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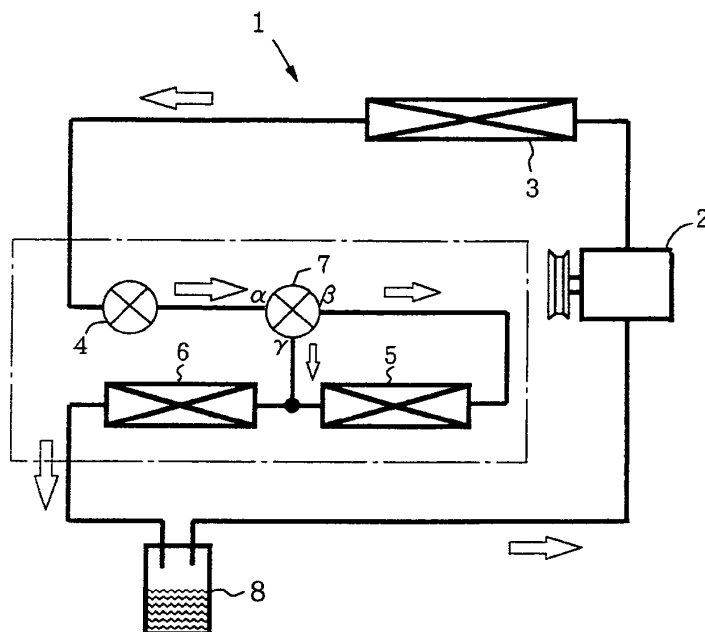
(54) Cooling cycle

(57) Theme : A cooling cycle for a twin air conditioning system which provide with a structure that eliminates the disadvantage arising from providing expansion devices with different control systems on each evaporator, thereby holding down manufacturing costs and eliminating or simplifying the work of tuning the system.

Means of Resolution : A structure having compressor 2 which raises the pressure of the coolant to beyond the supercritical pressure, radiator 3 which cools the coolant which has been pressurized by compressor 2,

expansion device 4 which reduces the pressure of the coolant flowing from the radiator so that the pressure on the outlet side of the radiator is held to a prescribed pressure determined by the temperature of the coolant on the outlet side of the radiator, first and second evaporators 5, 6 which evaporate coolant whose pressure has been reduced in expansion device 4, and a flow regulator means (flow regulator valve 7) which regulates the quantity of coolant supplied to evaporators 5, 6 respectively.

Figure 1



Description

[0001] The invention relates to a cooling cycle which uses a supercritical fluid such as carbon dioxide (CO₂) or the like as a coolant, and in particular relates to a cooling cycle used in a twin air-conditioning system.

[0002] Cooling cycles which employ carbon dioxide as a coolant have a structure which has a compressor that compresses the coolant, a radiator which cools the coolant discharged from the compressor, an expansion device which reduces the pressure of the coolant flowing out from the radiator, and an evaporator which vaporizes the coolant flowing out from the expansion device, but with such a cooling cycle a so-called high-pressure control operation is carried out using the expansion device to control the pressure on the outlet side of said radiator (high-pressure) to a prescribed pressure level determined by the temperature of the coolant on the outlet side of said radiator.

[0003] For this reason, this kind of structure is applied in a twin air-conditioning system with two evaporators, but where the respective evaporators are both fitted with an expansion device for controlling the high pressure on the upstream side, it may be expected that the respective expansion devices will both attempt to control the high pressure, thus interfering with one another and failing to operate properly.

[0004] To avoid this disadvantage, it has been found effective to use different systems to control the two respective evaporators, and in prior art consideration has been given to using the above-described high-pressure control expansion device to control one of the evaporators, the other evaporator being controlled using an expansion device which controls the degree of superheating. In other words a device has been considered which is provided with a compressor which compresses the coolant, a radiator which cools the coolant discharged from the compressor, a first pressure-reducer and second pressure-reducer which reduce the pressure of the coolant flowing from the radiator, a first evaporator which evaporates the coolant flowing from the first pressure reducer, and a second evaporator which evaporates the coolant flowing from the second pressure reducer, using the first pressure reducer to control the pressure on the outlet side of the radiator to a prescribed level determined by the temperature of the coolant on the outlet side of the radiator, with the second pressure reducer used to control the degree of superheating of the coolant on the outlet side of the second evaporator to a prescribed value.

[0005] However, with the above structure, although expansion devices (first pressure reducer, second pressure reducer) are provided for each of the respective evaporators, the expansion device itself is a relatively expensive component, and manufacturing costs will be high with an expansion valve fitted to each evaporator. Even accepting that an expansion valve needs to be fitted to each evaporator, since a differing expansion de-

vice is provided for the control of each evaporator (first pressure reducer, second pressure reducer) with the above structure, it is not possible to use common parts, which not only increases manufacturing costs but makes tuning of the system more complicated.

[0006] Thus the theme of the invention is to provide a cooling cycle which has a structure for a cooling cycle in a twin air-conditioning system where the expansion valves do not interfere with one another, and where the above disadvantage caused by the provision of expansion devices with differing control methods on each of the evaporators is eliminated, thus not only holding down manufacturing costs but eliminating or simplifying the operation of tuning the system.

[0007] In order to achieve the above purpose, the cooling cycle of the invention is characterized in that it has a structure having a compressor capable of increasing the pressure of the coolant to beyond the supercritical pressure, a radiator which cools the coolant compressed by said compressor, an expansion device which controls the pressure on the outlet side of said radiator to a prescribed pressure determined by the temperature of the coolant on the outlet side of said radiator, a first and a second evaporator which evaporate the coolant whose pressure has been reduced by said expansion device, and a flow regulator means which regulates the quantity of coolant distributed to the respective evaporators.

[0008] Accordingly, with this kind of structure, as coolant distributed by the flow regulator means is supplied to the first and second evaporators having had its pressure reduced in the common expansion device, having a single expansion device allows the quantities distributed to be regulated by the flow regulator means according to load. As a result, a twin air-conditioning system can be catered for without having to provide an expansion device for each evaporator.

[0009] In practical terms, the first evaporator and second evaporator may be connected in series downstream of the expansion device, the flow regulator means regulating the quantity of coolant supplied to the evaporator on the upstream side and the quantity of coolant supplied to the evaporator on the downstream side, or the first evaporator and second evaporator may be connected in parallel on the downstream side of the expansion device, the flow regulator means regulating the quantity of coolant supplied to the respective evaporators.

[0010] In particular, with respect to the first structure the flow regulator means may control the quantities distributed so that the degree of superheating of the evaporator on the upstream side remains constant, or with respect to the second structure the flow regulator means may control the quantities distributed so that the degree of superheating of one of the evaporators remains constant.

[0011] Furthermore, the abovementioned flow regulator means may comprise a three-way valve which simultaneously regulates the quantity supplied to the first

evaporator and the quantity supplied to the second evaporator, or may be comprised of a two-way valve which regulates the flow supplied to one evaporator by regulating the flow supplied to the other evaporator. Here the three-way valve may be a device which continuously regulates the quantities distributed or a device which simply switches the direction of flow. Further, the two-way valve may be a device which continuously regulates the degree of opening, or a device which simply opens or closes the passage.

[0012] In order to further realize the above purpose, the cooling cycle of the invention may have a compressor capable of increasing the pressure of the coolant to beyond the supercritical pressure, a radiator which cools the coolant compressed by said compressor, first and second expansion devices which reduce the pressure of the coolant flowing from said radiator, a first evaporator which evaporates the coolant flowing from the first expansion device, and a second evaporator which evaporates the coolant flowing from the second expansion device, and be provided with a flow ratio determining means which determines the proportion of the flow quantity of coolant supplied to each evaporator by forecasting the thermal load on the respective evaporators, and a control means which controls and maintains the ratio determined by said ratio-determining means for the degree of opening of the valve of said first and second expansion devices so that the pressure on the outlet side of said radiator remains at a constant pressure determined by the temperature of the coolant on the outlet side of said radiator.

[0013] With this type of structure, the proportion of coolant supplied to each evaporator is determined from the forecast thermal load, the through flow between the first and second expansion devices being simultaneously regulated so that the pressure on the outlet side of the radiator is a constant pressure determined from the temperature of the coolant on the outlet side of the radiator so as to maintain the determined proportion, so it is possible to adjust the flow quantity according to load by using the same control system for the expansion devices. As a result a twin air-conditioning system can be catered for without the need to provide expansion devices having different control systems on each evaporator.

[0014] A cooling cycle of the type described above is suited to a supercritical vapour compression cooling cycle which uses carbon dioxide compressed to beyond the supercritical pressure by a compressor as the coolant.

[0015] As described above, according to the invention the cooling cycle is arranged to have a structure having a compressor capable of increasing the pressure of the coolant itself to beyond the supercritical pressure, a radiator which cools the coolant compressed by the compressor, an expansion device which controls the pressure on the outlet side of the radiator to a prescribed pressure determined by the temperature of the coolant on the outlet side of the radiator, first and second evap-

orators which evaporate the coolant whose pressure has been reduced by said expansion device, and a flow regulator means which regulates the amount of coolant distributed to the respective evaporators, so coolant whose pressure has been reduced by one of the expansion devices can be distributed according to the load on each evaporator without needing to provide an expansion device for each evaporator, thus allowing a twin air-conditioning system to be catered for with one expansion device. As a result it is not necessary to provide an expansion device for each evaporator, enabling manufacturing costs to be reduced.

[0016] Further, as the cooling cycle is arranged to have a structure with a compressor capable of increasing the pressure of the coolant itself to beyond the supercritical pressure, a radiator which cools the coolant compressed by said compressor, first and second expansion devices which reduce the pressure of the coolant flowing from said radiator, a first evaporator which evaporates the coolant flowing from the first expansion device, and a second evaporator which evaporates the coolant flowing from the second expansion device, and is provided with a thermal load forecasting means which forecasts the thermal load on the respective evaporators, a ratio-determining means which determines the ratio of the degree of opening for each expansion device from the thermal load of each evaporator forecast using this thermal load forecasting means, and a control means which controls and maintains the ratio determined by said ratio-determining means for the degree of opening of the valves of said first and second expansion devices so that the pressure on the outlet side of said radiator remains at a constant pressure determined by the temperature of the coolant on the outlet side of said radiator, there is no need to provide an expansion device with a different control system for each evaporator, and the use of common parts can not only prevent an increase in manufacturing costs but also eliminate or simplify the operation of tuning the system.

[0017] An optimal configuration of an embodiment of the invention will now be described with reference to the attached drawings :

Figure 1 is a diagram showing an example of the overall structure of the cooling cycle for a twin air-conditioning system of the invention.

Figure 2 is a diagram showing an alternative example of the structure from the expansion device to the upstream side of the accumulator in Figure 1.

Figure 3 (a) is a diagram showing an example of a three-way valve used instead of the flow regulator valve of Figure 1, Figure 3 (b) being a diagram showing an example of a two-way valve being used instead of the flow regulator valve of Figure 2.

Figure 4 shows the structure of evaporators con-

ected in parallel downstream of the expansion device, Figure 4 (a) showing an example of a three-way valve type flow regulator valve being used, Figure 4 (b) showing an example of a structure where a two-way valve type flow regulator valve is used.

Figure 5 is a diagram showing another example of the structure of the cooling cycle for a twin air-conditioning system.

Figure 6 is a flow chart showing the control operation for the degree of opening for the expansion devices using the control unit shown in Figure 5.

[0018] In Figure 1, cooling cycle 1 has a structure having compressor 2 which raises the pressure of the coolant, radiator 3 which cools the coolant compressed by compressor 2, expansion device 4 which reduces the pressure of the coolant cooled by radiator 3, first and second evaporators 5, 6 which evaporate coolant whose pressure has been reduced in expansion device 4, flow regulator valve 7 which regulates the quantity of coolant distributed to the respective evaporators, and accumulator 8 which separates the gas and liquid in the coolant flowing from the respective evaporators 5, 6.

[0019] In practical terms, the discharge side of compressor 2 is connected via radiator 3 to expansion device 4, first evaporator 5 and second evaporator 6 being connected in series via flow regulator valve 7 on the downstream side of this expansion device 4. Flow regulator valve 7 comprises a three-way valve, and is provided with an inflow port α into which coolant flows from expansion device 4, a first outflow port β and a second outflow port γ from which the inflowing coolant flows out, it being arranged that the proportion of the coolant flowing out from first outflow port β to the coolant flowing out from second outflow port γ is continuously variable. First outflow port β of flow regulator valve 7 is connected to the inflow side of first evaporator 5, and second outflow port γ is connected to the inflow side of second evaporator 6. The outflow side of second evaporator 6 is connected to the inlet side of compressor 2 via accumulator 8.

[0020] Expansion device 4 is here a high-pressure control valve which reduces the pressure of the coolant flowing out from radiator 3 so that the pressure on the outlet side of the radiator is held at a constant pressure (the maximum pressure obtainable by COP) determined from the temperature of the coolant on the outlet side of the radiator, and is of a type known to the art disclosed for example in Japanese Patent 2000-35250. This expansion device 4 raises the pressure on the outlet side of radiator 3 by reducing the degree of opening with an increase in the detected temperature, and reducing the pressure on the outlet side of radiator 3 by increasing the degree of opening with a drop in the detected temperature, the degree of opening of the valve being controllable either electrically or mechanically.

[0021] Furthermore, flow regulator valve 7 controls the quantities distributed so that the degree of superheating of first evaporator 5 on the upstream side is held constant, and thus may be controlled electrically or mechanically.

[0022] Thus with the above structure, the coolant flowing out of radiator 3 has its pressure reduced by expansion device 4 before flowing into flow regulator valve 7, being supplied to first evaporator 5 in such a way that the degree of superheating of this evaporator remains constant. As a result, the coolant supplied to first evaporator 5 undergoes heat exchange with the air passing through this first evaporator 5 and evaporates, being sent on to second evaporator 6. The coolant distributed to second evaporator 6 from flow regulator valve 7 is supplied to second evaporator 6 together with coolant that has passed through said first evaporator 5, where it undergoes heat exchange with the air passing through second evaporator 6 and evaporates, being sent to accumulator 8. As a result, with the above structure the degree of opening of expansion device 4 is regulated according to the total thermal load of first and second evaporators 5, 6, and particularly as flow regulator valve 7 is set to regulate the degree of opening so that the cooling performance of first evaporator 5 remains constant, it is possible to adjust the amount of flow according to the performance of second evaporator 6, allowing a twin air-conditioning system to be catered for with a single expansion device 4. Thus by using a relatively inexpensive flow regulator valve 7, the number of costly expansion devices can be reduced, thus enabling a cooling cycle for a twin air-conditioning system to be manufactured at low cost.

[0023] The above structure has been described for the case where flow regulator valve 7 comprises a three-way valve with first evaporator 5 and second evaporator 6 connected in series, but as shown in Figure 2, it may be arranged that flow regulator valve 9 is provided between junction A for the coolant flowing out of expansion device 4 and the inlet port of first evaporator 5, thus not only allowing the quantity flowing into first evaporator 5 to be regulated by regulating the flow passing through, but also regulating the quantity flowing into second evaporator 6. With this kind of structure, as the degree of opening of expansion device 4 is regulated according to the total thermal load of first and second evaporators 5, 6, and as first evaporator 5 is set to regulate the degree of opening so that the cooling performance thereof remains constant, a single expansion device 4 is able to cater for a twin air-conditioning system, enabling a cooling cycle to be manufactured cheaply.

[0024] Further, with the above structure it is arranged to employ a three-way valve which continuously regulates the quantity distributed as flow regulator valve 7, but it may also comprise three-way valve 11 which switches the direction of flow either way as shown in Figure 3 (a), or two-way valve 12 which simply opens and closes, as shown in Figure 3 (b).

[0025] Moreover, with the above structure, first and second evaporators 5, 6 are arranged to be connected in series downstream of expansion device 4, but as shown in Figure 4a and 4b, first and second evaporators 5, 6 may also be connected in parallel downstream of expansion device 4, and flow regulator valve 7 comprising a three-way valve may be provided at the junction for the coolant flowing from expansion device 4. In this kind of structure as well, flow regulator valve 7 may be a device which controls the quantity distributed either electrically or mechanically so that the degree of superheating of one of the evaporators (for example, first evaporator 5) remains constant.

[0026] With this kind of structure, the coolant flowing from radiator 3 has its pressure reduced by expansion device 4 so that the pressure of the coolant on the outlet side of the radiator is kept to a prescribed value determined by the temperature of the coolant on the outlet side of the radiator, entering flow regulator valve 7 after passing through this expansion device 4, being supplied to one of the evaporators 5 in such a way that the degree of superheating of this evaporator 5 remains constant. As a result, the coolant supplied to first evaporator 5 undergoes heat exchange with the coolant that has passed through this first evaporator 5 and evaporates, being sent on to accumulator 8. Further, the remaining coolant not sent on to first evaporator 5 is conducted from flow regulator valve 7 to second evaporator 6, where it undergoes heat exchange with the air that has passed through second evaporator 6 and evaporates, being sent on to accumulator 8. As a result, with the above structure the degree of opening of expansion device 4 is regulated according to the total thermal load on first and second evaporators 5, 6, and particularly as flow regulator valve 7 is set to regulate the degree of opening so that the cooling performance of first evaporator 5 remains constant, it is possible to adjust the flow according to the performance of first evaporator 5, allowing a twin air-conditioning system to be catered for with a single expansion device 4. Thus by using a relatively inexpensive flow regulator valve, the number of costly expansion devices can be reduced, thus enabling a cooling cycle for a twin air-conditioning system to be manufactured at low cost.

[0027] In the above structure as shown in Figure 4a, flow regulator valve 7 is shown comprising a three-way valve, but as shown in Figure 4 (b), it may be arranged to have flow regulator valve 9 comprising a two-way valve provided between junction A for the coolant flowing from expansion device 4 and one of the evaporators (in the above example, the first evaporator) thus allowing regulation of the quantity flowing through here not only to regulate the quantity flowing into first evaporator 5 but also to regulate the quantity flowing into second evaporator 6.

[0028] In the structure shown in Figure 4 (a), a three-way valve which continuously adjusts the quantities distributed is used as flow regulator valve 7, but alternatively

a three-way valve which simply switches the direction of flow may be used, or, in the structure in Figure 4 (b), a two-way valve which simply opens and closes.

[0029] In the above structure the case is shown where a single expansion device 4 is used, the quantities distributed to first and second evaporators 5, 6 being regulated using flow regulator valves 7, 9 or the like, but where expansion devices need to be provided separately for evaporators 5, 6 respectively, a structure such as that shown in Figure 5 may be employed.

[0030] In Figure 5, cooling cycle 1 has a structure comprising compressor 2 which raises the pressure of the coolant itself to beyond the supercritical pressure, radiator 3 which cools the coolant compressed by compressor 2, first and second expansion devices 20, 21 which reduce the pressure of the coolant cooled by radiator 3, first evaporator 5 which evaporates the coolant whose pressure has been reduced by first expansion device 20, and a second evaporator 6 which evaporates the coolant whose pressure has been reduced by second expansion device 21, accumulator 8 which separates the gas and liquid in the coolant flowing from evaporators 5, 6 respectively, and internal heat exchanger 22 in which heat is exchanged between the low-pressure coolant conducted from accumulator 8 to compressor 2 and the high-pressure coolant conducted from radiator 3 to each expansion device 20, 21.

[0031] In other words, cooling cycle 1 has a structure whereby the discharge side of compressor 2 is connected to high-pressure duct 22a of internal heat exchanger 22 via radiator 3, the outlet side of this high-pressure duct 22a being divided and connected to first expansion device 20 and second expansion device 21. Further, the outflow side of first expansion device 20 and the outflow side of second expansion device 21 are respectively connected to the inlet port of accumulator 8 via first evaporator 5 and second evaporator 6 respectively, the outflow port of accumulator 8 being connected to the inlet side of compressor 2 via low-pressure duct 22b of internal heat exchanger 22. Thus high-pressure line 23 comprises the route from the discharge side of compressor 2 via radiator 3 and high-pressure duct 22a to expansion devices 20, 21, and low-pressure line 24 comprises the route from the outflow side of expansion devices 20, 21 via evaporators 5, 6, accumulator 8, and low-pressure duct 22b to compressor 2. With this structure, the degree of opening of the valves of first expansion device 20 and second expansion device 21 is then controlled electrically by control unit 25.

[0032] This control unit 25 has a structure comprising a central processing unit (CPU), a read-only memory (ROM) a random access memory (RAM), an in/out port and the like, being in itself a device known to the art with signals input from various sensors, it being arranged that the degree of opening of the respective expansion devices 20, 21 is controlled by a prescribed program which has been stored in the memory.

[0033] Figure 6 is a flow chart illustrating an example

of the control operation of each of the expansion devices using control unit 25, and an example of this control operation will be described using this flow chart. After starting up the air-conditioning device, control unit 25 embarks on this control routine after a series of initializing processes such as the initial setup, and inputs the parameters necessary for calculating the thermal load of first evaporator 5 (parameter A) and the parameters necessary for calculating the thermal load of second evaporator 6 (parameter B) (step 50). The parameters required for calculating the thermal load on first evaporator 5 may include, for example, the speed of rotation of the fan of the air-conditioning unit (blow rate), the air temperature on the inlet side of the first evaporator, room temperature, external temperature and the like, and parameters required for calculating the thermal load on second evaporator 6 may include the degree of superheating of second evaporator 6, the coolant temperature at the outlet of second evaporator 6, the pressure of the low-pressure line, and the air temperature of air passing through second evaporator 6 and the like.

[0034] In the next step 52, the thermal load of first evaporator 5 is calculated using input parameters A, and the thermal load of second evaporator 6 is calculated using parameters B. Thereafter in step 54 the ratio of the degree of opening for the valves in respective expansion devices 20, 21 is determined from the respective thermal loads that have been calculated, and in step 56 the pressure on the outlet side of the radiator is held at the prescribed pressure determined by the temperature of the coolant on the outlet side of the radiator (maximum pressure obtained by COP) while maintaining this degree of opening of the valve ratio.

[0035] Thus with this kind of structure, separate expansion devices 20, 21 are provided on the upstream side of evaporators 5, 6 respectively, but the ratio is fixed according to the thermal load on evaporators 5, 6 respectively without the need for individual control of respective expansion devices 20, 21, and as the pressure on the outlet side of the radiator is controlled with this ratio maintained, there is no interference between the control of the respective expansion devices. Thus with the above structure, since the same control system is used for first expansion device 20 and second expansion device 21, it is possible not only to prevent increases in manufacturing cost by using common parts, but also to eliminate or simplify tuning of the system.

Claims

1. Cooling cycle (1) **characterized in that** it has a structure having a compressor (2) capable of increasing the pressure of the coolant to beyond the supercritical pressure, a radiator (3) which cools the coolant compressed by said compressor, an expansion device (4) which controls the pressure on the outlet side of said radiator to a prescribed pressure

determined by the temperature of the coolant on the outlet side of said radiator, a first evaporator (5) and a second evaporator (6) which evaporate the coolant whose pressure has been reduced by said expansion device, and a flow regulator means ((7, 9) which regulates the quantity of coolant distributed to the respective evaporators.

2. Cooling cycle according to Claim 1, **characterized in that** said first evaporator (5) and second evaporator (6) are connected in series downstream of said expansion device (4), the flow regulator means (7, 9) being a device which regulates the quantity of coolant supplied to the evaporator on the upstream side and the quantity of coolant supplied to the evaporator on the downstream side.
3. Cooling cycle according to Claim 2, **characterized in that** the flow regulator means (7, 9) is a device which controls the quantities distributed so that the degree of superheating of the evaporator on the upstream side remains constant.
4. Cooling cycle according to Claim 1, **characterized in that** said first evaporator (5) and second evaporator (6) are connected in parallel on the downstream side of the expansion device (4), the flow regulator means (7, 9) being a device which regulates the quantities of coolant supplied to the respective evaporators.
5. Cooling cycle according to Claim 2, **characterized in that** the flow regulator means (7, 9) is a device which controls the quantities distributed so that the degree of superheating of one of the evaporators remains constant.
6. Cooling cycle according to Claim 2 or 4, **characterized in that** the flow regulator means (7) comprises a three-way valve which simultaneously regulates the quantity supplied to the first evaporator (5) and the quantity supplied to the second evaporator (6).
7. Cooling cycle according to Claim 2 or 4, **characterized in that** the flow regulator means (9) comprises a two-way valve which regulates the flow supplied to one evaporator by regulating the flow supplied to the other evaporator.
8. Cooling cycle (1) **characterized in that** has a compressor (2) capable of increasing the pressure of the coolant to beyond the supercritical pressure, a radiator (3) which cools the coolant compressed by said compressor, first expansion device (20) and second expansion device (21) which reduce the pressure of the coolant flowing from said radiator, a first evaporator (5) which evaporates the coolant

flowing from the first expansion device (20), and a second evaporator (6) which evaporates the coolant flowing from the second expansion device (21), and which is provided with a thermal load forecasting means which forecasts the thermal load on the respective evaporators, a ratio-determining means which determines the ratio of the degree of opening for each expansion device from the thermal load of each evaporator forecast using this thermal load forecasting means, and a control means which controls and maintains the ratio determined by said ratio-determining means for the degree of opening of the valves of said first and second expansion devices (20, 21) so that the pressure on the outlet side of said radiator remains at a constant pressure determined by the temperature of the coolant on the outlet side of said radiator.

9. Cooling cycle according to Claim 1 or 8, **characterized in that** said cooling cycle is a supercritical vapour compression cooling cycle which uses carbon dioxide as the coolant.

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Figure 1

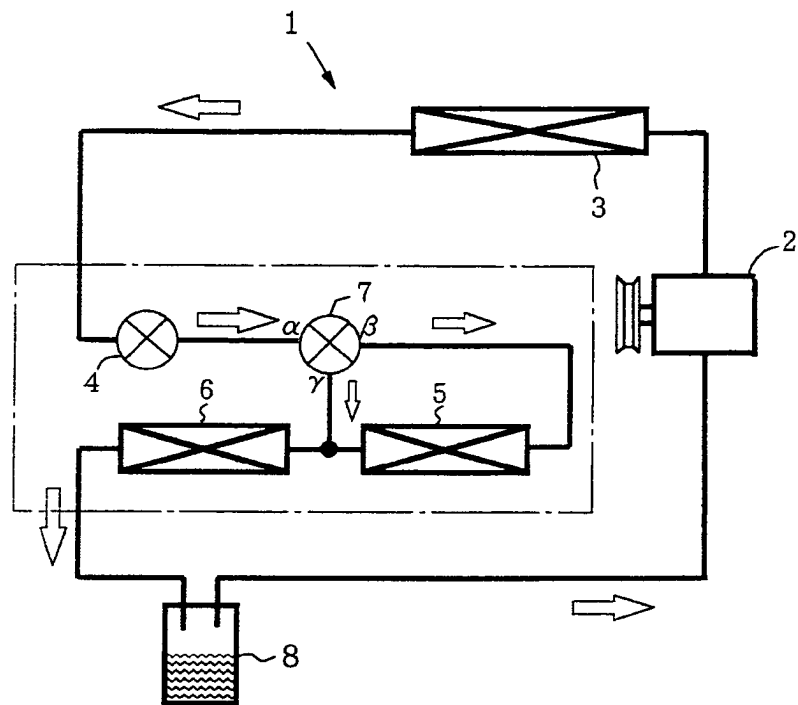


Figure 2

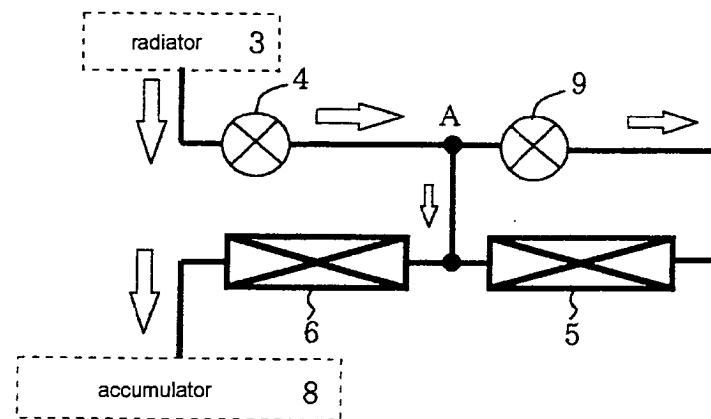


Figure 3

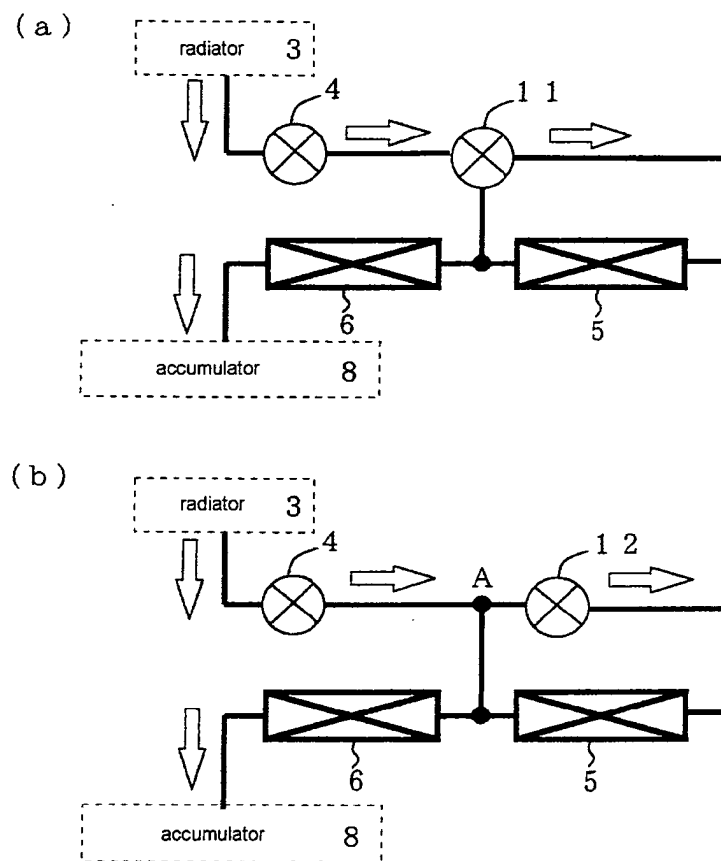
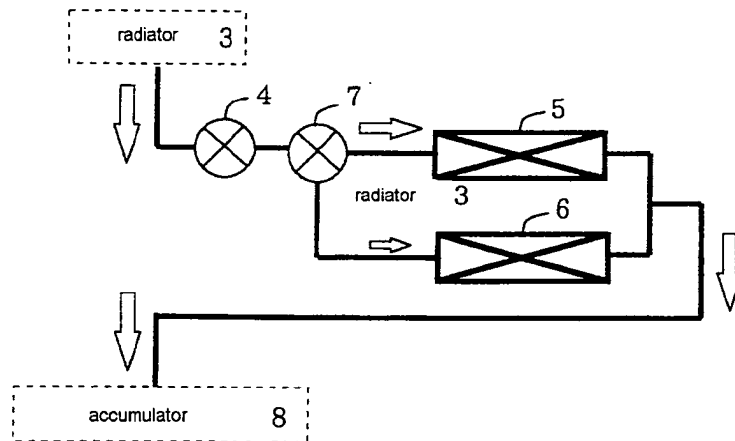


Figure 4

(a)



(b)

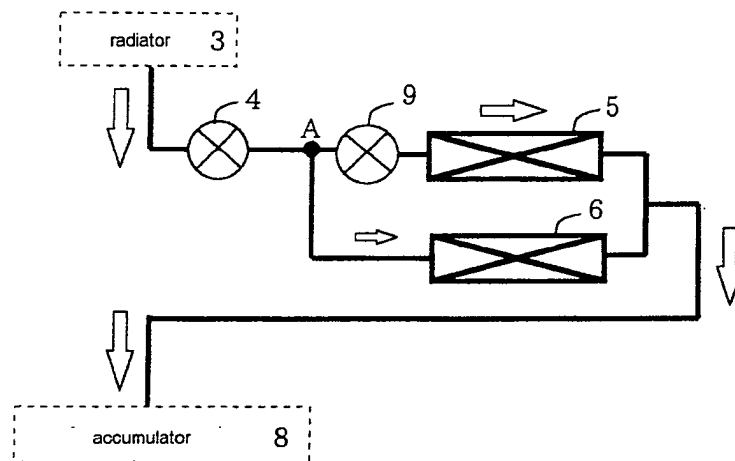


Figure 5

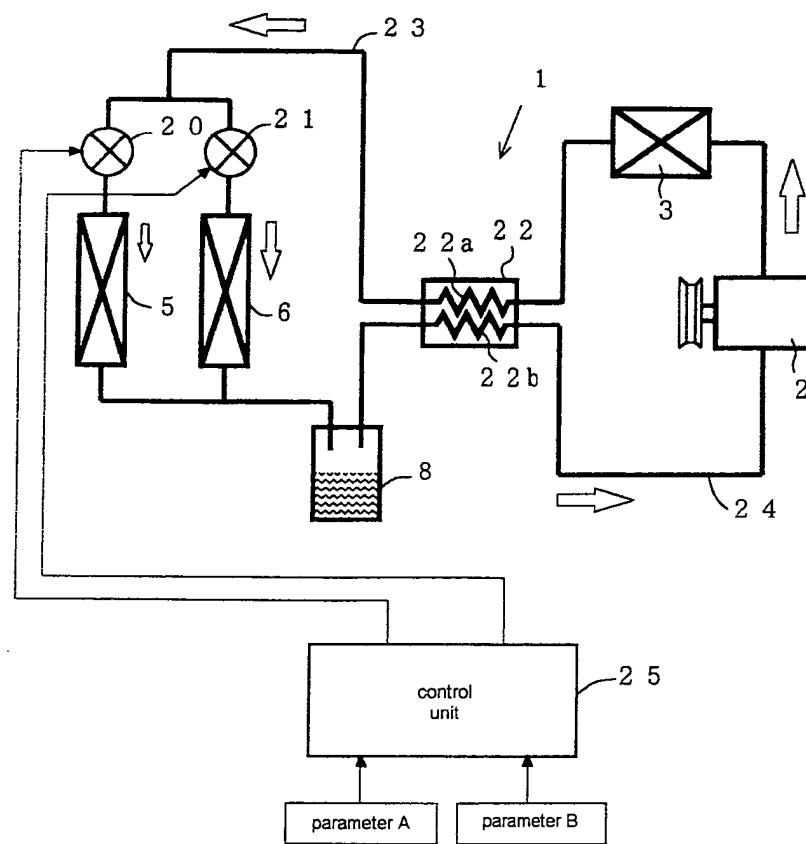


Figure 6

