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(54) COOLING CYCLE

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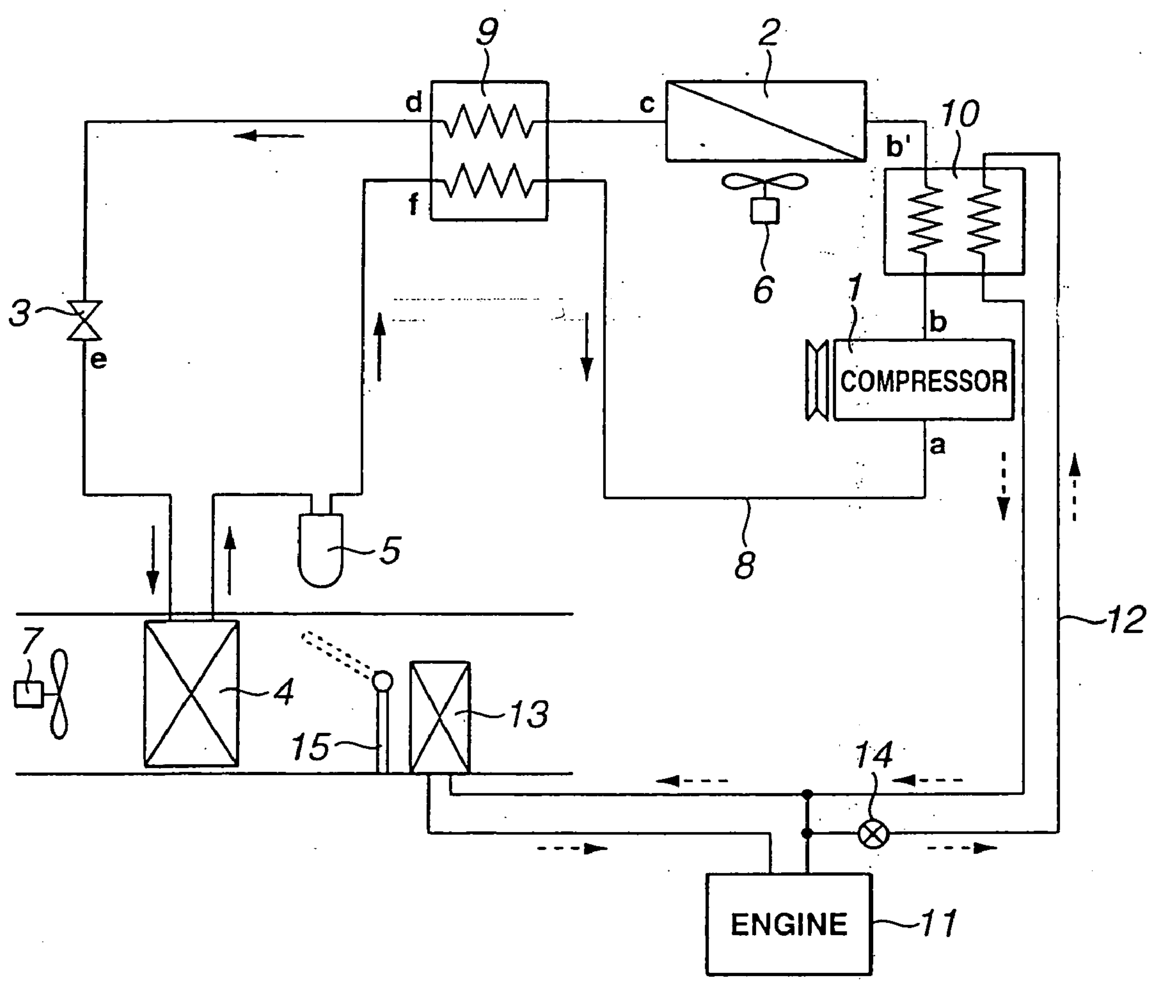
(57) **ABSTRACT**

In a cooling cycle including a compressor, a gas cooler, a throttling device, and an evaporator, a heat exchanger is arranged between the compressor and the throttling device for carrying out heat exchange through a refrigerant compressed by the compressor.



# FIG.1

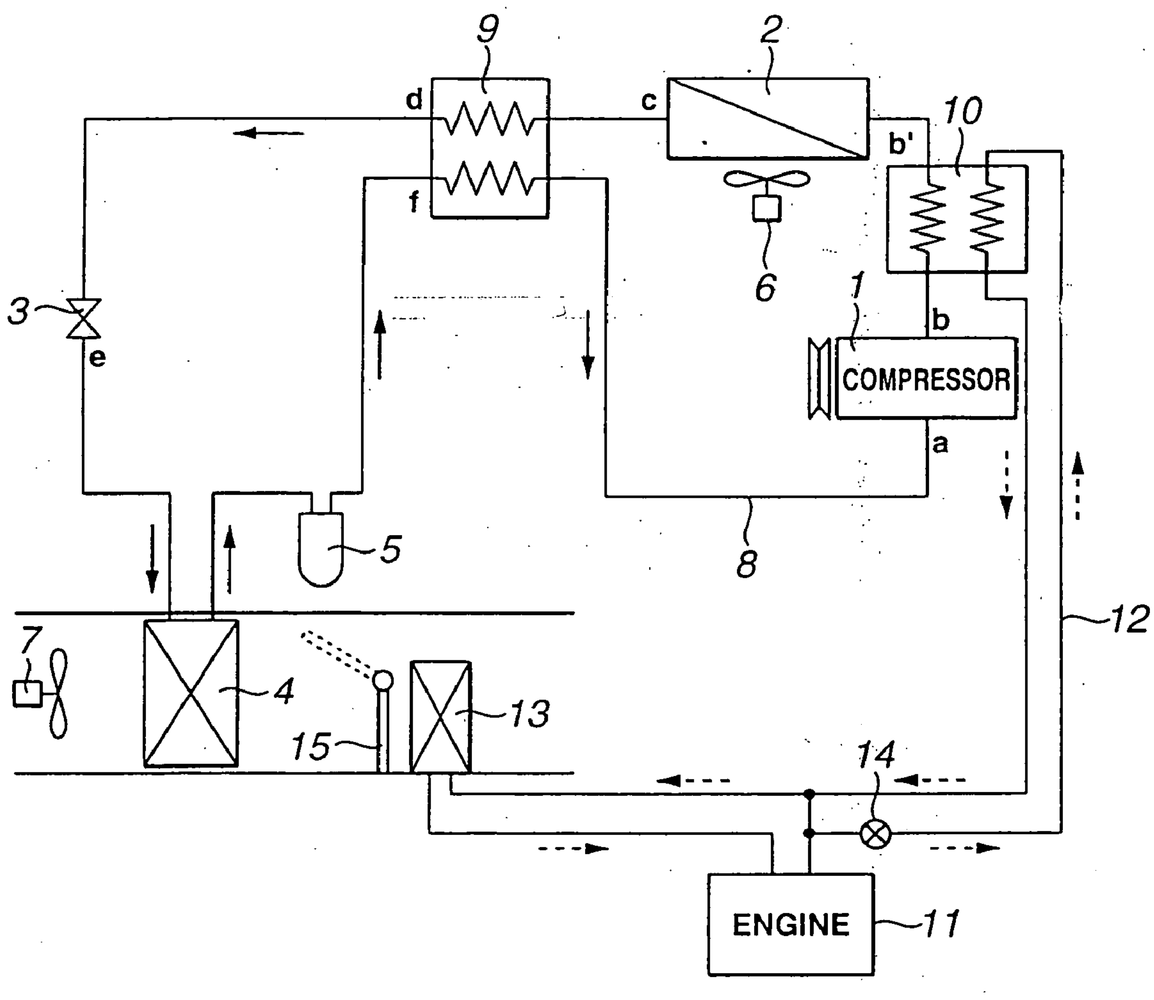
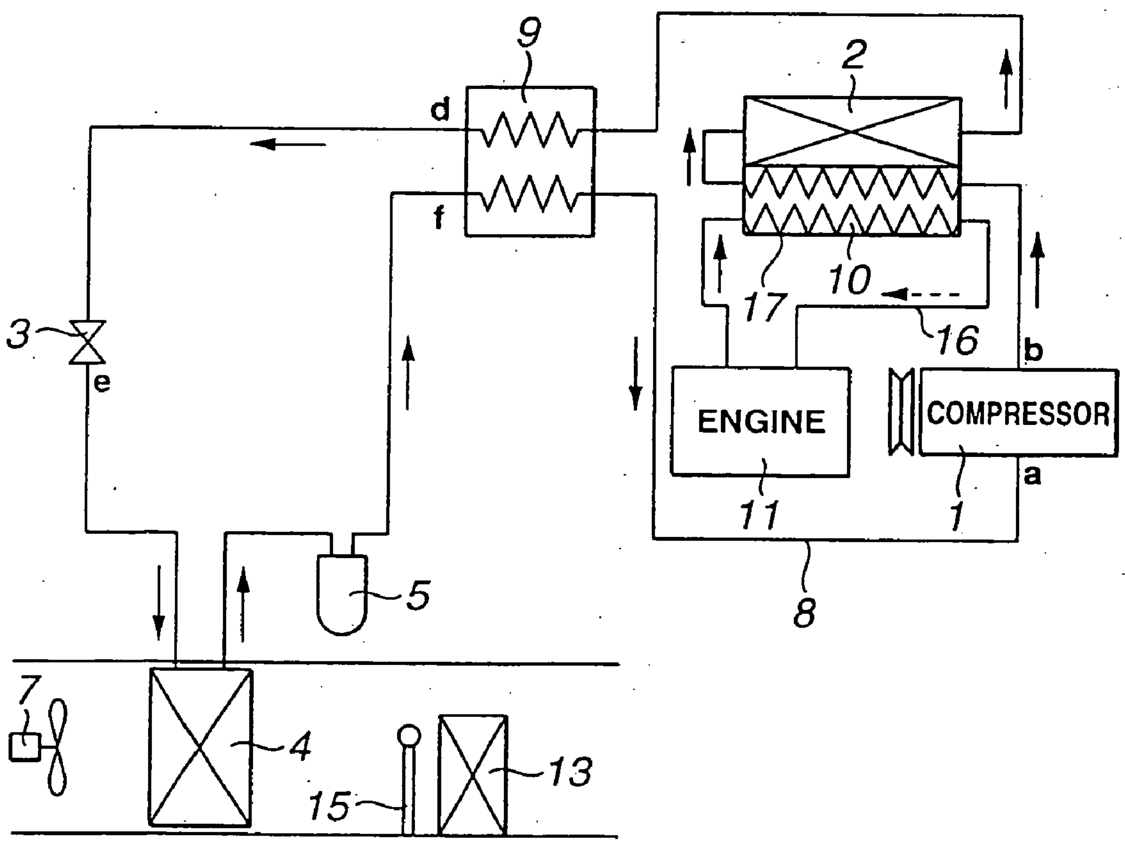
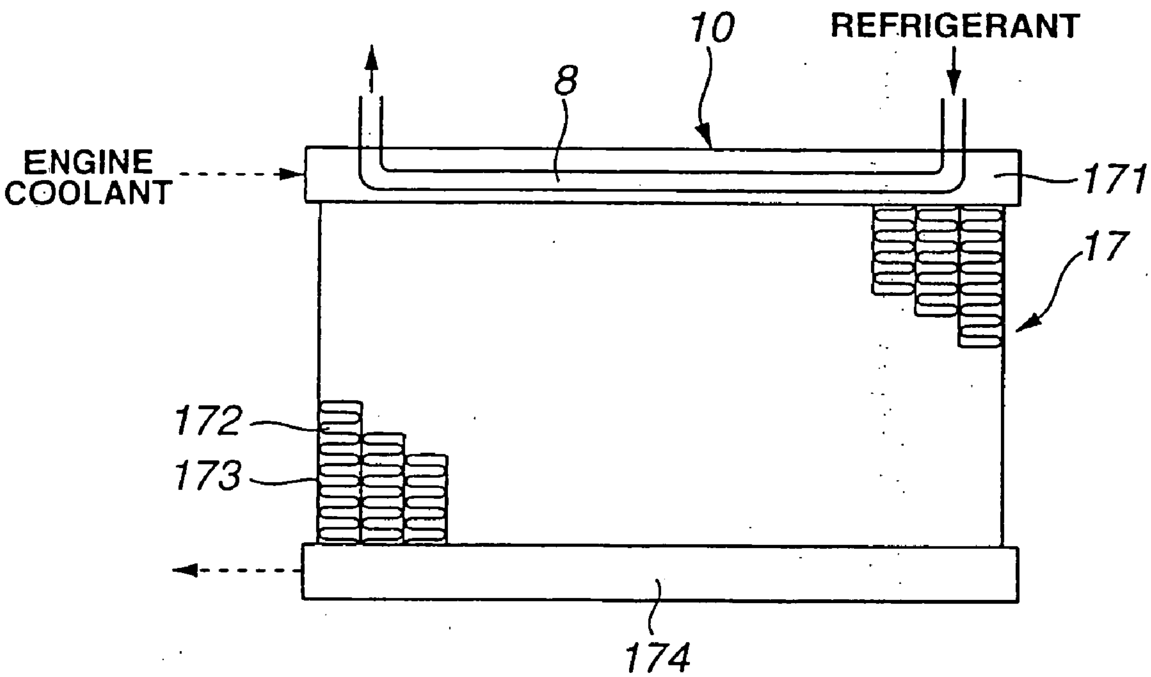


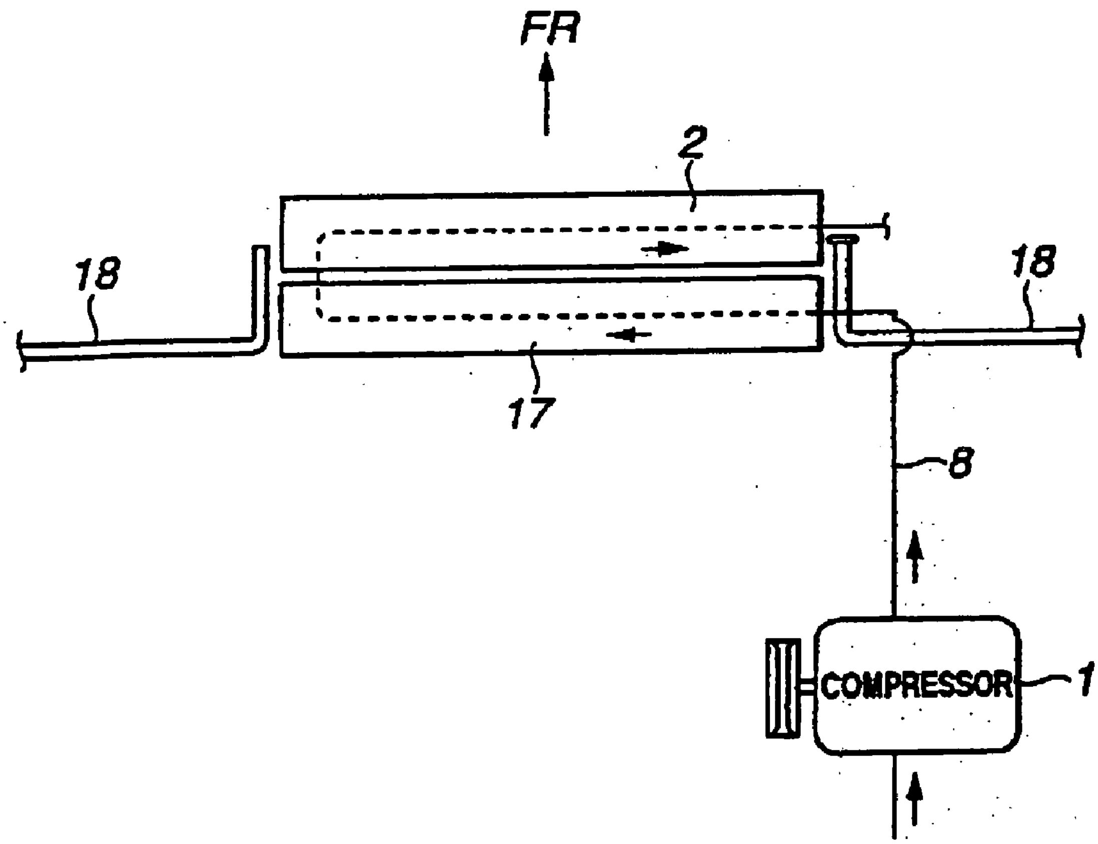
FIG.2



# FIG.3



# FIG.4



# FIG.5

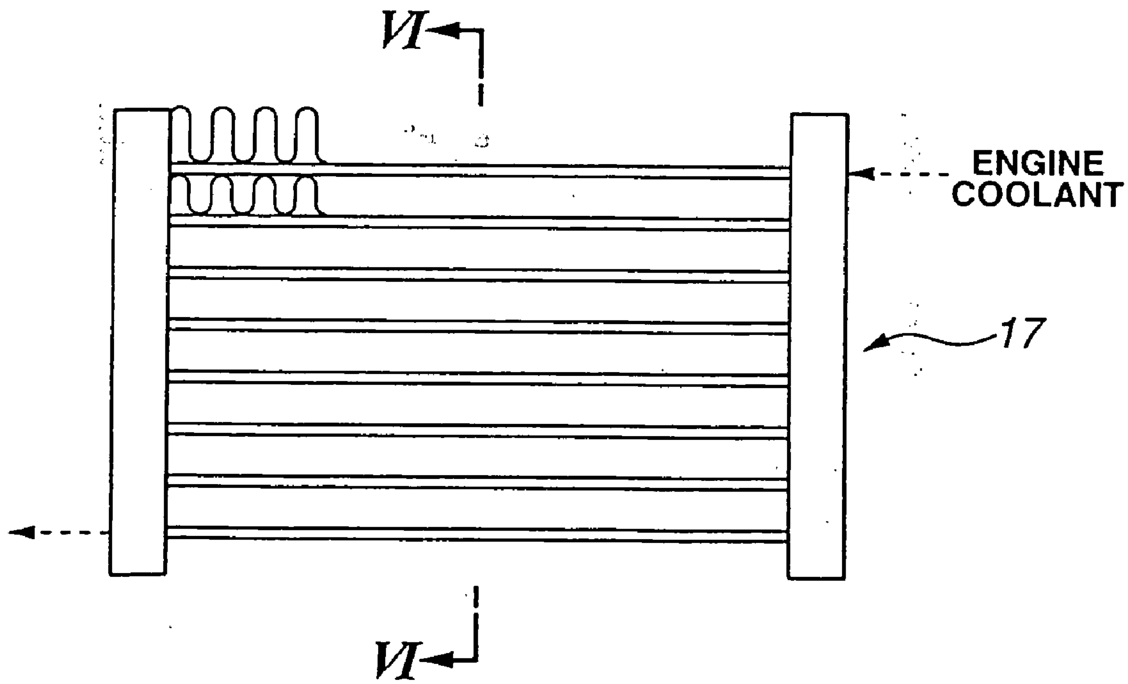


FIG.6

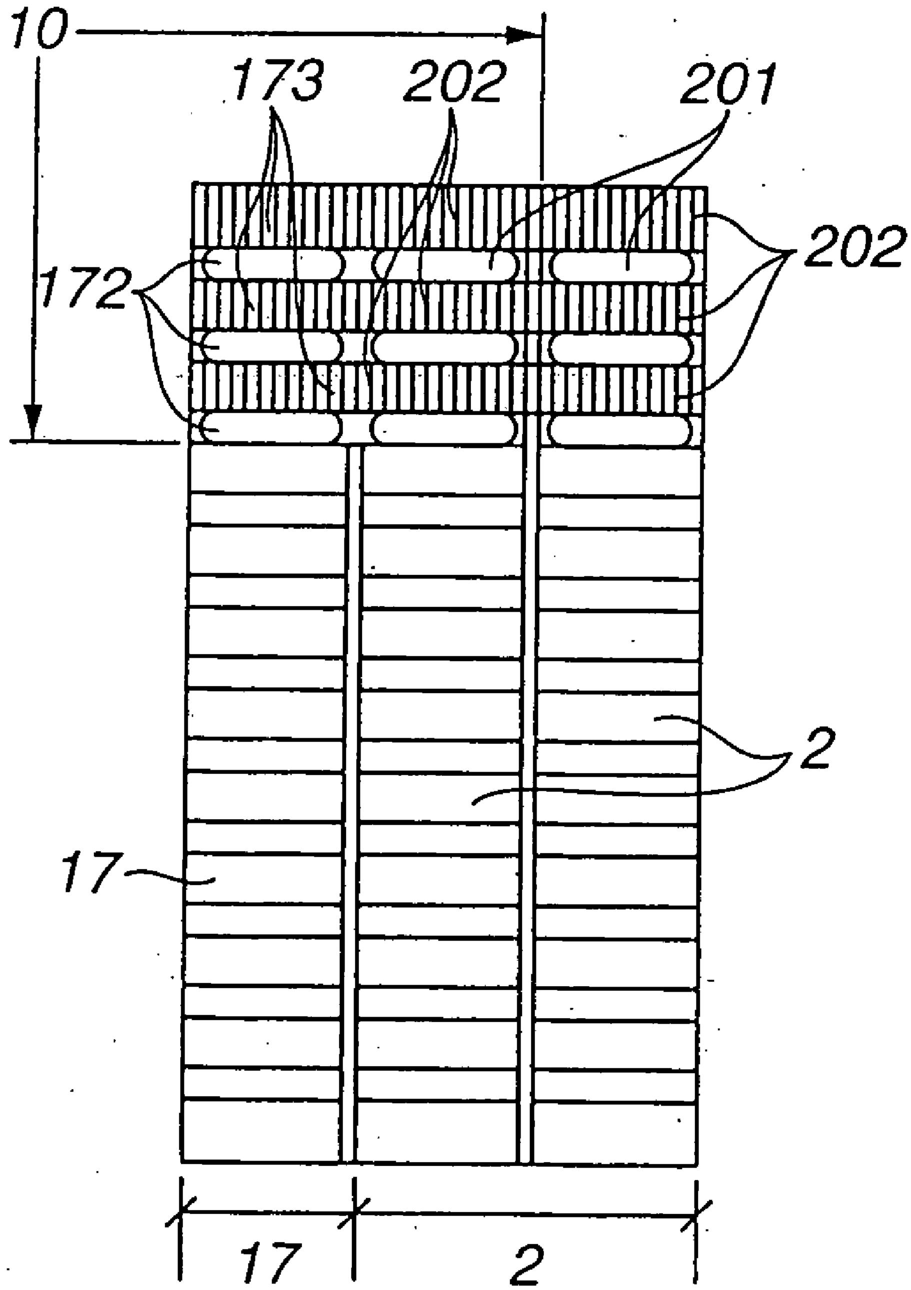
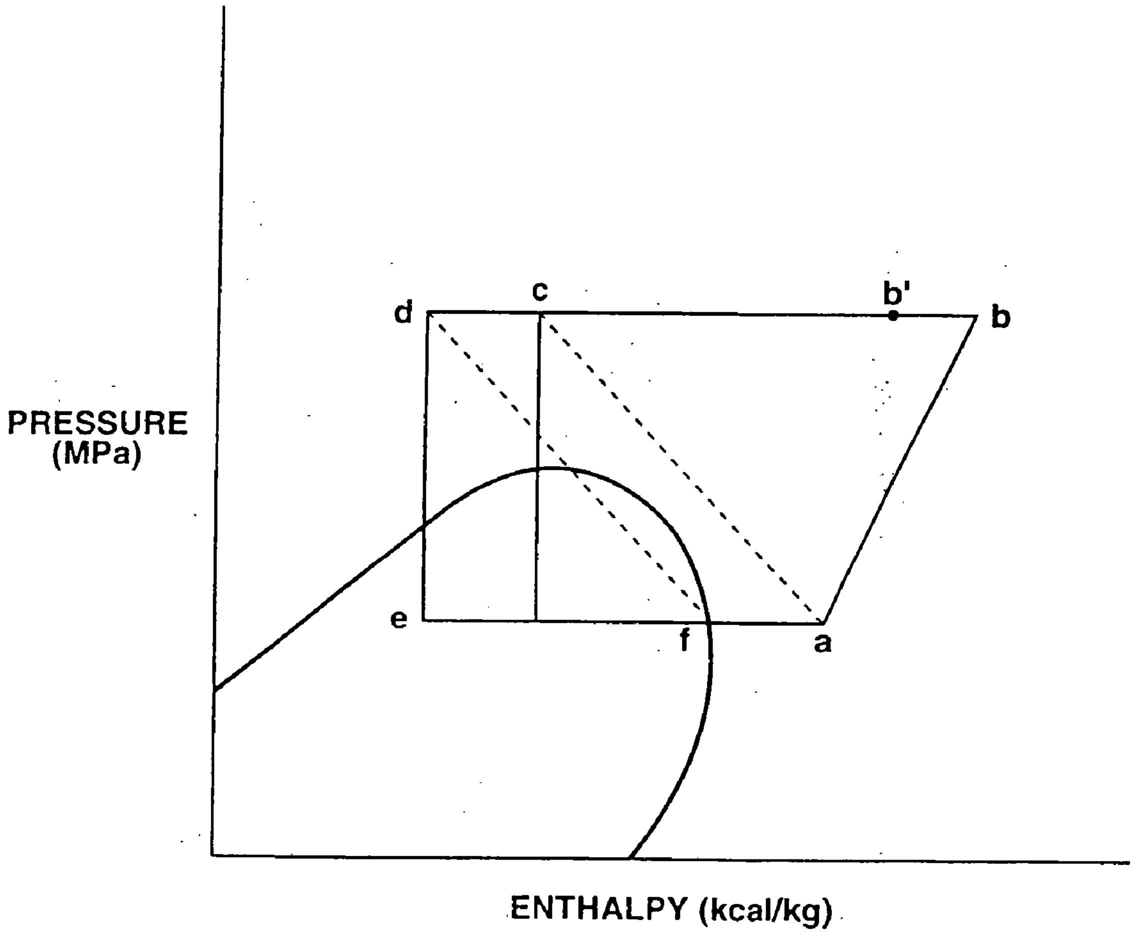


FIG.7



# COOLING CYCLE

[0001] The present application is a divisional of U.S. application Ser. No. 11/221,986, filed Sep. 9, 2005, which is a divisional of U.S. application Ser. No. 10/191,809, filed Jul. 10, 2002, the entire contents of which is incorporated herein by reference.

## BACKGROUND OF THE INVENTION

[0002] The present invention relates to a cooling cycle suited for use in automotive air-conditioning systems, and more particularly, to a cooling cycle using supercritical or transcritical refrigerant such as $CO_2$.

[0003] The cooling cycle for automotive air conditioners uses fluorocarbon refrigerant such as CFC12, HFC134a or the like. When released into the atmosphere, fluorocarbon can destroy an ozone layer to cause environmental problems such as global warming. On this account, the cooling cycle has been proposed which uses $CO_2$, ethylene, ethane, nitrogen oxide or the like in place of fluorocarbon.

[0004] The cooling cycle using $CO_2$ refrigerant, is similar in operating principle to the cooling cycle using fluorocarbon refrigerant except the following. Since the critical temperature of $CO_2$ is about 31° C., which is remarkably lower than that of fluorocarbon (e.g. 112° C. for CFC12), the temperature of $CO_2$ in a gas cooler or condenser becomes higher than the critical temperature thereof in the summer months where the outside-air temperature rises, for example, $CO_2$ does not condense even at the outlet of the gas cooler.

[0005] The conditions of the outlet of the gas cooler are determined in accordance with the compressor discharge pressure and the $CO_2$ temperature at the gas-cooler outlet. And the $CO_2$ temperature at the gas-cooler outlet is determined in accordance with the heat-radiation capacity of the gas cooler and the outside-air temperature. However, since the outside-air temperature cannot be controlled, the $CO_2$ temperature at the gas-cooler outlet cannot be controlled practically. On the other hand, since the gas-cooler-outlet conditions can be controlled by regulating the compressor discharge pressure, i.e. the refrigerant pressure at the gas-cooler outlet, the refrigerant pressure at the gas-cooler outlet is increased to secure sufficient cooling capacity or enthalpy difference during the summer months where the outside-air temperature is higher.

[0006] Specifically, the cooling cycle using fluorocarbon refrigerant has 0.2-1.6 Mpa refrigerant pressure in the cycle, whereas the cooling cycle using $CO_2$ refrigerant has 3.5-10.0 Mpa refrigerant pressure in the cycle, which is remarkably higher than in the fluorocarbon cooling cycle.

[0007] An attempt has been made in the cooling cycle using supercritical refrigerant to enhance the ratio of the cooling capacity of an evaporator to the workload of a compressor, i.e. coefficient of performance (COP). U.S. Pat. No. 5,245,836 issued Sep. 21, 1993 to Lorentzen, et al. proposes enhancement in COP by carrying out heat exchange between refrigerant that has passed through the evaporator and supercritical-area refrigerant that is present in a high-pressure line. In the cooling cycle including such internal heat exchanger, refrigerant is further cooled by the heat exchanger to reach a throttling valve. This leads to still lower temperature of refrigerant at the inlet of the throttling valve, which provides maximum COP.

[0008] Even in the cooling cycle including such internal heat exchanger, when the cooling cycle is in the high-load state where the outside-air temperature is higher than, for example, 30° C., and the vehicle is at a standstill where the velocity of cooling air for the gas cooler is low, the radiation performance of the gas cooler is remarkably degraded. As a result, the temperature of refrigerant at the gas-cooler outlet is not sufficiently lowered, thus degrading the cooling performance of the evaporator.

## SUMMARY OF THE INVENTION

[0009] It is, therefore, an object of the present invention to provide a cooling cycle which can provide sufficient cooling performance even when the radiation effect of the gas cooler is lower.

[0010] The present invention provides generally a cooling cycle, which comprises: a compressor that compresses a refrigerant; a gas cooler that cools the compressed refrigerant; a throttling device that throttles flow of the cooled refrigerant; an evaporator that cools intake air by a heat absorbing action of the cooled refrigerant; and a heat exchanger arranged between the compressor and the throttling device, the heat exchanger carrying out heat exchange through the compressed refrigerant.

## BRIEF DESCRIPTION OF THE DRAWINGS

[0011] The other objects and features of the present invention will become apparent from the following description with reference to the attached drawings, wherein:

[0012] **FIG. 1** is a circuit diagram showing a first embodiment of a control cycle for use in automotive air-conditioning systems according to the present invention;

[0013] **FIG. 2** is a diagram similar to **FIG. 1**, showing a second embodiment of the present invention;

[0014] **FIG. 3** is a front view showing an example of a radiator used in the second embodiment;

[0015] **FIG. 4** is a plan view showing the radiator in **FIG. 3**;

[0016] **FIG. 5** is a view similar to **FIG. 3**, showing another example of the radiator used in the second embodiment;

[0017] **FIG. 6** is a cross section taken along the line VI-VI in **FIG. 5**; and

[0018] **FIG. 7** is a Mollier diagram for explaining the cooling cycle of $CO_2$ refrigerant;

## DETAILED DESCRIPTION OF THE INVENTION

[0019] Referring to the drawings, a description is made with regard to preferred embodiments of the cooling cycle according to the present invention.

[0020] Referring to **FIG. 1**, the cooling cycle comprises a compressor **1**, a heat exchanger **10** (second exchanger), a gas cooler **2**, an internal heat exchanger **9** (first heat exchanger), a pressure control valve or throttling means **3**, an evaporator or heat sink **4**, and a trap or accumulator **5**, which are connected in this order by a refrigerant line **8** to form a closed circuit.

[0021] The compressor **1** is driven by a prime mover such as engine or motor to compress a $CO_2$ refrigerant in the gaseous phase and discharge the high-temperature high-pressure refrigerant to the gas cooler **2**. The compressor **1** may be of any type such as variable-displacement type wherein automatic control of the discharge quantity and pressure of refrigerant is carried out internally or externally in accordance with the conditions of refrigerant in a cooling cycle, constant-displacement type with rotational-speed control capability or the like.

[0022] The heat exchanger **10** carries out heat exchange between the high-temperature high-pressure refrigerant discharged from the compressor **1** and a coolant or cooling water of an engine or automotive prime mover **11**. The coolant is provided by a water pump, not shown, to the heat exchanger **10** through a coolant line **12**, which is led to a heater core or heating device **13** arranged in the vehicle cabin, then returned to the engine **11**. Note that the direction of flow of the coolant is shown by dotted arrow in **FIG. 1**. An open/close valve **14** is arranged in the coolant line **12** in the vicinity of the outlet of the engine **11**. When it is necessary to provide the coolant to the heat exchanger **10**, the open/close valve **14** is opened, whereas when it is not necessary, the valve **14** is closed to lead the coolant to the heater core **13** directly. The coolant is provided to a radiator, not shown, arranged at the front of the vehicle through another line, wherein its temperature is reduced to an optimum value for cooling of the engine **11**.

[0023] The gas cooler **2** carries out heat exchange between the high-temperature high-pressure $CO_2$ refrigerant compressed by the compressor **1** and subjected to passage through the heat exchanger **10** and the outside air or the like for cooling of the refrigerant. The gas cooler **2** is provided with a cooling fan **6** for allowing acceleration of heat exchange or implementation thereof even when the vehicle is at a standstill. In order to cool the refrigerant within the gas cooler **2** up to the outside-air temperature as closely as possible, the gas cooler **2** is arranged at the front of the vehicle, for example.

[0024] The internal heat exchanger **9** carries out heat exchange between the $CO_2$ refrigerant flowing from the gas cooler **2** and the refrigerant flowing from the trap **5**. During operation, heat is dissipated from the former refrigerant to the latter refrigerant.

[0025] The pressure control valve or pressure-reducing valve **3** reduces the pressure of $CO_2$ refrigerant by making the high-pressure (about 10 Mpa) refrigerant flowing from the internal heat exchanger **9** pass through a pressure-reducing hole. The pressure control valve **3** caries out not only pressure reduction of the refrigerant, but pressure control thereof at the outlet of the gas cooler **2**. The refrigerant with the pressure reduced by the pressure control valve **3**, which is in the two-phase (gas-liquid) state, flows into the evaporator **4**. The pressure control valve **3** may be of any type such as duty-ratio control type wherein the opening/closing duty ratio of the pressure-reducing hole is controlled by an electric signal, etc.

[0026] The evaporator **4** is accommodated in a casing of an automotive air-conditioning unit, for example, to provide cooling for air vented into the vehicle cabin. Air taken in from the outside or the cabin by a fan **7** is cooled by the passage through the evaporator **4**, which is discharged from a vent, not shown, to a desired position in the cabin. Specifically, when evaporating or vaporizing in the evaporator **4**, the two-phase $CO_2$ refrigerant flowing from the pressure control valve **3** absorbs latent heat of vaporization from introduced air for cooling thereof. The heater core **13** is arranged downstream of the evaporator **4**, at the front of which an air mixing door **15** is arranged rotatably. When heating intake air, the air mixing door **15** is rotated in a position shown by broken line in **FIG. 1**, whereas when carrying out no heating, it is rotated in a position shown by solid line in **FIG. 1**.

[0027] The trap **5** separates the $CO_2$ refrigerant that has passed through the evaporator **4** into a gaseous-phase portion and a liquid-phase portion. Only the gaseous-phase portion is returned to the compressor **1**, and the liquid-phase portion is temporarily accumulated in the trap **5**.

[0028] Referring to **FIG. 7**, the operation of the cooling cycle is described. A gaseous-phase $CO_2$ refrigerant is compressed by the compressor **1**(*a-b*). The high-temperature high-pressure gaseous-phase refrigerant is cooled by the heat exchanger **10** (*b-b*'). The temperature of the refrigerant is about 140° C. at the outlet "b" of the compressor **1**, while the temperature of the coolant provided from the engine **11** to the heat exchanger **10** is 95° C. at maximum. Thus, the refrigerant is cooled to about 130° C. by the passage through the heat exchanger **10**.

[0029] The refrigerant precooled by the heat exchanger **10** is cooled further by the gas cooler **2**(*c-d*). Then, the refrigerant is reduced in pressure by the pressure control valve **3**(*d-e*), which makes the refrigerant fall in the two-phase (gas-liquid) state. The two-phase refrigerant is evaporated in the evaporator **4**(*e-f*) to absorb latent heat of vaporization from introduced air for cooling thereof. Such operation of the cooling cycle allows cooling of air introduced in the air-conditioning unit, which is vented into the cabin for cooling thereof.

[0030] In the trap **5**, the refrigerant that has passed through the evaporator **4** is separated into a gaseous-phase portion and a liquid-phase portion. Only the gaseous-phase portion passes through the internal heat exchanger **9** to absorb heat (f-a), and is inputted again to the compressor **1**.

[0031] In such a way, the heat exchanger **10** is arranged at the outlet of the compressor **1** to precool the high-temperature refrigerant to be provided to the gas cooler **2**. Thus, even when the cooling capacity of the gas cooler **2** is degraded temporarily due to higher outside-air temperature and vehicle standstill, the refrigerant that has passed through the gas cooler **2** is sufficiently low in temperature, allowing preservation of the cooling capacity of the evaporator **4**.

[0032] On the other hand, fulfillment of sufficient heating capacity is desired due to lower outside-air temperature, the air mixing door **15** arranged in front of the heater core **13** is rotated in the position shown by broken line in **FIG. 1**. During normal heating, there is no need to precool the refrigerant by supplying the coolant, whereas when quick heating is desired, the open/close valve **14** is opened to circulate the coolant to the heat exchanger **10**, starting the cooling cycle. With this, the low-temperature coolant provided to the heat exchanger **10** absorbs heat from the high-temperature refrigerant to become high-temperature coolant, which is supplied to the heater core **13**. Therefore, even when the temperature of the coolant is not high enough to carry out heating, quick dehumidifying heating can be achieved due to heating by the heat exchanger **10**.

[**0033**] In the first embodiment, the heat exchanger **10** is arranged in the refrigerant line **8** at the position between the compressor **1** and the gas cooler **2**. Optionally, when a space for the heat exchanger **10** is difficult to secure in the engine room, it is recommended to adopt the following embodiment.

[**0034**] Specifically, in the second embodiment, referring to **FIG. 2**, the heat exchanger **10** for carrying out heat exchange between the refrigerant at the outlet of the compressor **1** and the coolant of the engine **11** is integrated with an automotive radiator **17**. Specifically, the gas cooler **2** and the radiator **17** are disposed adjacently at the front of the vehicle. In ordinary cases, the gas cooler **2** is disposed in front of the radiator **17**. The coolant is provided to the radiator **17** by a water pump, not shown, wherein its temperature is reduced to an optimum value for cooling of the engine **11**. Then, the coolant is returned to the engine **11**. As is not shown, another line is arranged for the coolant to be provided to the heater core **13**.

[**0035**] Referring to **FIGS. 3-4**, there is shown an example of the radiator **17** which comprises an upper tank **171** to which the coolant is provided from the engine **11**, a plurality of radiating tubes **172** through which the coolant in the upper tank **171** flows down, a plurality of radiating fins **173** arranged between the tubes **172**, and a lower tank **174** into which the coolant after the passage through the tubes **172** is accumulated for return to the engine **11**. Air out of the cooling fan **6** and that resulting from cruising pass through spaces between the tubes **172** and the fins **173**, cooling the coolant flowing down through the tubes **172**.

[**0036**] In this embodiment, the heat exchanger **10** is constructed by arranging the refrigerant line **8** between the compressor **1** and the gas cooler **2** through the upper tank **171** of the radiator **17**, i.e. it is of the double-tube structure having the refrigerant line **8** arranged inside the upper tank **171**. The heat exchanger **10** may be constructed by arranging the refrigerant line **8** through the lower tank **174**. However, arrangement in the upper tank **171**, i.e. at the inlet of the radiator **17** is preferable to arrangement in the lower tank **174**, i.e. at the outlet of the radiator **17** in view of easy control of the coolant at an optimum temperature. Note that the present invention is applicable to the cooling cycle having the heat exchanger **10** arranged at the outlet of the radiator **17**.

[**0037**] In view of the efficiency of heat exchange, it is preferable to oppose the direction of the coolant flowing into the upper tank **171** to that of the refrigerant flowing down therein, i.e. to form counter flow. Note that the present invention is applicable not only to the cooling cycle having counter flow, but the cooling cycle having forward flow.

[**0038**] Referring to **FIG. 4**, numeral **18** designates a radiator-core panel of a vehicle body. In this embodiment, the heat exchanger **10** is constructed by arranging the refrigerant line **8** through the upper tank **171** of the radiator **17**. This not only prevents taking-up of a space in the engine room, but allows a piping path of the refrigerant line **8** as shown in **FIG. 4**, the refrigerant line **8** crosses over the radiator panel **18** only once. Specifically, with the earlier-art gas cooler **2**, the refrigerant line **8** crosses on the inlet side over the left radiator-core panel **18** for connection to the gas cooler **2**, then on the outlet side the right radiator-core panel **18**. This leads to problems of difficult securing of a piping space for the refrigerant line **8** and increasing of the length of the refrigerant line **8**. On the other hand, in this embodiment, the gas cooler **2** produces an auxiliary effect that the refrigerant line **8** can be arranged in a short path.

[**0039**] Referring to **FIGS. 5-6**, there are shown another example of the radiator **17** and the gas cooler **2** (which is not seen in **FIG. 5** as being located behind the radiator **17**). The radiator **17** and the gas cooler **2** both include right and left tanks. Note that the radiator **17** shown in **FIG. 3** may include right and left tanks, and the radiator **17** shown in **FIG. 5** may include upper and lower tanks.

[**0040**] As shown in **FIG. 6**, the radiator **17** and the gas cooler **2** are constructed such that the tubes **172** of the radiator **17** for circulation of the coolant and tubes **201** of the gas cooler **2** for circulation of the refrigerant are arranged in the same row. The radiating fins **173**, **202** interposed between the respective tubes **172**, **201** are also arranged in the same row. Specifically, the tubes **172**, **201** of the radiator **17** and gas cooler **2** are arranged at the same pitch. The tubes **172**, **201** in three rows and two lines from the upper left in **FIG. 6** are connected to radiating fins **173**, **202** (which are actually in the form of a series of radiation fins). The other radiating fins **173**, **202** are insulated thermally. With this, a portion of the radiator **17** and gas cooler **2** in three rows and two lines from the upper left constitutes heat exchanger **10** of the present invention, wherein heat exchange is carried out between the coolant circulating through the tubes **172** of the radiator **17** and the refrigerant circulating through the tubes **201** of the gas cooler **2**. In the other portions of the radiator **17** and gas cooler **2** (including the tubes **201** of the gas cooler **2** in the three rows of the upper right line) the coolant in the radiator **17** and the refrigerant in the gas cooler **2** are cooled by air, respectively.

[**0041**] Having described the present invention in connection with the preferred embodiments, it is to be understood that the present invention is not limited thereto, and various changes and modifications can be made without departing from the scope of the present invention.

[**0042**] By way of example, in the illustrative embodiments, the heat exchanger **10** is arranged between the compressor **1** and gas cooler **2**. Alternatively, the heat exchanger **10** may be arranged between the compressor **1** and the pressure control valve **3**. Moreover, in the illustrative embodiments, the pressure control valve **3** is of the electric type. Alternatively, the pressure control valve **3** may be of the mechanical expansion type wherein the valve opening degree is adjusted by detecting the pressure and temperature of the high-pressure side refrigerant. In this alternative, a high-pressure side refrigerant pressure detecting part and a high-pressure side refrigerant temperature detecting part are arranged to ensure communication between a valve main body and the gas cooler **2** and internal heat exchanger **9**. Further, the internal heat exchanger **9**, which is arranged in the illustrative embodiments, can be eliminated if required. Furthermore, the coolant may be a coolant for a drive motor for electric vehicles or a coolant for a generating unit for fuel cell powered vehicles.

[**0043**] As described above, according to the present invention, the heat exchanger is arranged between the compressor and the pressure control valve for carrying out heat exchange through the refrigerant. With this, the temperature of the refrigerant provided to the gas cooler is reduced in advance, so that even when the radiation effect of the gas cooler is low, the temperature of the refrigerant at the outlet of the gas cooler is lowered relatively, resulting in securing of the cooling performance of the evaporator.

**[0044]** Moreover, according to the present invention, the heat exchanger is constructed to allow circulation of an engine coolant therethrough. Since the engine-coolant system is indispensable for the vehicle, the requirement is only extension of its line without any arrangement of additional cooling means, having an advantage in terms of manufacturing cost and space. Further, at engine start, the engine coolant is heated by the high-temperature refrigerant at the outlet of the compressor, contributing to shortening of an engine worm up time.

**[0045]** Furthermore, according to the present invention, the heat exchanger is integrated with an automotive radiator. This allows arrangement of the heat exchanger with practically no taking-up of a space in the engine room.

What is claimed is:

**1**. A cooling cycle system of a motor vehicle powered by an engine that is configured to be cooled by a coolant flowing through a radiator, the cooling cycle system comprising:

a compressor that is configured to compress a refrigerant;

a gas cooler that is configured to cool the compressed refrigerant;

a throttling device that is configured to throttle flow of the cooled refrigerant;

an evaporator that is configured to cool an intake air by a heat absorbing action of the cooled refrigerant; and

a heat exchanger being provided downstream of the compressor and being integrated with a radiator and with the gas cooler,

wherein the heat exchanger comprises tubes in which coolant is configured to flow and tubes in which the compressed refrigerant is configured to flow,

wherein heat exchange is configured to occur between the coolant and the compressed refrigerant flowing through some of the tubes through which the coolant and the compressed refrigerant flow by means of fins that connect such tubes, and

wherein the coolant and the compressed refrigerant flowing through the remaining tubes are configured to be air cooled.

**2**. The cooling cycle system as claimed in claim 1, further comprising:

a second heat exchanger that is configured to conduct heat exchange between the refrigerant that flows from: (a) the gas cooler to the throttle device; and (b) the evaporator to the compressor.

**3**. The cooling cycle system as claimed in claim 2, further comprising:

an accumulator that is arranged in a refrigerant line from the evaporator to the second heat exchanger.

**4**. The cooling cycle system as claimed in claim 1, wherein the coolant is supplied to a heater core for heating the intake air that is cooled by the evaporator.

**5**. The cooling cycle system as claimed in claim 1, wherein the gas cooler is provided with a cooling fan for accelerating the heat exchange of the gas cooler.

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