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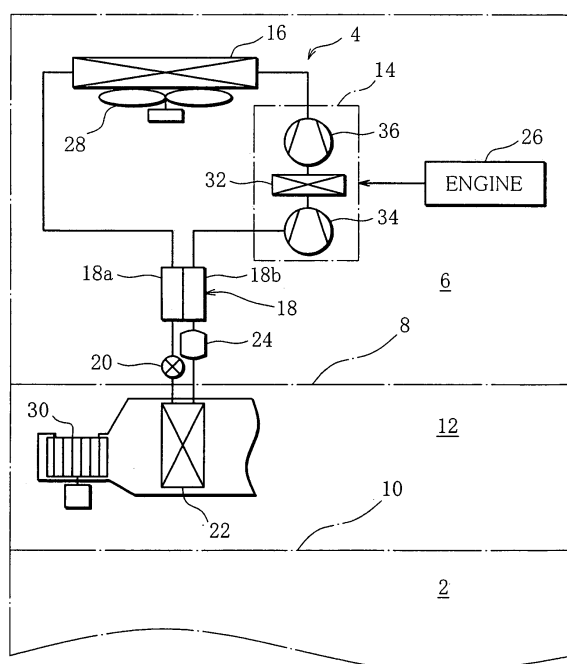
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(54) **Vapor-compression refrigeration circuit and automotive air-conditioning system using the refrigeration circuit**

(57) A vapor-compression refrigeration circuit includes a compound compressor (14) having a low-stage compression section (34) and a high-stage compression section (36) connected in series with each other, and an intercooler (32, 104) inserted in a refrigerant passage connecting between the low- and high-stage compression sections (34, 36), for cooling refrigerant discharged from the low-stage compression section (34) and then allowing the refrigerant to be sucked into the high-stage compression section (36). The compound compressor (14) has a swash plate (62), cylinder bores (42a) and pistons (48a) constituting the low-stage compression section (34), cylinder bores (42b) and pistons (48b) constituting the high-stage compression section (36), and shoes (64) for converting rotation of the swash plate (62) to reciprocating motions of the pistons (48a, 48b) of the low- and high-stage compression sections (34, 36).

FIG. 1



Description

BACKGROUND OF THE INVENTION

Field of the Invention

[0001] The present invention relates to a vapor-compression refrigeration circuit and an automotive air-conditioning system using the refrigeration circuit.

Description of the Related Art

[0002] A vapor-compression refrigeration circuit is used, for example, in an air-conditioning system for a motor vehicle and has a circulation passage for circulating a refrigerant therethrough. In the circulation passage are generally inserted a compressor, a heat radiator (condenser or gas cooler), a pressure reducer (expansion valve), and an evaporator in the mentioned order as viewed in the flowing direction of the refrigerant.

[0003] In recent years, refrigeration circuits using refrigerants with small global warming potential have been actively developed in consideration of environmental problems. Natural CO₂ (carbon dioxide), which is non-toxic and noninflammable, has been proposed as one of such refrigerants. The refrigeration cycle of a refrigeration circuit using CO₂ as the refrigerant is a transcritical cycle (supercritical cycle) because the critical temperature of CO₂ is as low as about 31°C, and the high-pressure side of the refrigeration circuit remains in a supercritical state where the refrigerant pressure is about 7.4 MPa, for example.

[0004] Thus, where CO₂ is used as the refrigerant, the high-pressure side of the refrigeration circuit is subjected to higher pressure than in the case of using conventional HFC refrigerants. Consequently, more motive power is required for the compressor to compress the refrigerant, which lowers the coefficient of performance (COP).

[0005] To reduce the motive power required of the compressor, a compound compressor and an intercooler may be used, as disclosed in Unexamined Japanese Patent Publication No. H05-164041. Specifically, the compound compressor has a low-stage compression section and a high-stage compression section connected in series with each other. The intercooler is inserted in a refrigerant passage connecting between the discharge port of the low-stage compression section and the suction port of the high-stage compression section. The refrigerant discharged from the low-stage compression section is cooled by the intercooler, and the refrigerant thus cooled by the intercooler is further compressed by the high-stage compression section, whereby the motive power consumed by the compressor as a whole is presumably reduced.

[0006] In the disclosed compound compressor, however, three pistons are coupled to the crankshaft each by a connecting rod, and thus vibration and noise are produced due to fluctuation of torque. Where the com-

pound compressor is used in the refrigeration circuit of an air-conditioning system for a motor vehicle, such vibration and noise impair the ride comfort of the vehicle.

[0007] Also, because of the vibration, the compound compressor is not suited for operation at high rotating speeds. Accordingly, the compressor is not suited to be supplied with motive power from an automotive engine because the rotational speed of the automotive engine varies significantly.

[0008] Further, where the compound compressor and the intercooler are applied to the refrigeration circuit of an automotive air-conditioning system, the mountability of the refrigeration circuit onto a vehicle is low, because the refrigeration circuit requires an increased number of component parts as well as complicated piping.

SUMMARY OF THE INVENTION

[0009] An object of the present invention is to provide a vapor-compression refrigeration circuit provided with a compound compressor capable of stable and quiet operation even at high rotational speeds and also with an intercooler simplified in construction, and an automotive air-conditioning system using the refrigeration circuit.

[0010] To achieve the object, the present invention provides a vapor-compression refrigeration circuit comprising: a compound compressor having a low-stage compression section and a high-stage compression section connected in series with each other and each adapted to perform a process of sucking in a refrigerant, a process of compressing the refrigerant, and a process of discharging the refrigerant; and an intercooler inserted in a refrigerant passage connecting between the low-stage compression section and the high-stage compression section, for cooling the refrigerant discharged from the low-stage compression section and then allowing the refrigerant to be sucked into the high-stage compression section. The compound compressor includes: a swash plate; a cylinder bore and a piston constituting the low-stage compression section; a cylinder bore and a piston constituting the high-stage compression section; and conversion means for converting rotation of the swash plate to reciprocating motions of the pistons of the low- and high-stage compression sections.

[0011] In the compound compressor used in the vapor-compression refrigeration circuit of the present invention, rotation of the swash plate is converted to reciprocating motions of the pistons of the low- and high-stage compression sections. Accordingly, during the operation of the compressor, torque fluctuation is small, thus reducing vibration and noise. Also, since vibration can be reduced, the compressor is suited for operation at high rotational speeds.

[0012] Preferably, the intercooler is combined integrally with the compound compressor.

[0013] In the preferred refrigeration circuit, the intercooler is combined integrally with the compound compressor, whereby the refrigeration circuit is simplified in

construction.

[0014] Preferably, each of the low- and high-stage compression sections has a suction port and a discharge port, both opening in the housing of the compound compressor, and the intercooler includes a pipe member having opposite ends connected to the discharge port of the low-stage compression section and the suction port of the high-stage compression section, respectively, and an outer surface spaced from the housing of the compound compressor.

[0015] In the preferred refrigeration circuit, the pipe member of the intercooler is set apart from the outer surface of the housing of the compound compressor, whereby the refrigerant flowing through the pipe member is efficiently cooled.

[0016] Preferably, the intercooler has surface irregularities formed on one or both of the inner and outer peripheral surfaces of the pipe member.

[0017] In the preferred refrigeration circuit, the intercooler has surface irregularities formed on one or both of the inner and outer peripheral surfaces of the pipe member and thus has an increased surface area. The refrigerant can therefore be efficiently cooled through the intercooler, and as a result, the refrigeration circuit has an improved coefficient of performance, despite its simple construction.

[0018] Preferably, the intercooler is combined integrally with a heat radiator.

[0019] In this preferred refrigeration circuit, since the intercooler is combined integrally with the radiator, the refrigerant can be efficiently cooled by the intercooler, so that the refrigeration circuit has a significantly high coefficient of performance.

[0020] Preferably, the intercooler has an inlet connected to the discharge port of the low-stage compression section and an outlet connected to the suction port of the high-stage compression section, and a first pipe connecting between the inlet of the intercooler and the discharge port of the low-stage compression section and a second pipe connecting between the inlet of the heat radiator and the discharge port of the high-stage compression section are integrally formed into a one-piece body.

[0021] In the preferred refrigeration circuit, the first pipe connecting between the inlet of the intercooler and the discharge port of the low-stage compression section and the second pipe connecting between the inlet of the radiator and the discharge port of the high-stage compression section are integrally formed as a one-piece body. Thus, the number of pipes used is reduced, making it possible to simplify the construction of the refrigeration circuit.

[0022] Preferably, the vapor-compression refrigeration circuit further comprises an internal heat exchanger having a high-temperature section inserted in a refrigerant passage extending between the outlet of the radiator and the inlet of a pressure reducer, and a low-temperature section inserted in a refrigerant passage extending between the outlet of an evaporator and the inlet of the

low-stage compression section of the compound compressor.

[0023] With the preferred refrigeration circuit additionally provided with the internal heat exchanger, the enthalpy of the refrigerant at the inlet of the evaporator is reduced. As a consequence, the amount of change of the enthalpy in the evaporator increases, making it possible to further increase the coefficient of performance of the refrigeration circuit.

[0024] Preferably, the refrigerant used is CO₂.

[0025] The preferred refrigeration circuit uses CO₂ as the refrigerant and thus is environmentally friendly. Where CO₂ is used as the refrigerant, the refrigerant pressure in the high-pressure side of the refrigeration circuit is considerably high. However, since the refrigeration circuit is provided with the compound compressor and the intercooler, increase in the motive power needed to drive the compressor is restrained, ensuring a sufficiently high coefficient of performance.

[0026] An automotive air-conditioning system according to the present invention is provided with any one of the aforementioned vapor-compression refrigeration circuits.

[0027] With the automotive air-conditioning system equipped with any one of the aforementioned refrigeration circuits, vibration and noise can be reduced, and therefore, the ride comfort of the vehicle improves. Also, since the compound compressor used in the air-conditioning system is suited for operation at high rotational speeds, the motive force of the engine can be transmitted to the compressor by using simple mechanical equipment. Further, the intercooler or the piping of the refrigeration circuit is simple in construction, and therefore, it is easy to mount the air-conditioning system onto a vehicle.

BRIEF DESCRIPTION OF THE DRAWINGS

[0028] The present invention will become more fully understood from the detailed description given hereinafter and the accompanying drawings which are given by way of illustration only, and thus, are not limitative of the present invention, and wherein:

FIG. 1 schematically shows a refrigeration circuit of an automotive air-conditioning system according to one embodiment of the present invention;

FIG. 2 is a schematic sectional view of a compressor used in the refrigeration circuit of FIG. 1;

FIG. 3 is a sectional view taken along line III-III in FIG. 2;

FIG. 4 shows an intercooler mounted on the compressor shown in FIG. 1;

FIG. 5 is a Mollier diagram for explaining the operation of the compressor and the intercooler in the refrigeration circuit of FIG. 1;

FIG. 6 is a partly sectional view showing part of an intercooler according to a modification;

FIG. 7 is a perspective view showing part of an intercooler according to another modification;
 FIG. 8 is a partly sectional view showing part of an intercooler according to a further modification;
 FIG. 9 illustrates part of a refrigeration circuit to which an intercooler according to another modification is applied;
 FIG. 10A is a front view schematically showing the intercooler combined with a radiator;
 FIG. 10B is a bottom view schematically showing the intercooler combined with the radiator;
 FIG. 10C is a side view schematically showing the intercooler combined with the radiator; and
 FIG. 11 is a perspective view showing part of a discharge pipe connecting between the inlet of the radiator and a high-stage discharge port of the compressor and between the inlet of the intercooler and a low-stage discharge port of the compressor, all appearing in FIG. 9.

DETAILED DESCRIPTION

[0029] FIG. 1 schematically shows a refrigeration circuit of an automotive air-conditioning system according to one embodiment of the present invention. The refrigeration circuit is of a vapor compression type and is used to cool or dehumidify the air supplied to a passenger compartment 2.

[0030] The refrigeration circuit has a circulation passage 4, and CO₂ refrigerant (R-744), which is a natural refrigerant and which contains a small amount of lubricating oil as a refrigerating machine oil, is circulated through the circulation passage 4. The circulation passage 4 extends from an engine compartment 6 into a front part of the passenger compartment 2 through a partition wall 8. The front part of the passenger compartment 2 is partitioned by an instrument panel 10 and serves as a machinery compartment 12.

[0031] In the circulation passage 4, a compressor 14, a heat radiator (gas cooler) 16, a high-temperature section 18a of an internal heat exchanger 18, a pressure reducer (expansion valve) 20, an evaporator 22, an accumulator (gas-liquid separator) 24 and a low-temperature section 18b of the internal heat exchanger 18 are inserted in the mentioned order as viewed in the flowing direction of the refrigerant.

[0032] The refrigeration circuit operates in the manner described below. The compressor 14 is driven by motive power transmitted from an engine 26 via a belt to suck in the low-temperature, low-pressure refrigerant of gas phase from the low-temperature section 18b of the internal heat exchanger 18. Then, the compressor 14 compresses the refrigerant into a high-temperature, high-pressure supercritical state and discharges the compressed refrigerant to the radiator 16. Namely, the compressor 14 successively performs the process of sucking in the refrigerant, the process of compressing the refrigerant, and the process of discharging the refrigerant.

Consequently, the refrigerant is circulated through the circulation passage 4 to successively pass through the radiator 16, the high-temperature section 18a of the internal heat exchanger 18, the pressure reducer 20, the evaporator 22, the accumulator 24, and the low-temperature section 18b of the internal heat exchanger 18.

[0033] A fan 28 is arranged near the radiator 16. When passing through the radiator 16, the refrigerant is cooled by the air flow produced by the fan 28 or produced as the vehicle runs, so that the temperature of the refrigerant lowers. When the refrigerant passes through the high-temperature section 18a of the internal heat exchanger 18 thereafter, the temperature thereof further lowers because the refrigerant is cooled due to heat exchange with the refrigerant passing through the low-temperature section 18b of the internal heat exchanger 18. The high-pressure, supercritical or liquid-phase refrigerant cooled in this manner then passes through the pressure reducer 20, where the refrigerant is allowed to expand, causing a drop in both the pressure and temperature of the refrigerant. Consequently, the refrigerant turns into a low-temperature, low-pressure gas-liquid mixture state (two-phase state).

[0034] A blower 30 is arranged close to the evaporator 22. When the refrigerant, which is in the gas-liquid mixture state, passes through the evaporator 22, the liquid-phase component contained therein evaporates while removing heat from the ambient air, whereby the air flow produced by the blower 30 and flowing around the evaporator 22 is cooled. The cooled air flows into the passenger compartment 2, so that the passenger compartment 2 is cooled or dehumidified.

[0035] The low-temperature, low-pressure refrigerant, of which part of the liquid-phase component has evaporated in the evaporator 22, then passes through the accumulator 24, where the remaining liquid-phase component is substantially totally removed. Subsequently, the low-temperature, low-pressure refrigerant in the gas phase passes through the low-temperature section 18b of the internal heat exchanger 18, in which the refrigerant is superheated due to heat exchange with the refrigerant passing through the high-temperature section 18a of the internal heat exchanger 18. The superheated refrigerant is sucked into the compressor 14, and the aforementioned cycle is repeated thereafter.

[0036] The compressor 14 is a compound compressor having a low-stage compression section 34 and a high-stage compression section 36 connected in series with each other with an intercooler 32 therebetween.

[0037] More specifically, the compressor 14 has a basic construction similar to a variable-displacement swash plate compressor, as shown in FIG. 2. The compressor 14 has a cylinder block 40 having a cylindrical shape, and seven cylinder bores 42, for example, are formed in the cylinder block 40. The cylinder bores 42 are arranged around the axis of the cylinder block 40 concentrically therewith and penetrate through the cylinder block 40 in its axial direction.

[0038] The cylinder block 40 is fitted into one end portion of a cylindrical casing 44. A crank chamber 46 is defined inside the casing 44 and between the cylinder block 40 and the other end wall of the casing 44. An end portion of a piston 48 received in each cylinder bore 42 projects into the crank chamber 46.

[0039] A drive shaft 50 extends through the crank chamber 46 parallel with the pistons 48 and is rotatably supported by radial bearings and thrust bearings. The drive shaft 50 penetrates through the other end wall of the casing 44, and a driven unit of an electromagnetic clutch 52 is fixed on the outer end portion of the drive shaft 50. A drive unit, with which the driven unit is coupled by electromagnetic force, is rotatably supported on the casing 44 by a radial bearing. The drive unit has a pulley 54, and a belt is passed around the pulley 54 and the output shaft of the engine 26.

[0040] A base rotor 56 is securely fixed on a portion of the drive shaft 50 extending through the crank chamber 46 and is coupled through a hinge 58 to the boss 60. The drive shaft 50 penetrates through the boss 60, and the swash plate 62, which is annular in shape, is securely fitted on the boss 60. Accordingly, the swash plate 62 is rotatable together with the drive shaft 50 and is also tiltable with respect to the drive shaft 50.

[0041] The outer peripheral portion of the swash plate 62 is positioned in recesses formed at the projecting end portions of the individual pistons 48, and a pair of semi-spherical shoes 64 are arranged in each of the recesses. Each pair of shoes 64 hold the swash plate 62 from opposite sides thereof, as viewed in the thickness direction of the swash plate 62, so that the individual pistons 48 are coupled to the swash plate 62 by the shoes 64. Consequently, rotation of the drive shaft 50 is converted to reciprocating motions of the pistons 48 through the base rotor 56, the hinge 58, the boss 60, the swash plate 62, and the shoes 64.

[0042] A cylinder head 66, which constitutes the housing of the compressor 14 together with the casing 44, is airtightly fixed to the one end of the casing 44 with a valve plate 68 and a gasket interposed between the cylinder head 66 and the cylinder block 40. The valve plate 68 has regions closing the respective cylinder bores 42, and a suction hole 70 and a discharge hole 72 are formed through each region. Each suction hole 70 is opened and closed by a suction reed valve arranged on the same side as the cylinder bore 42, and each discharge hole 72 is opened and closed by a discharge reed valve 74 arranged on the same side as the cylinder head 66.

[0043] The cylinder head 66 has a low-stage suction chamber 78, a low-stage discharge chamber 80, a high-stage suction chamber 82 and a high-stage discharge chamber 84 defined therein in an airtight fashion with respect to one another. As shown in FIG. 3, four cylinder bores 42a, out of the seven cylinder bores 42, communicate with the low-stage suction chamber 78 and the low-stage discharge chamber 80 through the suction holes 70 and the discharge holes 72, respectively. The

remaining three cylinder bores 42b communicate with the high-stage suction chamber 82 and the high-stage discharge chamber 84 through the suction holes 70 and the discharge holes 72, respectively.

[0044] Referring again to FIG. 2, the cylinder head 66 has a low-stage suction port 86, a low-stage discharge port 88, a high-stage suction port 90 and a high-stage discharge port 92, all opening in the outer surface thereof. The low-stage suction port 86, the low-stage discharge port 88, the high-stage suction port 90 and the high-stage discharge port 92 communicate respectively with the low-stage suction chamber 78, the low-stage discharge chamber 80, the high-stage suction chamber 82, and the high-stage discharge chamber 84.

[0045] The low-stage suction port 86 is connected with the outlet of the low-temperature section 18b of the internal heat exchanger 18. The high-stage discharge port 92 is connected to the inlet of the radiator 16. Accordingly, the low-stage suction port 86 functions as the suction port of the compressor 14, and the high-stage discharge port 92 functions as the discharge port of the compressor 14.

[0046] The low-stage discharge port 88 and the high-stage suction port 90 are connected, for example, by brazing, with the respective opposite ends of a heat exchange pipe 94 serving as the intercooler 32, as shown in FIG. 4. The heat exchange pipe 94 has a plurality of collar-shaped fins 96 securely brazed to the outer peripheral surface of an intermediate portion thereof. The heat exchange pipe 94 is spaced from the outer surface of the cylinder head 66, except for the opposite ends thereof.

[0047] The operation of the compressor 14 and the intercooler 32 will be now described with reference to the Mollier diagram of FIG. 5.

[0048] The refrigerant delivered from the low-temperature section 18b of the internal heat exchanger 18 flows into the low-stage suction chamber 78 through the low-stage suction port 86 and then is sucked into the cylinder bores 42a through the respective suction holes 70. The state of the refrigerant in the low-stage suction chamber 78 is indicated at point A in the Mollier diagram of FIG. 5.

[0049] As the pistons 48a reciprocate, the refrigerant sucked into the respective cylinder bores 42a is compressed and then discharged into the low-stage discharge chamber 80 through the respective discharge holes 72. The state of the refrigerant in the low-stage discharge chamber 80 is indicated at point B in FIG. 5.

[0050] The refrigerant in the low-stage discharge chamber 80 then flows into the intercooler 32 through the low-stage discharge port 88. While passing through the intercooler 32, the refrigerant is cooled due heat exchange with the air (external medium) surrounding the intercooler 32. The refrigerant thus cooled in the intercooler 32 flows into the high-stage suction chamber 82 through the high-stage suction port 90. The state of the refrigerant in the high-stage suction chamber 82 is indicated at point C in FIG. 5.

[0051] As the pistons 48b reciprocate, the refrigerant in the high-stage suction chamber 82 is introduced into the cylinder bores 42b through the respective suction holes 70, then compressed and discharged into the high-stage discharge chamber 84 through the respective discharge holes 72. The state of the refrigerant in the high-stage discharge chamber 84 is indicated at point D in FIG. 5.

[0052] The refrigerant in the high-stage discharge chamber 84 is then delivered from the compressor 14 through the high-stage discharge port 92 and flows to the inlet of the radiator 16.

[0053] As is clear from the above, the four pistons 48a and their associated cylinder bores 42a constitute the low-stage compression section 34, and the three pistons 48b and their associated cylinder bores 42b constitute the high-stage compression section 36.

[0054] In the compressor 14 used in the above refrigeration circuit, rotation of the swash plate 62 is converted to reciprocating motions of the pistons 48a and 48b of the low- and high-stage compression sections 34 and 36. Thus, during the operation of the compressor 14, torque fluctuation is small, whereby vibration and noise of the compressor 14 can be reduced. Also, since vibration can be reduced, the compressor 14 is suited for operation at high rotational speeds.

[0055] Further, the intercooler 32 is combined integrally with the compressor 14, and thus the refrigeration circuit is simplified in construction.

[0056] In the refrigeration circuit, moreover, the heat exchange pipe 94 of the intercooler 32 is, except for its opposite ends, set apart from the outer surface of the compressor housing, namely, the casing 44 and the cylinder head 66, whereby the refrigerant flowing through the intercooler 32 is efficiently cooled.

[0057] Also, the heat exchange pipe 94 of the intercooler 32 has the fins 96 attached to its outer surface and has an increased surface area. Accordingly, the refrigeration circuit can cool the refrigerant efficiently through the heat exchange pipe 94 and has a high coefficient of performance, despite its simple construction.

[0058] The present invention is not limited to the above embodiment alone and may be modified in various ways. For example, the refrigerant to be used is not limited to CO₂. In the light of global environment, however, CO₂ is preferred. Where CO₂ is used as the refrigerant, the refrigerant pressure in the high-pressure side of the refrigeration circuit is considerably high. However, since the aforementioned refrigeration circuit is provided with the compressor 14 and the intercooler 32, increase in the motive power needed to drive the compressor 14 is restrained, thus ensuring a sufficiently high coefficient of performance.

[0059] The refrigeration circuit of the foregoing embodiment includes the internal heat exchanger 18, but the internal heat exchanger 18 may be omitted. By using the internal heat exchanger 18, however, it is possible to lower the enthalpy of the refrigerant at the inlet of the evaporator 22.

As a consequence, the amount of change of the enthalpy in the evaporator 22 increases, making it possible to further increase the coefficient of performance.

[0060] In the above embodiment, rotation of the swash plate 62 is converted to reciprocating motions of the pistons 48 by means of the shoes 64. The shoes 64 may be replaced by a wobble plate, which moves from side to side as the swash plate rotates, and connecting rods connecting the outer peripheral portion of the wobble plate and the respective pistons. Namely, the compressor may be a wobble plate compressor. Further, a fixed-displacement compressor or an electrically-driven compressor may be used.

[0061] Also, in the above embodiment, the heat exchange pipe 94 is used as the intercooler 32. Instead of the heat exchange pipe 94, a low fin tube shown in FIG. 6 may be used. The low fin tube has a helical ridge 98 formed on an outer peripheral surface thereof by rolling and has an increased surface area because of its ridge 98.

[0062] Instead of the heat exchange pipe 94, an internally grooved pipe shown in FIG. 7 may also be used. The internally grooved pipe has a plurality of grooves 100 cut in an inner peripheral surface thereof and thus has an increased surface area.

[0063] Further, the heat exchange pipe 94 may be replaced by a flat pipe shown in FIG. 8. The flat pipe has a plurality of internal passages 102, thereby increasing the internal surface area that contacts with the refrigerant.

[0064] Furthermore, grooves as surface irregularities may be cut in the inner peripheral surface of the heat exchange pipe 94 with fins, or conversely, fins may be attached to the outer surface of the internally grooved pipe or flat pipe.

[0065] In the foregoing embodiment, the intercooler 32 is joined integrally to the compressor 14. Alternatively, as shown in FIG. 9, an intercooler 104 may be combined integrally with the radiator 16.

[0066] FIGS. 10A, 10B and 10C show the radiator 16 and the intercooler 104. The intercooler 104 is attached, for example, to a lower part of the radiator 16. In this case, like the radiator 16, the intercooler 104 can also be efficiently cooled by the air flow produced by the fan 28 or produced as the vehicle runs. As a result, the coefficient of performance of the refrigeration circuit significantly increases.

[0067] Preferably, in this case, a discharge pipe 106 shown in FIG. 11 is used to connect between the inlet of the radiator 16 and the high-stage discharge port 92 and between the inlet of the intercooler 104 and the low-stage discharge port 88. The discharge pipe 106 has two internal passages separated from each other by a partition wall 108. In other words, a first pipe connecting between the inlet of the intercooler 104 and the low-stage discharge port 88 and a second pipe connecting between the inlet of the radiator 16 and the high-stage discharge

port 92 are integrally formed into a one-piece body. By using the discharge pipe 106, it is possible to reduce the number of pipes used in the refrigeration circuit and thus to simplify the construction.

[0068] As shown in FIG. 5, there is no great difference between the temperature of the refrigerant flowing from the low-stage discharge port 88 to the inlet of the intercooler 104 and the temperature of the refrigerant flowing from the high-stage discharge port 92 to the inlet of the radiator 16. Accordingly, the use of the single discharge pipe 106 does not entail the situation where the refrigerant flowing from the low-stage discharge port 88 to the intercooler 104 is heated by the refrigerant flowing from the high-stage discharge port 92 to the radiator 16, or the situation where the refrigerant flowing from the high-stage discharge port 92 to the radiator 16 is cooled by the refrigerant flowing from the low-stage discharge port 88 to the intercooler 104.

[0069] Needless to say, the vapor-compression refrigeration circuit of the present invention is applicable not only to automotive air-conditioning system but to refrigerator-freezer and the like. In cases where the refrigeration circuit is applied to automotive air-conditioning system, the ride comfort of the vehicle improves because vibration and noise of the compressor 14 can be reduced. Also, since the compressor 14 is suited for operation at high rotational speeds, the motive force of the engine 26 can be transmitted to the compressor 14 by using simple mechanical equipment. Further, the intercooler 32 or the discharge pipe 106 of the refrigeration circuit is simple in construction, which makes it easier to mount the air-conditioning system onto a vehicle.

[0070] The invention being thus described, it will be obvious that the same may be varied in many ways. Such variations are not to be regarded as a departure from the spirit and scope of the invention, and all such modifications as would be obvious to one skilled in the art are intended to be included within the scope of the following claims.

Claims

1. A vapor-compression refrigeration circuit comprising:

a compound compressor (14) having a low-stage compression section (34) and a high-stage compression section (36) connected in series with each other and each adapted to perform a process of sucking in a refrigerant, a process of compressing the refrigerant, and a process of discharging the refrigerant; and an intercooler (32, 104) inserted in a refrigerant passage connecting between the low-stage compression section (34) and the high-stage compression section (36), for cooling the refrigerant discharged from the low-stage compression

section (34) and then allowing the refrigerant to be sucked into the high-stage compression section (36),

characterized in that the compound compressor (14) includes:

a swash plate (62);
a cylinder bore (42a) and a piston (48a) constituting the low-stage compression section (34);
a cylinder bore (42b) and a piston (48b) constituting the high-stage compression section (36); and
conversion means (64) for converting rotation of the swash plate (62) to reciprocating motions of the pistons (48a, 48b) of the low- and high-stage compression sections (34, 36).

2. The vapor-compression refrigeration circuit according to claim 1, **characterized in that** the intercooler (32) is combined integrally with the compound compressor (14).
3. The vapor-compression refrigeration circuit according to claim 1 or 2, **characterized in that** each of the low- and high-stage compression sections (34, 36) has a suction port (86, 90) and a discharge port (88, 92), both opening in a housing (44, 66) of the compound compressor (14), and the intercooler (32) includes a pipe member (94) having opposite ends connected to the discharge port (88) of the low-stage compression section (34) and the suction port (90) of the high-stage compression section (36), respectively, and an outer surface spaced from the housing (44, 66) of the compound compressor (14).
4. The vapor-compression refrigeration circuit according to any one of claims 1 to 3, **characterized in that** the intercooler (32) has surface irregularities formed on one or both of inner and outer peripheral surfaces of the pipe member (94).
5. The vapor-compression refrigeration circuit according to claim 1, **characterized in that** the intercooler (104) is combined integrally with a heat radiator (16).
6. The vapor-compression refrigeration circuit according to claim 5, **characterized in that** the intercooler (104) has an inlet connected to a discharge port (88) of the low-stage compression section (34), and an outlet connected to a suction port (90) of the high-stage compression section (36), and a first pipe connecting between the inlet of the intercooler (104) and the discharge port (88) of the low-stage compression section (34) and a second pipe connecting between an inlet of the heat radiator (16) and a discharge port (92) of the high-stage compression

sion section (36) are integrally formed into a one-piece body.

7. The vapor-compression refrigeration circuit according to any one of the preceding claims, **characterized by** further comprising an internal heat exchanger (18) having a high-temperature section (18a) inserted in a refrigerant passage extending between an outlet of a heat radiator (16) and an inlet of a pressure reducer (20), and a low-temperature section (18b) inserted in a refrigerant passage extending between an outlet of an evaporator (22) and an inlet of the low-stage compression section (34) of the compound compressor (14).
8. The vapor-compression refrigeration circuit according to any one of the preceding claims, **characterized in that** the refrigerant is CO₂.
9. An automotive air-conditioning system comprising the vapor-compression refrigeration circuit according to any one of the preceding claims.

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FIG. 1

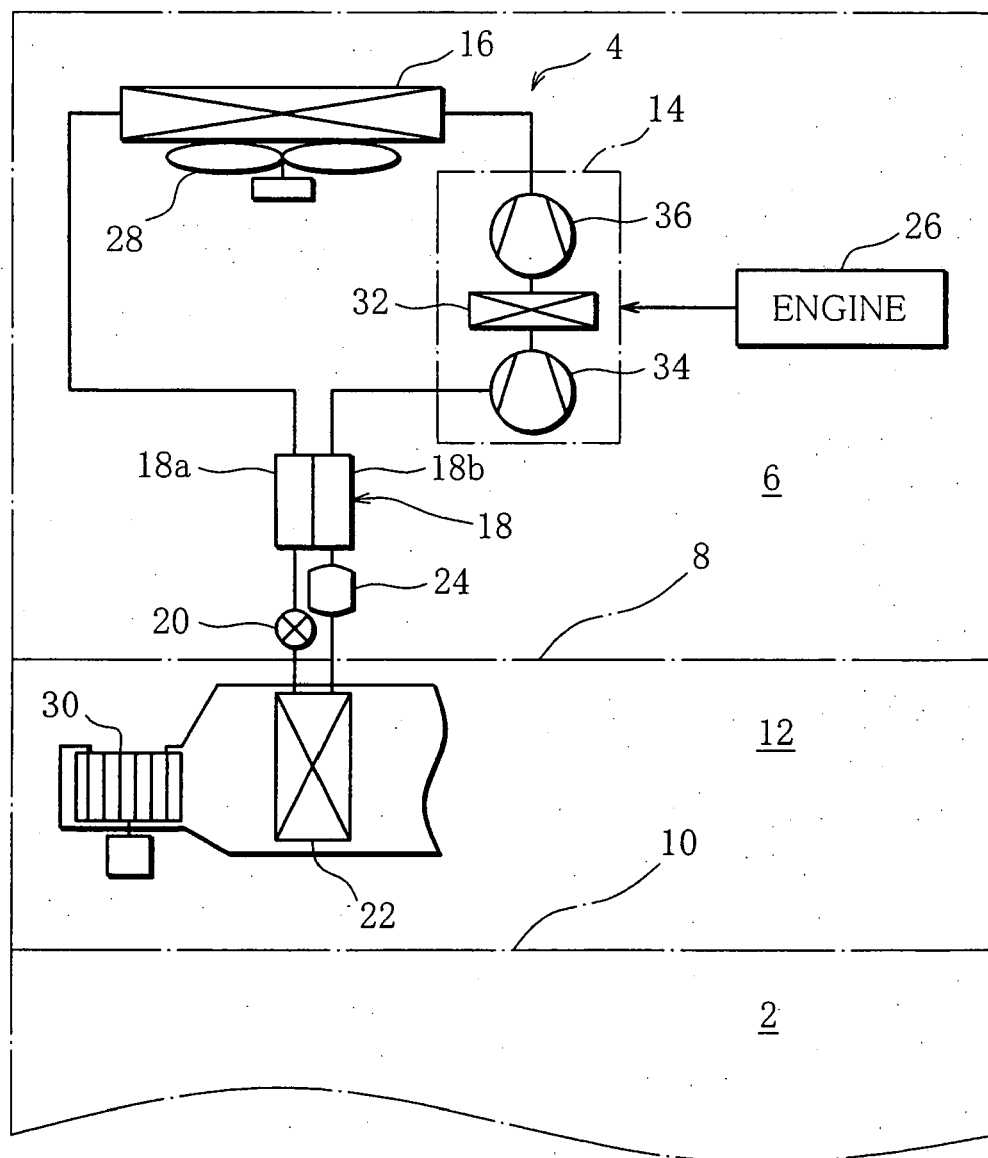


FIG. 2

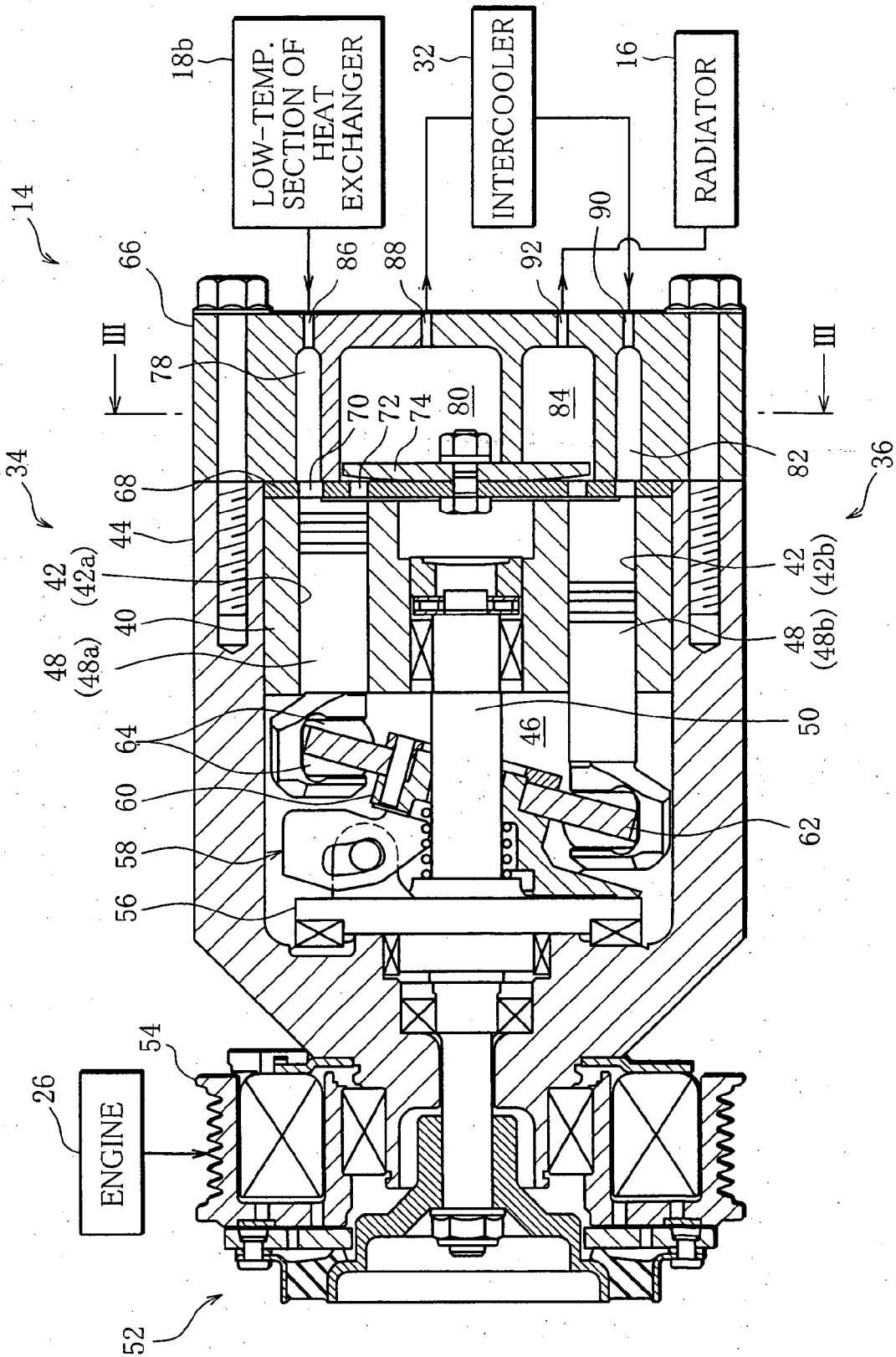


FIG. 3

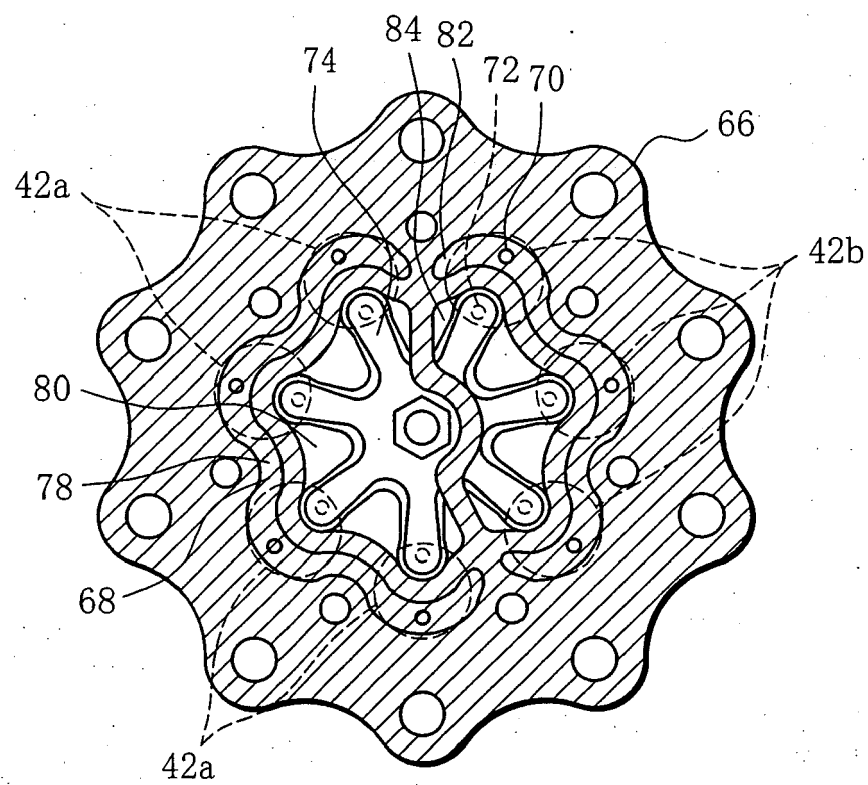


FIG. 4

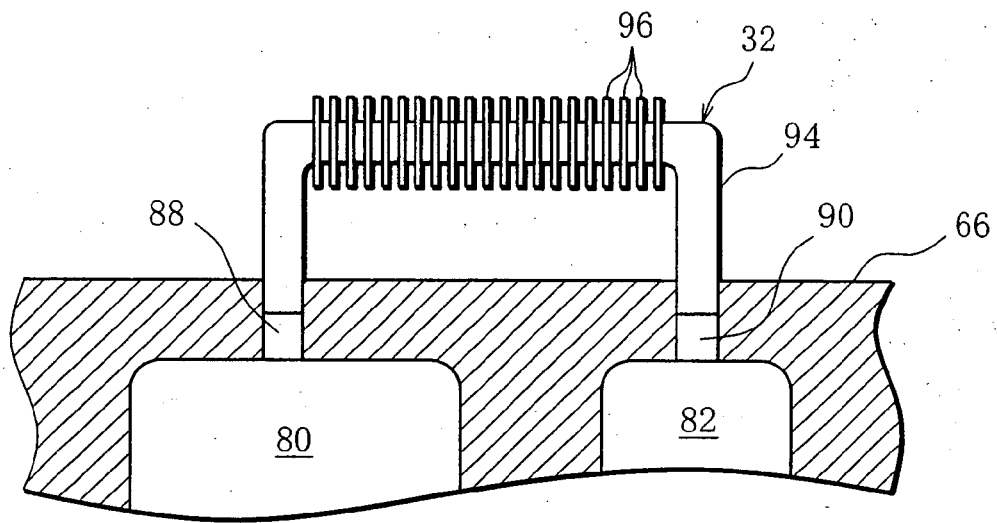


FIG. 5

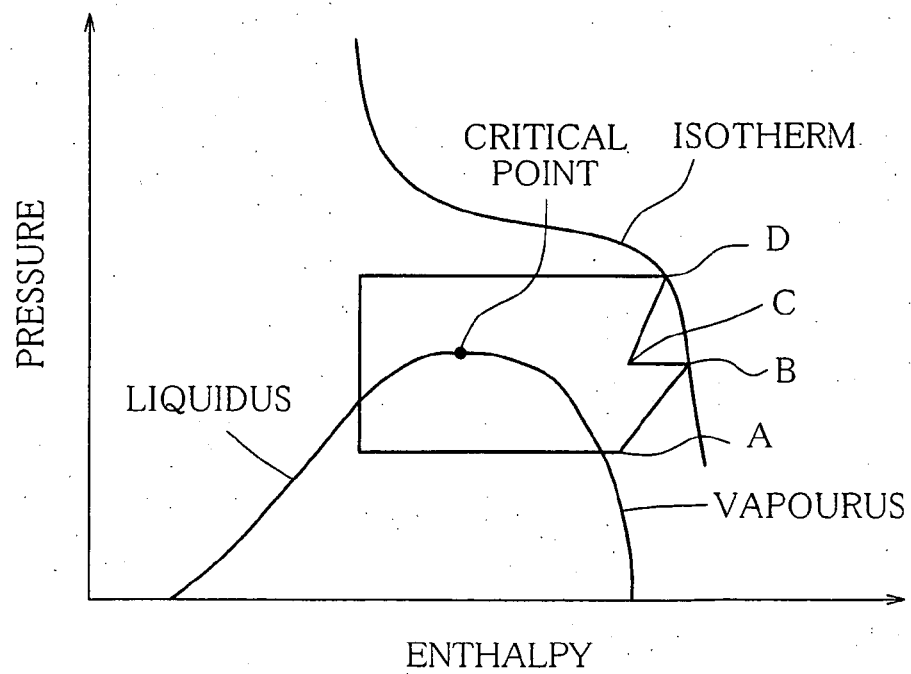


FIG. 6

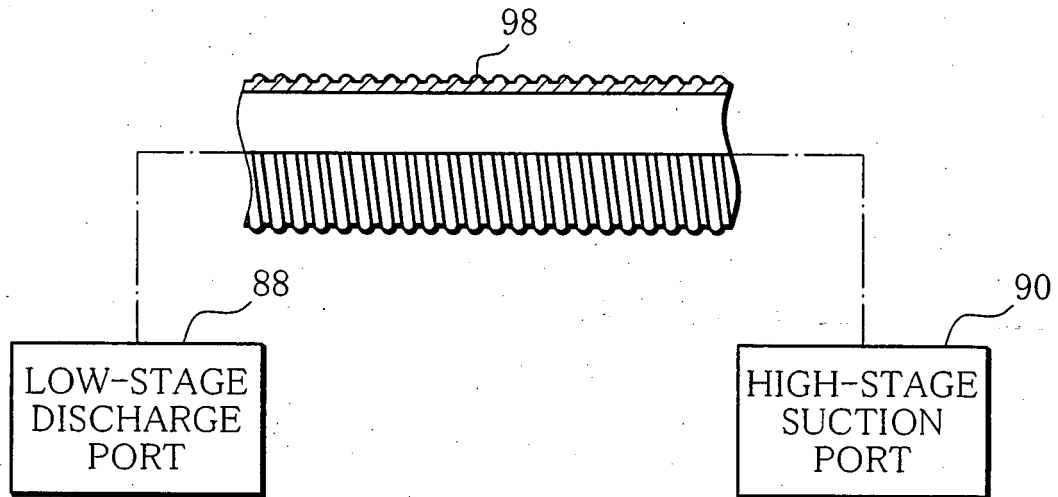


FIG. 7

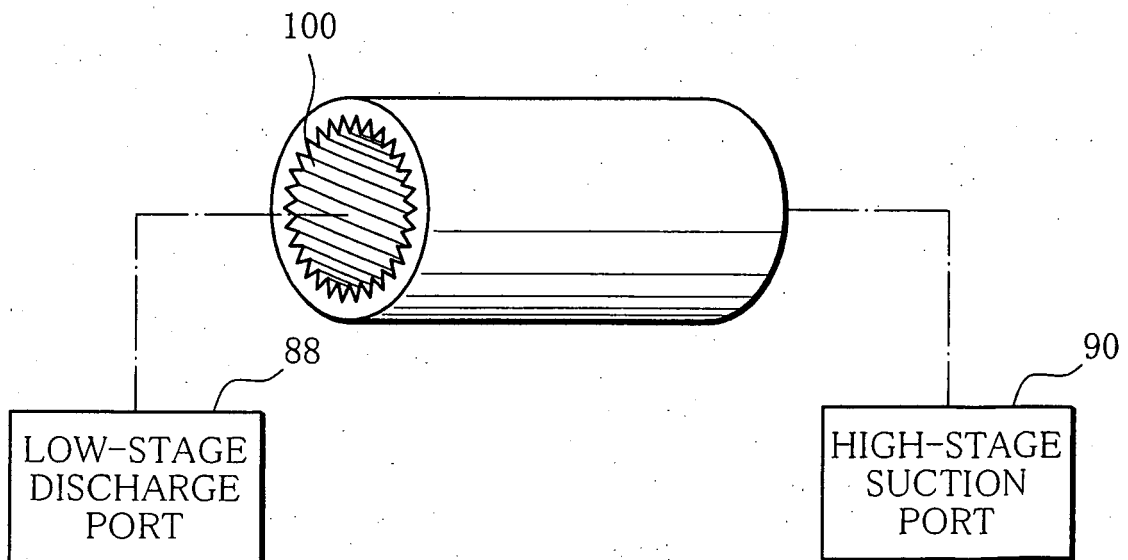


FIG. 8

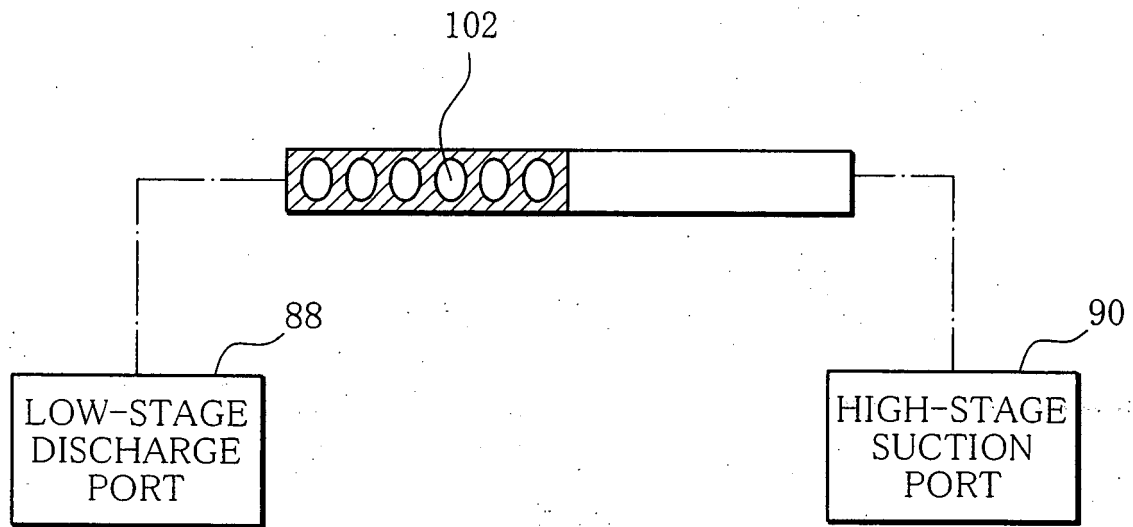


FIG. 9

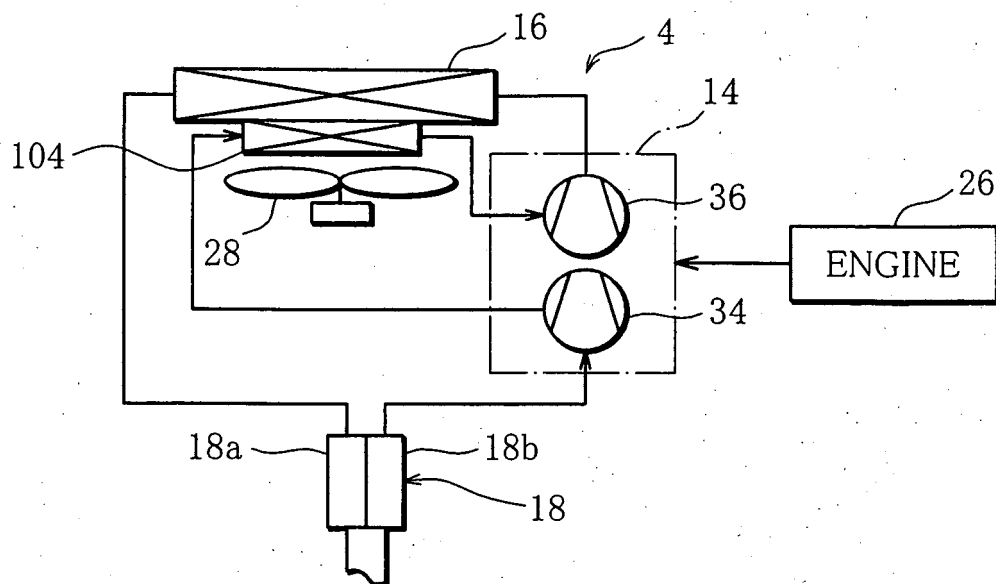


FIG. 10A

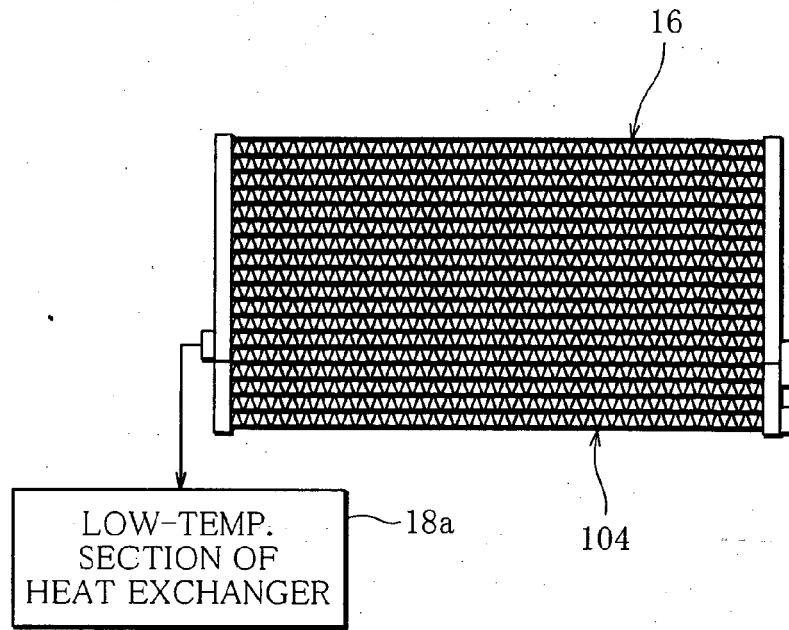


FIG. 10B

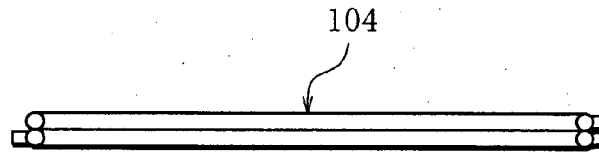


FIG. 10C

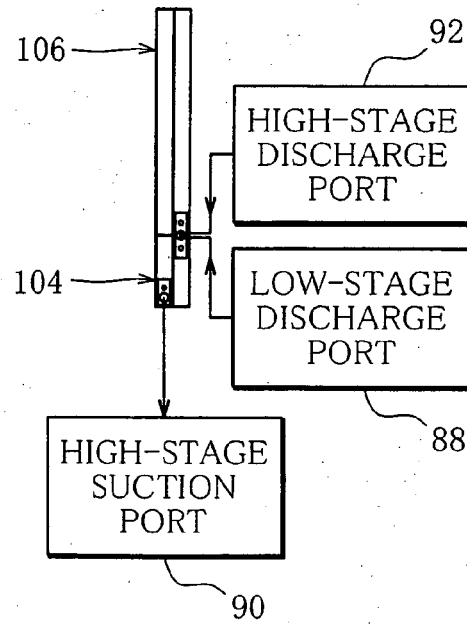
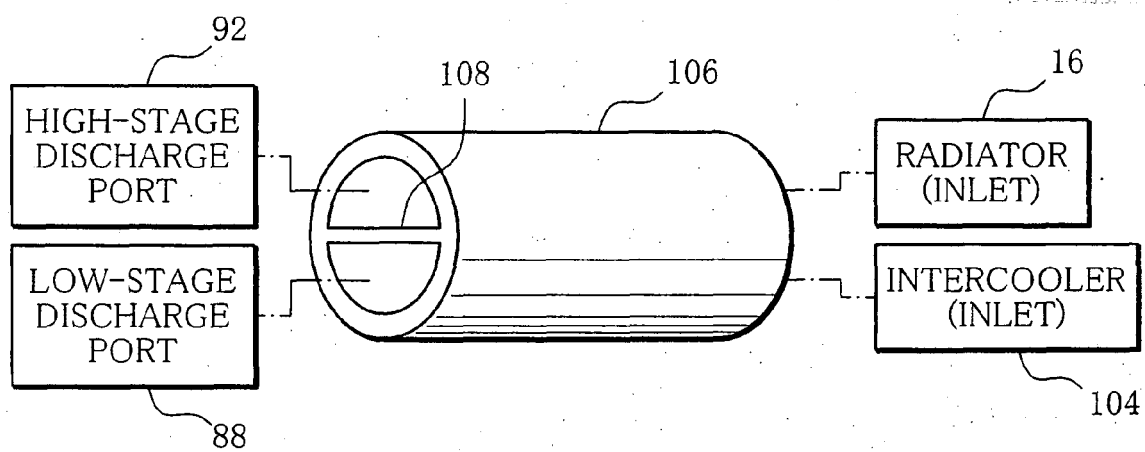


FIG. 11





European Patent
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EUROPEAN SEARCH REPORT

Application Number
EP 07 01 0829

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Place of search Munich		Date of completion of the search 18 September 2007	Examiner Szilagyi, Barnabas
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