(19) Europäisches Patentamt
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(11) EP 1 669 697 A1

(12) EUROPEAN PATENT APPLICATION

(43) Date of publication:
14.06.2006 Bulletin 2006/24

(51) Int Cl.:
F25B 25/00 *(2006.01)* ***F25B 9/00*** *(2006.01)*

(21) Application number: **04257654.6**

(22) Date of filing: **09.12.2004**

(84) Designated Contracting States:
AT BE BG CH CY CZ DE DK EE ES FI FR GB GR HU IE IS IT LI LT LU MC NL PL PT RO SE SI SK TR
Designated Extension States:
AL BA HR LV MK YU

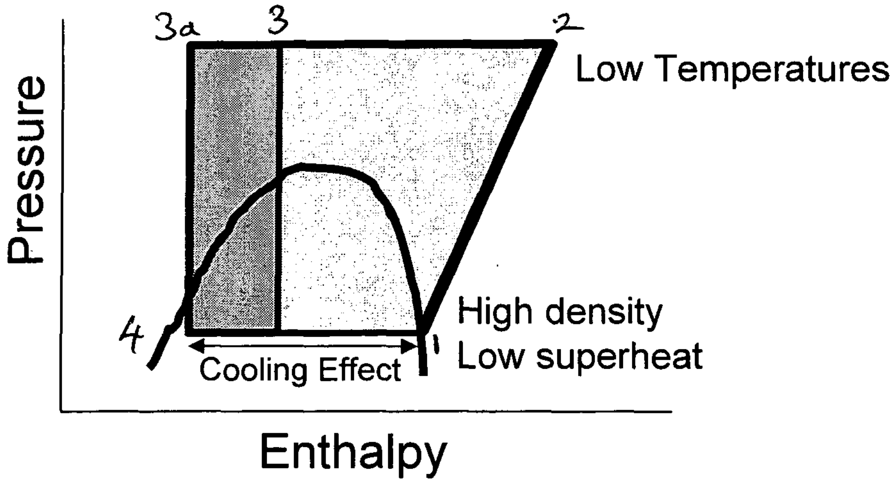
(71) Applicant: **Delphi Technologies, Inc.**
Troy, MI 48007 (US)

(72) Inventor: **Nacer, Achaichia**
1429 Luxembourg (LU)

(74) Representative: **Waller, Stephen et al**
Murgitroyd & Company,
165-169 Scotland Street
Glasgow G5 8PL (GB)

(54) **Thermoelectrically enhanced CO2 cycle**

(57) Figure 1c illustrates a vapour compression cycle according to the present invention wherein a thermoelectric device is used to sub-cool the refrigerant exiting the gas cooler from point 3a to point 3, thus increasing the cooling effect of the evaporator/heat exchanger between points 4 and 1 without the detrimental increase in the temperature of the refrigerant at the suction inlet of the compressor that occurs in known systems through the use of an internal heat exchanger. The thermoelectric device may be provided at the outlet of the gas cooler or may be incorporated into the gas cooler.



c) CO_2 Cycle with thermoelectric sub-cooling

Fig.-1- Transcritical Cycles

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Description

[0001] The present invention relates to a refrigeration system for an air conditioner and to an improved transcritical vapour compression cycle and in particular to a refrigeration system and cycle using carbon dioxide as the refrigerant.

[0002] Carbon dioxide refrigerant is being considered as a replacement refrigerant for use by the automotive industry for air conditioning, as well as in other applications, mainly due to the low toxicity of such refrigerant. However, carbon dioxide based systems have many challenges resulting from the fact that such systems operates in transcritical mode leading to high pressures and high compressor out temperatures. Other challenges are the low critical temperature and the shape of the isotherms around the critical point. The performance of the gas cooler is therefore limited by the ambient air temperature.

[0003] In order to improve the performance of such carbon dioxide systems it is important to have additional cooling at the exit from the gas cooler. This is usually achieved in the prior art through an internal heat exchanger, where cold refrigerant at exit from the evaporator is used to further cool down the refrigerant leaving the gas cooler. This method, although achieving the goal of improving the cooling capacity, has the drawback that it will increase drastically the amount of superheat going into the compressor and therefore results in lower refrigerant density at the compressor suction inlet and higher compressor outlet temperature, which can shorten the life of the compressor and require the gas cooler to be made from special heat resistant materials.

[0004] The object of the present invention is to avoid the need to have high superheat and high compressor outlet temperature whilst improving the efficiency and performance of the system.

[0005] According to the present invention there is provided a refrigeration system for an air conditioner comprising a compressor for compressing a refrigerant, a gas cooler downstream of the compressor for cooling the refrigerant, an expansion valve downstream of the gas cooler for reducing the pressure of the refrigerant and a heat exchanger or evaporator downstream of the expansion valve for evaporating the refrigerant, characterised by the provision of thermoelectric means for reducing the temperature of the refrigerant at the inlet of the expansion valve.

[0006] Preferably the refrigerant is carbon dioxide.

[0007] In one embodiment the thermoelectric means may be provided at or adjacent the outlet of the gas cooler. In an alternative embodiment the thermoelectric means be incorporated within the gas cooler to cool the refrigerant at the outlet of the gas cooler.

[0008] According to a further aspect of the present invention there is provided a transcritical vapour compression cycle for carbon dioxide refrigerant comprising the steps of compressing a superheated refrigerant to increase the temperature, pressure and enthalpy of the refrigerant into the supercritical region, cooling the refrigerant in a gas cooler at a substantially constant pressure, expanding the refrigerant through an expansion valve to a temperature and pressure below the critical values, evaporating the refrigerant in an evaporator/heat exchanger whereby the refrigerant absorbs heat from a cooled space, characterised by the further step using thermoelectric means to further cool the refrigerant exiting the gas cooler thereby reducing the temperature of the refrigerant at the inlet of the expansion valve.

[0009] Two embodiments of the present invention will now be described by way of example only, and with reference to the accompanying drawings in which:

Figure 1a is a pressure-enthalpy diagram of a typical transcritical vapour compression cycle using carbon dioxide as a refrigerant without the use of an internal heat exchanger;

Figure 1b is a pressure-enthalpy diagram of a typical transcritical vapour compression cycle using carbon dioxide as a refrigerant, the cycle including an internal heat exchanger, to improve system performance;

Figure 1c is a pressure-enthalpy diagram of a vapour compression cycle according to the present invention;

Figure 2a is a schematic view of a gas cooler and thermoelectric sub-cooler according to a first embodiment of the present invention;

Figure 2b is a schematic view of a gas cooler and thermoelectric sub-cooler according to a second embodiment of the present invention.

[0010] Figure 1a illustrates a typical transcritical vapour compression cycle for carbon dioxide. Carbon dioxide vapour enters a compressor at point 1. The compressor compresses the vapour whereby its pressure, temperature and enthalpy are increased, using power from a vehicle engine in the case of a vehicle air conditioning system, until it leaves the compressor at point 2 located in the supercritical region. Next the carbon dioxide refrigerant enters a gas cooler, usually water or air cooled, whose function is to transfer heat from the fluid to a coolant (for example air or water) to cool the refrigerant at a constant pressure. The cooled refrigerant leaves the gas cooler at point 3. The refrigerant then undergoes a substantially constant enthalpy expansion process through an expansion valve to reach point 4 in the mixed liquid-vapour region. Finally the refrigerant is vapourised in an evaporator/heat exchanger whereby it absorbs heat from a space to be cooled, for example the vehicle cabin in a vehicle air conditioning system until it enters the compressor again at point 1 and repeats the cycle. The cooling effect of the cycle is represented by the line between points 4 and 1.

[0011] As can be seen from Figure 1a, the cooling effect could be increased by further reducing the temperature/enthalpy of the refrigerant in the gas cooler to move point 3 further to the left.

[0012] Figure 1b illustrates a typical vapour compression cycle for carbon dioxide refrigerant using internal heat exchange to further cool the supercritical refrigerant at the outlet of the gas cooler using refrigerant from the outlet of the evaporator/heat exchanger. The internal heat exchanger cools the refrigerant between points 3a and 3, this heat being transferred to the refrigerant between points 4a and 1 downstream of the compressor.

[0013] The heat removed from the refrigerant at the outlet of the gas cooler by the internal heat exchanger provides an increased cooling effect but since such heat is transferred to the refrigerant at the outlet of the evaporator/heat exchanger, this increases the temperature of the refrigerant and reduces its density at the suction inlet of the compressor, further increasing the temperature of the refrigerant at the outlet of the compressor at point 2. This has an impact on the compressor durability, lubrication characteristics and gas cooler material selection. Analysis of the cycle performance characteristics will show an operating condition point at which the system, operates at optimum cycle efficiency. Away from this point the system efficiency deteriorates.

[0014] Figure 1c illustrates a vapour compression cycle according to the present invention wherein a thermoelectric device is used to sub-cool the refrigerant exiting the gas cooler from point 3a to point 3, thus increasing the cooling effect of the evaporator/heat exchanger between points 4 and 1 without the detrimental increase in the temperature of the refrigerant at the suction inlet of the compressor that occurs in known systems through the use of an internal heat exchanger.

[0015] Thermoelectric cooling devices utilise semiconductor materials to remove heat through the use of electrical energy by the Peltier effect, the theory that there is a heating or cooling effect when electric current passes through two conductors. A voltage applied to the free ends of two dissimilar materials creates a temperature difference. With this temperature difference, Peltier cooling will cause heat to move from one end to the other. A typical thermoelectric cooler will consist of an array of p- and n- type semiconductor elements that act as the two dissimilar conductors. As an electric current passes through one or more pairs of elements, there is a decrease in temperature at the junction ("cold side") resulting in the absorption of heat from the environment. The heat is carried through the cooler by electron transport and released on the opposite ("hot") side as the electrons move from a high to low energy state.

[0016] In an automotive air conditioning system the electrical power for the thermoelectric device can be provided by the vehicle's electrical system, such as alternator and battery, or fuel cell system.

[0017] A first embodiment of the invention is shown in Figure 2a, wherein a thermoelectric device is incorporated into the gas cooler to sub-cool the refrigerant at the exit thereof. The heat exchanger details are shown for information only and other geometrical and design concepts are envisaged.

[0018] A second embodiment of the invention is shown in Figure 2b, wherein the refrigerant passes through a separate thermoelectric sub-cooler downstream of the gas cooler.

[0019] A control device can be provided controlling the operation of the thermoelectric device to provide the level of cooling required to achieve a desired cooling effect or system performance, thus providing a simple and effective control arrangement for the air conditioning system.

[0020] Current transcritical carbon dioxide refrigerant cycles make use on an internal heat exchanger to improve system efficiency and cooling capacity, resulting in drawbacks in terms of excessive compressor outlet temperature and lower refrigerant density at the compressor inlet.

[0021] The present invention, through the use of thermoelectric means in order to cool down the refrigerant leaving the gas cooler, leads to lower compressor outlet temperature, lower refrigerant specific volume at suction point leading to much higher refrigerant mass flow rate and better volumetric efficiency. Furthermore, the use of thermoelectric cooling of the refrigerant enables the degree of refrigerant sub-cooling to be controlled to a desired amount depending on system parameters, ambient conditions, and refrigeration requirements. The present invention also provides improved compressor durability due to the lower temperature of the refrigerant and improved oil quality therein due to the more favourable operating conditions, and also eliminates the impact of high pressure and temperature on the choice of gas cooler material and strength. The present invention also offers the possibility to optimise the use of the thermoelectric element depending on system or performance needs, fan operation, and ambient condition.

Claims

1. A refrigeration system for an air conditioner comprising a compressor for compressing a refrigerant, a gas cooler downstream of the compressor for cooling the refrigerant, an expansion valve downstream of the gas cooler for reducing the pressure of the refrigerant and a heat exchanger or evaporator downstream of the expansion valve for evaporating the refrigerant, **characterised by** the provision of thermoelectric means for reducing the temperature of the refrigerant at the inlet of the expansion valve.

2. A refrigeration system as claimed in claim 1, wherein the refrigerant is carbon dioxide.

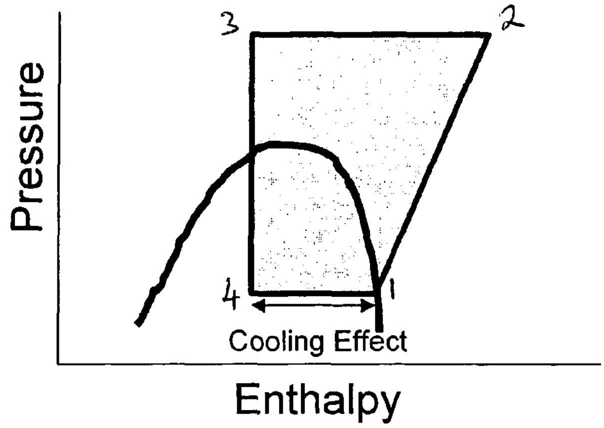
3. A refrigeration system as claimed in any preceding

claim, wherein the thermoelectric means is provided at or adjacent the outlet of the gas cooler.

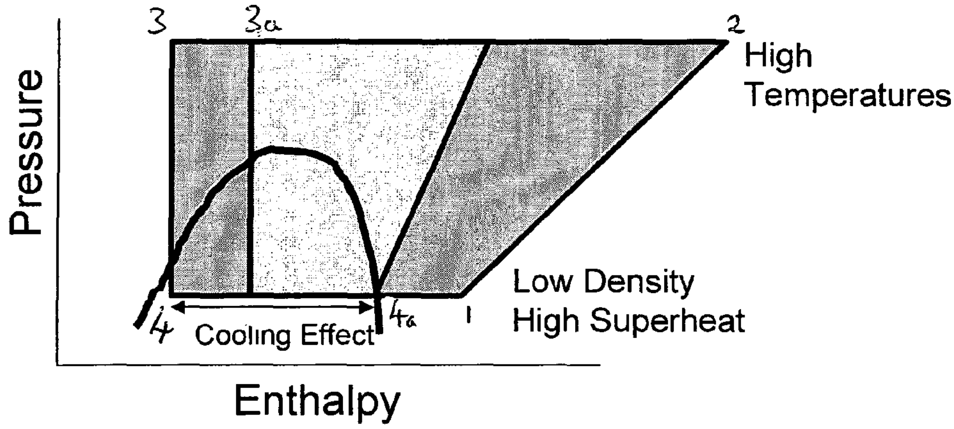
4. A refrigeration system as claimed in claim 1 or claim 2, wherein the thermoelectric means is incorporated within the gas cooler to cool the refrigerant at the outlet of the gas cooler.

5. A refrigeration system as claimed in any preceding claim, wherein control means are provided for controlling the degree of cooling provided by the thermoelectric means to optimise the cooling effect depending on system or performance needs, gas cooler performance, and ambient conditions.

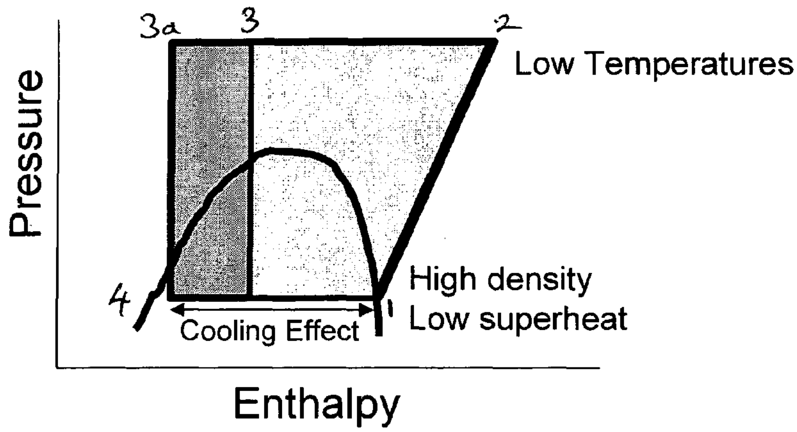
6. A transcritical vapour compression cycle for carbon dioxide refrigerant comprising the steps of compressing a superheated refrigerant to increase the temperature, pressure and enthalpy of the refrigerant into the supercritical region, cooling the refrigerant in a gas cooler at a substantially constant pressure, expanding the refrigerant through an expansion valve to a temperature and pressure below the critical values, evaporating the refrigerant in an evaporator/heat exchanger whereby the refrigerant absorbs heat from a cooled space, **characterised by** the further step using thermoelectric means to further cool the refrigerant exiting the gas cooler thereby reducing the temperature of the refrigerant at the inlet of the expansion valve.



a) CO_2 Cycle without internal heat exchanger

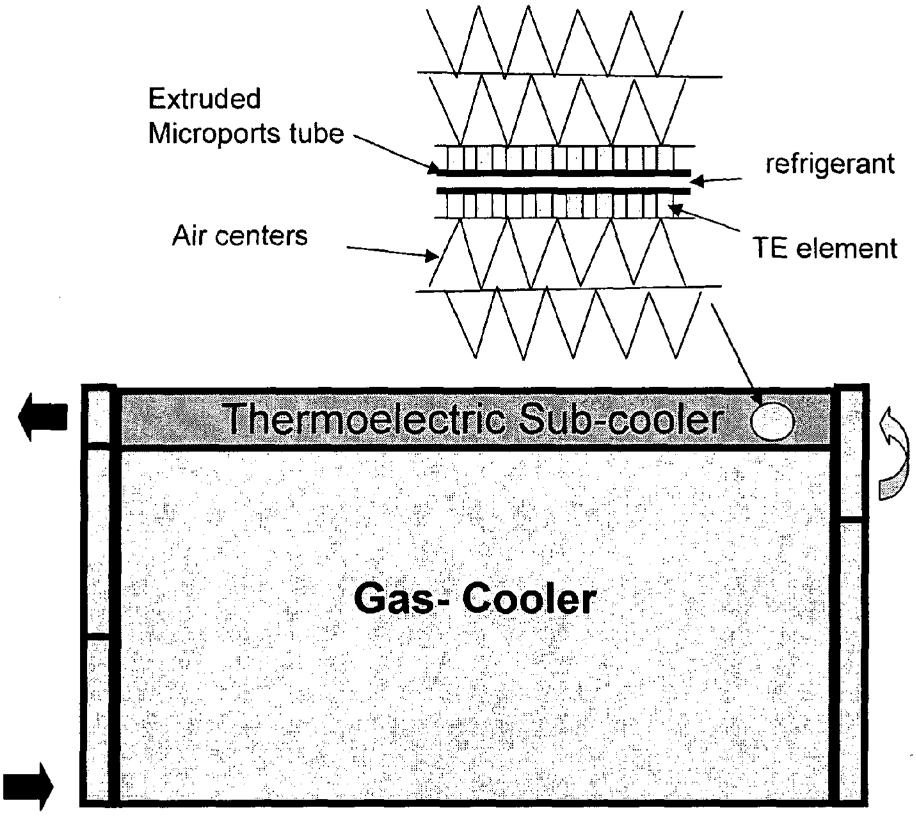


b) CO_2 Cycle with internal heat exchanger

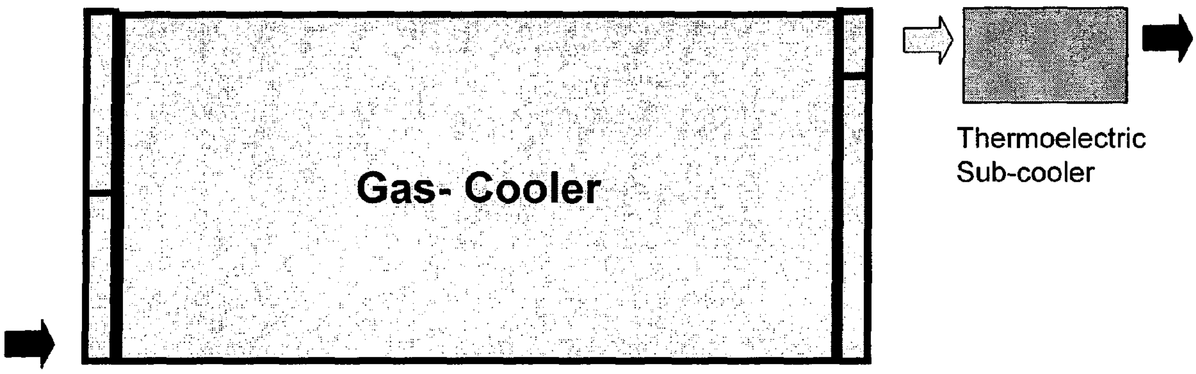


c) CO_2 Cycle with thermoelectric sub-cooling

Fig.-1- Transcritical Cycles



a) Sub-cooler integrated into the gas-cooler



b) Remote sub-cooler. Water or air cooled

Fig.-2- Thermoelectric Sub-cooling concepts

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EUROPEAN SEARCH REPORT

Application Number
EP 04 25 7654

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The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
The Hague	27 April 2005	De Graaf, J.D.

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X : particularly relevant if taken alone
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EPO FORM 1503 03.82 (P04C01)

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