7 at the low-temperature cooler 6. The evaporation temperature and the refrigerating capacity are adjusted

by means of the cross-sections of the expansion valves 14, 15. The cooling system 1 is operated at medium ambient temperatures between 30° C. and 40° C., with simultaneous and/or combined use of the chiller 10 and low-temperature cooler 6.

[0068] At high ambient temperatures above 40° C., the temperature of the coolant entering the battery 2 is adjusted by varying the temperature level of the evaporation and the refrigerating capacity in the chiller 10. The heat to be dissipated from the coolant circuit 3 is transferred to the refrigerant in the refrigerant circuit 4 and is controlled on the refrigerant side. The temperature level and/or the pressure level of the refrigerant in the evaporator 10 is adjusted by the cross-sections of the expansion valves 14, 15. At the same time, the fan 7 of the low-temperature cooler 6 is deactivated, so that no heat is transferred in the heat exchanger 6. The low-temperature cooler 6 is blocked on the air side and is not active.

[0069] Depending on the design of the coolant circuit 3, the coolant can be conducted through the bypass 18, so that no coolant flows through the low-temperature cooler 6. The low-temperature cooler 6 is blocked on the coolant side and is not active.

[0070] The supply of very warm ambient air having temperatures of above 40° C. to the heat exchanger 6 could result in the coolant circuit 3 absorbing additional heat from the surroundings if the coolant has a lower temperature than the ambient air.

[0071] The configurations shown in FIGS. 1 and 2 offer advantages for integrating the evaporator 10 in the refrigerant circuit 4 of the air-conditioning system, which is operated as an air heat pump. If the ambient temperatures are lower than the required temperature of the coolant in the coolant circuit 3 of the battery 2, the evaporating temperature level in the evaporator 10 can be controlled independent of the temperature level in the parallel connected air/refrigerant heat exchanger 19 of the refrigerant circuit 4, which is operated as an air heat pump by heat transfer with the ambient air.

[0072] Even at very low ambient temperatures below 0° C., the temperature level of the evaporation in the chiller 10 is controlled by the cross-sections of the expansion valves 14, 15. When transferring the waste heat of the battery 2 from the coolant circuit 3 into the refrigerant circuit 4 of the air-conditioning system of the vehicle, which is operated in heat pump mode using the ambient air as a heat source, very high temperature gradients within the battery 2 can occur when the cooling system 1 is switched on at ambient temperatures below 0° C. In order to prevent high temperature gradients within the battery 2, the temperature level in the chiller 10 is controlled independent of the parallel connected evaporator 19 of the refrigerant circuit 4. The independent control of the pressure levels and/or of the temperature levels within the evaporator 10, 19 in the refrigerant circuit 4 is made possible by the arrangement of two-stage expansion valves 14, 15. The temperature level of the heat transfer between the coolant and the refrigerant of the air-conditioning system within the chiller 10 can be controlled independent of the air/refrigerant heat exchanger 19 of the air-conditioning system.

[0073] The above embodiments and operating modes are suitable for use with various refrigerants, which undergo a phase transition from liquid to gas on the low pressure side and absorb heat in the process. On the high pressure side, the refrigerant releases the absorbed heat again, by heat withdrawal and/or gas cooling, and subsequently condenses, for example, by supercooling, to a heat sink, such as the ambient

air or air coming into the vehicle interior. Suitable refrigerants are natural substances, for example, such as R744, as well as chemical substances, such as R134a, R152a, HFO-1234yf.

[0074] 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.

LIST OF REFERENCE NUMBERS

[0075]	1 Cooling system
[0076]	2 Energy storage device, battery
[0077]	3 Coolant circuit
[0078]	4 Refrigerant circuit
[0079]	5 Heat exchanger, battery cooler
[0080]	6 Heat exchanger, low-temperature cooler, air/coolant heat exchanger
[0081]	7 Fan, blower
[0082]	8 Junction, switching valve, three-way valve
[0083]	9 Flow path
[0084]	10 Heat exchanger, evaporator, chiller refrigerant/coolant heat exchanger
[0085]	11 Chiller bypass
[0086]	12 Mouth point, T-piece
[0087]	13 Pump device, coolant pump
[0088]	14 First expansion device, expansion valve,
[0089]	15 second expansion device, expansion valve
[0090]	16 Junction, T-piece
[0091]	17 Mouth point, switching valve, three-way valve
[0092]	18 Low-temperature cooler bypass
[0093]	19 Heat exchanger, evaporator, air/refrigerant heat exchanger

1-10. (canceled)

11. A cooling system for cooling a battery of a vehicle comprising:

- a cooling circuit for receiving a coolant therein;
- a pump disposed in the cooling circuit;
- a first heat exchanger in fluid communication with the pump for transferring heat between the coolant and the battery;
- a second heat exchanger in fluid communication with the pump and the first heat exchanger for transferring heat between the coolant and the atmosphere; and
- a third heat exchanger in fluid communication with the pump, the first heat exchanger and the second heat exchanger in the cooling circuit for transferring heat between the coolant and a refrigerant circulating through a refrigerant circuit, the refrigerant circuit in fluid communication with the third heat exchanger and including a fourth heat exchanger, a first expansion element, and a second expansion element;

wherein the first expansion element is positioned upstream of the third heat exchanger, and the second expansion element is arranged downstream of the third heat exchanger in respect of a direction of flow of the refrigerant so the third heat exchanger and the fourth heat exchanger can be operated at different pressures and temperatures.

12. The cooling system according to claim 11, wherein the refrigerant circuit is a component of an air-conditioning system of the vehicle and the fourth heat exchanger conditions incoming air in a vehicle interior.

13. The cooling system according to claim 11, wherein the third heat exchanger is connected in parallel with the fourth heat exchanger.

14. The cooling system according to claim 11, wherein the third heat exchanger is connected in series with the fourth heat exchanger.

15. The cooling system according to claim 11, wherein each of the first expansion element and the second expansion element is an adjustable expansion valve allowing the refrigerant circuit to be operated using a two-stage expansion at the third heat exchanger so a temperature at which heat transfers between the coolant and the refrigerant can be controlled independent of a temperature at which heat transfers within the fourth heat exchanger.

16. The cooling system according to claim 11, wherein the second heat exchanger includes a fan allowing heat to be transferred from the coolant to the atmosphere.

17. The cooling system according to claim 16, wherein the fan delivers a flow of air across a surface of the second heat exchanger.

18. The cooling system of claim 16, wherein the fan is an adjustable speed fan allowing a variable volume of air to flow across the surface of the second heat exchanger and wherein at least the volume of air controls an amount of heat transfer in the second heat exchanger.

19. The cooling system of claim 11, wherein at least a flow rate of the coolant controls an amount of heat transfer in the first heat exchanger and the second heat exchanger.

20. The cooling system of claim 11, wherein a junction disposed between the second heat exchanger and the third exchanger selectively directs the coolant to the third heat exchanger or to bypass the third heat exchanger.

21. A method for operating a cooling system for cooling a battery of a vehicle comprising the steps of:

circulating a coolant through a first heat exchanger of a cooling circuit for transferring heat between the coolant and the battery;

circulating the coolant through a second heat exchanger of the cooling circuit in fluid communication with the pump and the first heat exchanger for transferring heat between the coolant and the atmosphere; and

circulating the coolant through a third heat exchanger of the cooling circuit in fluid communication with the first heat exchanger and the second heat exchanger;

wherein the third heat exchanger transfers heat between the coolant and a refrigerant circulating through a refrigerant circuit, the refrigerant circuit in fluid communication with the third heat exchanger and including a fourth heat exchanger, a first expansion element, and a second expansion element; and

wherein the first expansion element is positioned upstream of the third heat exchanger, and the second expansion element is arranged downstream of the third heat exchanger in respect of a direction of flow of the refrigerant so the third heat exchanger and the fourth heat exchanger can be operated at different pressures and temperatures.

22. The method according to claim 21, wherein the third heat exchanger is connected in parallel to the fourth heat exchanger.

23. The method according to claim 21, wherein each of the first expansion element and the second expansion element is an adjustable expansion valve.

24. The method according to claim 21, wherein the refrigerant is decompressed before and after flowing into the third heat exchanger so the refrigerant undergoes a two-stage expansion across the third heat exchanger.

25. The method according to claim 21, wherein the second heat exchanger includes a fan allowing heat to be transferred from the coolant to the atmosphere.

26. The method according to claim 25, wherein the fan rotates at an adjustable speed allowing a variable volume of air to flow across a surface of the second heat exchanger and wherein at least the volume of air controls an amount of heat transfer in the second heat exchanger.

27. The method according to claim 26, wherein a junction disposed between the second heat exchanger and the third exchanger selectively directs the coolant to one of the third heat exchanger and a bypass of the third heat exchanger.

28. The method according to claim 27, wherein at ambient temperatures below about 30 degrees Celsius, a temperature

of the coolant entering the battery is controlled by the speed of the fan, and the coolant, after passing through the second heat exchanger, flows through one of the bypass and the third heat exchanger after the third heat exchanger has been deactivated.

29. The method according to claim 21, wherein at ambient temperatures between about 30 degrees Celsius and 40 degrees Celsius, an evaporation temperature of the refrigerant and a refrigerating capacity of the third heat exchanger are controlled by adjusting a cross-section of the first expansion valve and a cross section of the second expansion valve, and wherein the third heat exchanger is activated.

30. The method according to claim 21, wherein at ambient temperatures above about 40 degrees Celsius, a temperature of the coolant entering the battery is controlled by at least one of varying an evaporation temperature of the refrigerant and varying a refrigerating capacity of the third heat exchanger, and wherein the second heat exchanger is deactivated.

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