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(54) METHOD FOR OPERATING A COMBINED HEAT AND POWER DEVICE, COMBINED HEAT AND POWER DEVICE AND USE OF A LUBRICANT

(71) Applicant: **Magna Powertrain Bad Homburg GmbH**, Bad Homburg (DE)

(72) Inventors: **Jan Hinrichs**, Friedrichsdorf (DE); **Tilo Schafer**, Daubach (DE)

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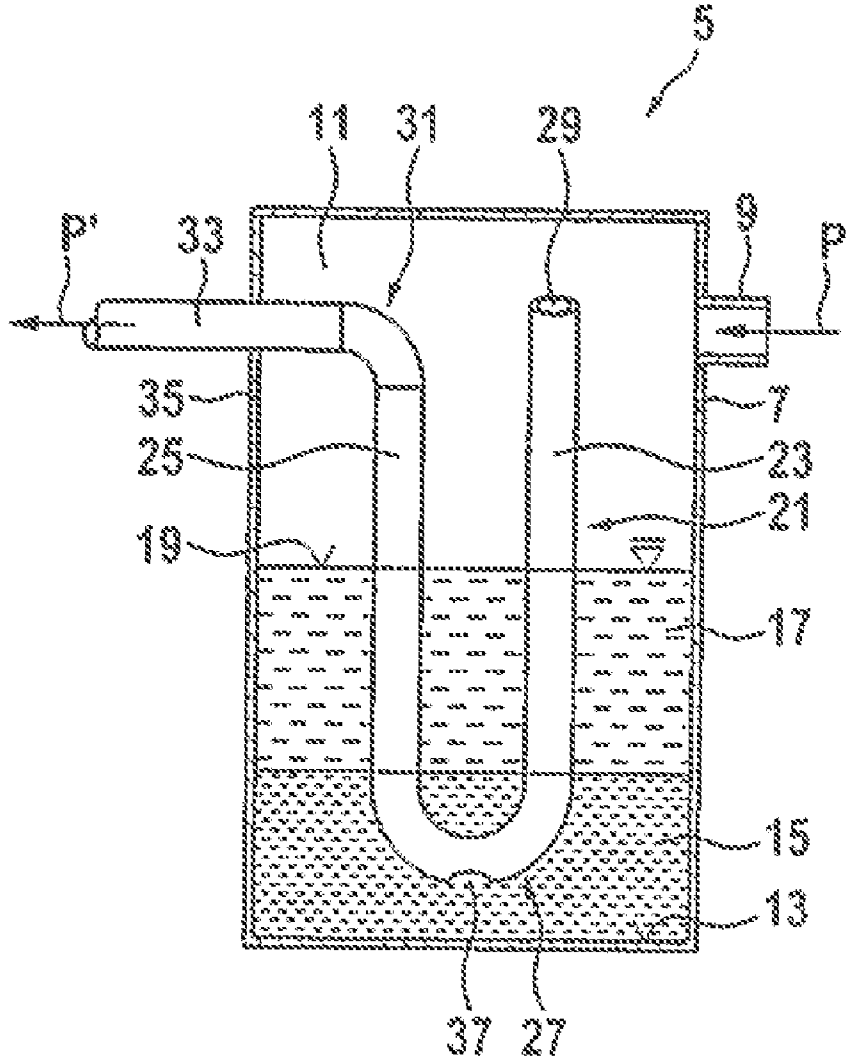
(57) **ABSTRACT**

This disclosure relates to a method for operating a combined heat and power device, wherein carbon dioxide as a refrigerant (**17**) is compressed in a compressor, wherein the carbon dioxide is carried along a refrigerant circuit and routed back to the compressor via a collecting vessel (**5**). The method is distinguished by the fact that the compressor is lubricated with a lubricant (**15**) which has a density of more than 1004 g/l, and that a hot gas temperature in the compressor is held below a predetermined value, above which overheating and/or ageing of the lubricant occurs.



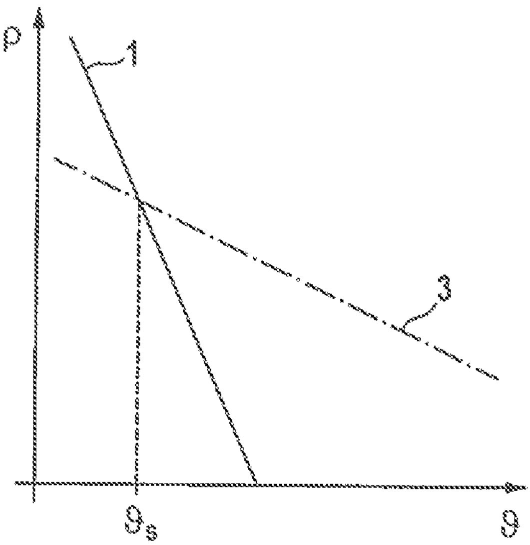


Fig. 1

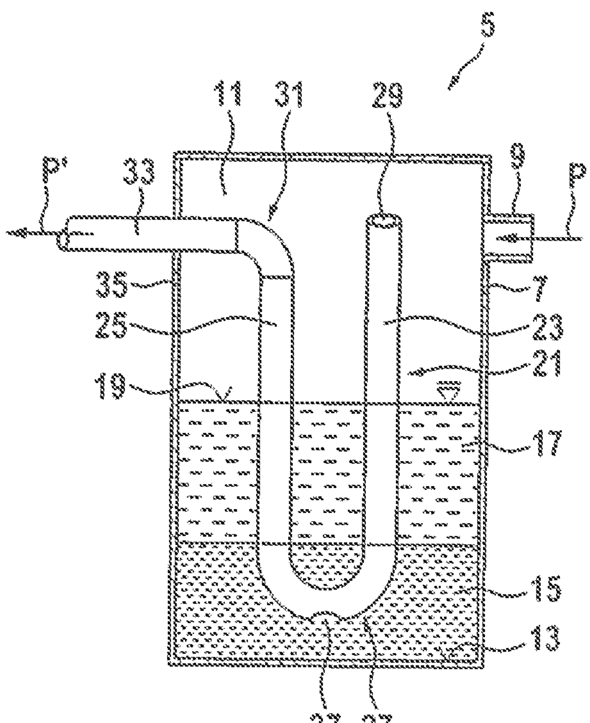


Fig. 2

METHOD FOR OPERATING A COMBINED HEAT AND POWER DEVICE, COMBINED HEAT AND POWER DEVICE AND USE OF A LUBRICANT

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application claims the benefit and priority of German Application No. DE 102013108618.7, filed Aug. 9, 2013. The entire disclosures of the above application is incorporated herein by reference,

FIELD

[0002] The present disclosure relates to a method for operating a combined heat and power device in which carbon dioxide is a refrigerant compressed in a compressor and wherein the compressor is lubricated with a lubricant having a density exceeding 1004 g/l and the hot gas temperature in the compressor is maintained below a predetermined value.

BACKGROUND

[0003] This section provides background information related to the present disclosure which is not necessarily prior art.

[0004] Methods for operating combined heat and power devices, combined heat and power devices themselves and the use of lubricants in connection with such devices are known. A combined heat and power device of this kind, which is designed as an air-conditioning system or heat pump for a motor vehicle, for example, has a refrigerant circuit and a compressor, by which a refrigerant is compressed and delivered along the refrigerant circuit. The refrigerant, which is heated during compression and, in this state, is also referred to as hot gas, is first of all cooled in a first heat exchanger, releasing its heat to a first heat reservoir. Downstream of the first heat exchanger, the cooled compressed refrigerant is expanded, cooling down greatly in the process. The expanded, greatly cooled refrigerant flows through a second heat exchanger, in which it absorbs heat from a second heat reservoir. Downstream of the second heat exchanger, the refrigerant passes into a collecting vessel, wherein liquid and gaseous refrigerant are jointly present at least at this point in the refrigerant circuit. In the collecting vessel, the liquid refrigerant collects at the bottom, while the gaseous refrigerant is carried back to the compressor from the collecting vessel. Combined heat and power devices, in particular air-conditioning systems and/or heat pumps, are distinguished by the fact that the first heat reservoir is at a higher temperature than the second heat reservoir. With the aid of the mechanical work performed in the compressor, heat is accordingly transferred or pumped from the cold second heat reservoir to the hot first heat reservoir. The compressor is lubricated with a lubricant, which partially mixes with the refrigerant and, together with the latter, is delivered along the refrigerant circuit. Thus, a mixture of refrigerant and lubricant enters the collecting, vessel, in which both the liquid refrigerant components and the liquid lubricant settle. Here, a phase stratification is established, depending on the density of the liquid refrigerant, on the one hand, and the density of the liquid lubricant, on the other hand.

[0005] Typically, the collecting vessel, which is also referred to as a receiver, is designed as a closed cylindrical container, in which is arranged a U-shaped tube, the legs of which, which are connected by a curved section, extend in the direction of a longitudinal axis of the cylindrical container. A first leg of the U-shaped tube has an open end, which projects at all times above a maximum level of the liquid phases. Through this open end, the gaseous refrigerant enters the U-shaped tube. The curved region of the U-shaped tube dips into the liquid phases, and a second leg of the U-shaped tube typically re-emerges from the liquid phases. This leg is bent over at the end thereof, wherein, further along, the tube penetrates a wall of the cylindrical container, and, outside the container, is in fluid communication with a fluid path which leads back to the compressor. At its lowest point—as seen in the direction of gravity—the curved region of the U-shaped tube has an opening through which liquid can enter the U-shaped tube from the lower phase of the two liquid phases present in the collecting vessel, as a result of which the components of said liquid phase which enter the U-shaped tube are delivered back to the compressor together with the gaseous refrigerant flowing through the U-shaped tube. The refrigerant, on the one hand, and the lubricant, on the other hand, are chosen so that, under the operating conditions that typically occur, their densities are always such relative to one another that—as seen in the direction of gravity—the lubricant is arranged below the liquid component of the refrigerant, i.e. that the density of the lubricant is always greater than the density of the liquid refrigerant in the collecting vessel. This makes it possible to collect the lubricant delivered along the refrigerant circuit in the collecting vessel and to return it to the compressor through the opening in the U-shaped tube.

[0006] Combined heat and power devices, particularly those for air-conditioning applications in passenger vehicles, which comprise carbon dioxide as a refrigerant, are operated with lubricants that have a density of at least 960 g/l to at most 1004 g/l, for example. The disadvantage here is that these refrigerant devices can only be operated under conditions in which the temperature in the collecting vessel does not fall below −8'C. Below this temperature, there is a reversal in the liquid phase stratification because the density of the liquid refrigerant becomes greater than the density of the lubricant. It is therefore no longer possible to return the lubricant to the compressor and, as a result, the operation of the combined heat and power device is impaired.

[0007] In combined heat and power devices which are operated with refrigerants whose refrigerant circuits have a lower hot gas temperature and consequently a lower temperature of the compressed refrigerant in the compressor than carbon dioxide circuits, e.g. combined heat and power devices having subcritical ammonia or propane circuits, use is made in some cases of lubricants which have a higher density. However, the use of these lubricants in a carbon dioxide circuit is out of the question since the lubricants have a low thermal stability owing to the chemical structure thereof and are overheated or subject to increased ageing at the high hot gas temperature of a carbon dioxide circuit, especially during operation of the combined heat and power device in the transcritical range.

SUMMARY

[0008] This section provides a general summary of the disclosure, and is not a comprehensive disclosure of its full scope or all of its objectives, aspects and features.

[0009] It is the underlying object of the invention to provide a method for operating a combined heat and power device, wherein the combined heat and power device is operated with carbon dioxide as a refrigerant, although its area of application is significantly increased, in particular is extended to temperatures of a cold heat reservoir of below −8° C. It is also an object of the invention to provide a corresponding usable combined heat and power device, and to specify the use of a lubricant in a combined heat and power device of this kind.

[0010] The object is achieved by providing a method having the features of claim **1**. This is distinguished by the fact that the compressor is lubricated with a lubricant which has a density of more than 1004 g/l, wherein the hot gas temperature in the compressor is held below a predetermined value. The predetermined value is chosen in such a way that overheating and/or increased ageing of the lubricant is avoided if the hot gas temperature in the compressor is held below the predetermined value. It has been recognized that the use of a lubricant of this kind is possible, despite the lower thermal stability, if the hot gas temperature in the compressor is held below the predetermined value. In this case, it is namely possible to hold the temperature in a critical region of the combined heat and power device, namely in the compressor, at a level at which the lubricant remains thermally stable. It is therefore possible to use a lubricant which still has a greater density than the liquid refrigerant, even at temperatures of less than −8° C. in the collecting vessel, ensuring that no reversal in the phase stratification occurs and that return of lubricant from the collecting vessel is possible, even at these temperatures. In particular, it is possible to use a low-cost lubricant which, at the same time, has good lubricating properties and good properties in terms of refrigeration. It is possible here to use a lubricant which is actually not envisaged for combined heat and power applications, especially transcritical combined heat and power applications, involving carbon dioxide as the refrigerant, but for applications in which propane or, in particular, ammonia is used as a refrigerant in the subcritical region.

[0011] In the case of the lubricant densities discussed here and below, the density discussed is always that at 15° C.

[0012] In the context of the method, various measures are possible for holding the hot gas temperature in the compressor below the predetermined value: one embodiment of the method envisages that the hot gas temperature should be monitored or controlled, wherein measures are taken if the hot gas temperature approaches the predetermined value in a predetermined way, e.g. exceeds a predetermined limiting value below the predetermined value. It is possible in this case for the capacity of the combined heat and power device to be reduced or adapted in order to prevent any further increase in the hot gas temperature or to lower the latter. As an alternative, it is possible for a cooling device of the combined heat and power device to be activated or for the cooling capacity thereof to be adapted. As a particularly preferred option, the hot gas temperature in the compressor is adjusted to a predetermined setpoint, preferably below the predetermined value. For this purpose, it is possible, in particular, for the capacity of the compressor to be adapted and/or for a cooling device for cooling the compressor to be used. A very simple embodiment of the method envisages that the compressor should be switched off if the hot gas temperature exceeds the predetermined limiting value or the predetermined value, thereby avoiding a further increase in the hot gas temperature at least with the minimum effort.

[0013] Preference is given to a method which is distinguished by the fact that the combined heat and power device is operated in a transcritical range. According to the conventional opinion, it is precisely in this range that it is not possible to use a lubricant which has a density of more than 1004 g/l because this has inadequate thermal stability, and it would therefore overheat or age prematurely at the customarily prevailing hot gas temperature of a transcritical carbon dioxide circuit. However, by limiting the hot gas temperature in the compressor to below the predetermined value it is possible in such an application to use an appropriate low-cost lubricant, while it is simultaneously possible to extend the use of the combined heat and power device to a range in which the cold heat reservoir has a temperature below −8° C., and, in particular, it is also possible for the temperature in the collecting vessel to fall below −8° C. without unwanted reversal in the phase stratification occurring there.

[0014] Preference is given to a method in which the combined heat and power device is operated as an air-conditioning system, especially in a motor vehicle.

[0015] Preference is also given to a method in which the combined heat and power device is operated as a heat pump, especially in a motor vehicle, particularly preferably for heating a driver's cab. In such heat pump applications, in particular, it is possible for an external temperature and hence a temperature of the cold heat reservoir to fall significantly below −8° C.

[0016] The combined heat and power device is preferably operated in a range in which the cold heat reservoir has a temperature of less than −8° C., preferably less than −15° C., preferably less than −20° C., particularly preferably 30° C. or less. As a particularly preferred option, the combined heat and power device has a corresponding temperature in the collecting vessel. In such temperature ranges, it has hitherto not been possible to use combined heat and power devices with carbon dioxide as the refrigerant because, with the lubricants used for the compressor, reversal in the phase stratification would occur in the collecting vessel, preventing the lubricant from being carried back to the compressor.

[0017] It has been realized that it is also possible to use carbon dioxide as the refrigerant in such applications, however, if use is simultaneously made of a lubricant which has a density of more than 1004 g/l at 15° C. This lubricant can be used in a transcritical carbon dioxide circuit if the hot gas temperature in the compressor is held below the predetermined value, ensuring that the lubricant is not overheated or prematurely aged.

[0018] As a particularly preferred option, a temperature difference of at least 60° C. to at most 100° C., preferably of at least 70° C. to at most 90° C., particularly preferably of 80° C., is established and maintained between the cold heat reservoir and the hot heat reservoir with the aid of the combined heat and power device. In a preferred embodiment of the method, e.g. for operation of a heat pump, the cold heat reservoir, in particular an external environment, has a temperature of −30° C., while the hot heat reservoir, which is preferably connected to a feed of a heating medium, in particular a hot water feed, has a temperature of 55° C.

[0019] Preference is given to a method which is distinguished by the fact that a lubricant with a density of at most 1100 g/l, preferably of at least 1010 g/l to at most 1080 g/l, preferably of at least 1020 g/l to at most 1070 g/l, preferably of at least 1030 g/l to at most 1060 preferably of at least 1040 g/l to at most 1050 g/l, and particularly preferably of 1044 g/l, is used.

[0020] In particular, preference is given to a method which is distinguished by the fact that a PAG oil, namely a synthetic oil based on polyalkylene glycols, is used. This preferably has a density of 1044 g/l.

[0021] As a particularly preferred option, use is made of lubricant which is characterized by the following parameters: a density of 1044 g/l at 15° C., a Cleveland flashpoint of 250° C., a kinematic viscosity at 40° C. of 70 mm2/s, a kinematic viscosity at 100° C. of 14.0 mm2/s, a viscosity index of 210 and a pour point of −52° C.

[0022] Preference is also given to a method which is distinguished by the fact that the compressor is cooled with a liquid coolant, preferably a water/glycol mixture. This makes it possible to hold the hot gas temperature in the compressor at a level at which the lubricant remains thermally stable, in particular below the predetermined value. Use is preferably made of a compressor which has a compressor unit and an electric motor that drives the compressor unit. The electric motor is cooled by the liquid coolant. Merely cooling the electric motor reduces the operating temperature in a range in which it would otherwise reach critical values for the lubricant. This is because, in a preferred illustrative embodiment of the refrigerant device, the lubricant also enters the electric motor, in particular because a lubricant sump, i.e. a storage area for the lubricant, is preferably arranged in the electric motor. It is furthermore found that the cooling of the electric motor also has the effect of reducing the operating temperature of the compressor unit and hence the hot gas temperature of the refrigerant, thus ensuring that there is a reduced temperature acceptable for the lubricant prevailing in the region of the compressor unit.

[0023] In this context, preference is given to a method which is distinguished by the fact that a flow of the liquid coolant through the compressor is subjected to open-loop and/or closed-loop control in such a way that the hot gas temperature in the compressor is held below the predetermined value. Closed-loop control of flow is thus preferably provided in order to ensure that the temperature in the compressor does not at least rise beyond a value critical for the lubricant and is preferably held constant at a temperature uncritical for the lubricant. Preferably, a flow of the liquid coolant through a liquid cooling jacket of the electric motor is subjected to closed-loop control.

[0024] Finally, preference is given to a method which is distinguished by the fact that a flow of the liquid coolant through the compressor is subjected to closed-loop control in such a way that the carbon dioxide is compressed isentropically in the compressor. The closed-loop control of flow in the region of the compressor or in the region of the liquid cooling jacket of the electric motor accordingly ensures that compression of the refrigerant takes place in a substantially isentropic manner, wherein substantially very little or no heat exchange with the environment takes place during the compression of the refrigerant. Substantially adiabatic or isentropic compression is thus preferably achieved in the compressor unit.

[0025] The object is also achieved by providing a combined heat and power device having the features of claim **8**. This comprises a refrigerant circuit, which has a collecting vessel. A compressor is provided, by means of which the refrigerant can be compressed and delivered along the refrigerant circuit. The combined heat and power device comprises carbon dioxide as a refrigerant. It is characterized by a lubricant for the compressor which has a density of more than 1004 g/l. The combined heat and power device furthermore has a temperature limiting device for limiting the hot gas temperature in the compressor. The temperature limiting device is designed to hold the hot gas temperature below a predetermined value. In this case, the predetermined value is chosen in such a way that overheating and/or increased ageing of the lubricant is avoided. There are advantages in respect of the combined heat and power device, and these have already been explained in connection with the method.

[0026] It is possible for the temperature limiting device to be designed as a control unit of the combined heat and power device or to be integrated into a control unit of the combined heat and power device. It is also possible for the temperature limiting device to interact with the control unit of the combined heat and power device to limit the hot gas temperature. In one illustrative embodiment of the combined heat and power device, it is possible for the temperature limiting device to be designed only to limit the hot gas temperature to an upper limit. In one illustrative embodiment, the combined heat and power device is switched off by the control unit or adapted in terms of its capacity if the hot gas temperature in the compressor exceeds the predetermined value or a predetermined limiting value below the predetermined value. In another illustrative embodiment, it is possible for the temperature limiting device to comprise a cooling device by means of which the compressor can be actively cooled. As a particularly preferred option, the temperature limiting device is designed to exercise open-loop or closed-loop control over the hot gas temperature in the compressor. It is possible here to include the control unit of the combined heat and power device and the cooling device in the open-loop or closed-loop control system, wherein the control unit is used, for example, to adapt the capacity—and, in the case of closed-loop control, also to raise the hot gas temperature if required.

[0027] The combined heat and power device is preferably designed as an air-conditioning system, in particular for a motor vehicle, or as a heat pump, in particular for a motor vehicle. It is preferably configured for transcritical or supercritical operation of the carbon dioxide circuit.

[0028] Preference is given to a combined heat and power device which is distinguished by the fact that the lubricant has a density of at least 1004 g/l to at most 1100 g/l, preferably of at least 1010 g/l to at most 1080 g/l, preferably of at least 1020 g/l to at most 1070 g/l, preferably of at least 1030 g/l to at most 1060 g/l, preferably of at least 1040 g/l to at most 1050 g/l, particularly preferably of 1044 g/l.

[0029] In this context, preference is also given to a combined heat and power device which is distinguished by the fact that the lubricant is a lubricating oil based on polyalkylene glycols, namely a "PAG oil", preferably with a density of 1044 g/l.

[0030] As a particularly preferred option, the lubricant has the following parameters: a density of 1044 g/l at 15° C., a Cleveland flashpoint of 250° C., a kinematic viscosity at 40° C. of 70 mm2/s, a kinematic viscosity at 100° C. of 14.0 mm2/s, a viscosity index of 210 and a pour point of −52° C.,

[0031] Preference is also given to a combined heat and power device which is distinguished by the fact that the compressor is cooled with a liquid coolant. In this case, the temperature limiting device thus preferably comprises a cooling device which is designed to cool the compressor by means of a liquid coolant, in particular a water/glycol mixture.

[0032] In a preferred illustrative embodiment, the compressor has a compressor unit and an electric motor that drives the compressor unit. In this case, the liquid coolant flows around the electric motor, at least locally. The electric motor preferably has a liquid cooling jacket, through which the liquid coolant flows. As already described in connection with the method, it is thereby possible to hold the operating temperature of the electric motor and also that in the compressor unit at a level which is uncritical in respect of overheating and/or ageing of the lubricant.

[0033] Preference is also given to a combined heat and power device which is distinguished by the fact that the temperature limiting device comprises a feed pump for delivering the liquid coolant. With the aid of the feed pump, the liquid coolant is preferably delivered through the liquid cooling jacket of the electric motor. The temperature limiting device preferably has a controllable feed pump. In this case, it is possible with the aid of the controllable feed pump to adjust a flow of the liquid coolant in such a way that a temperature in the compressor is held below the predetermined value above which overheating and/or ageing of the lubricant occurs.

[0034] The description of the method and of the device are to be taken as complementary to one another. This means, in particular, that preference is given to a method which is distinguished by at least one method step that is determined by at least one feature of the refrigerant device, preferably combinations thereof. Conversely, preference is given to a combined heat and power device which is distinguished by at least one feature that is determined by at least one method step, preferably by combinations thereof. Accordingly, in as much as the preferred embodiments of the method relate to the combined heat and power device, or in as much as the preferred illustrative embodiments of the combined heat and power device relate to specific embodiments of the method, these illustrative embodiments or embodiments are each disclosed independently of whether they are described in connection with the method or with the combined heat and power device.

[0035] Finally, the object is also achieved by providing a use of a lubricant having the features of claim **13**. This relates to the use of a lubricant with a density of more than 1004 g/l in a compressor of a combined heat and power device, wherein the combined heat and power device comprises carbon dioxide as a refrigerant, and wherein the compressor has a temperature limiting device for limiting the hot gas temperature in the compressor, which is designed to hold the hot gas temperature below a predetermined value, wherein the compressor is preferably cooled by means of a liquid coolant. It has been realized that the combination of features discussed here can be used to advantage, in particular that a lubricant with a density of more than 1004 g/l can be used in a compressor of a combined heat and power device with carbon dioxide as a refrigerant if the hot gas temperature in the compressor is held below the predetermined value. It is possible here to extend the area of application of the combined heat and power device, in particular to lower temperatures of a cold heat reservoir, as already discussed in connection with the method.

[0036] As a particularly preferred option, the lubricant is used in a compressor in a combined heat and power device which is operated in the transcritical or supercritical range.

[0037] As an alternative or in addition, the lubricant is preferably used in a compressor of a combined heat and power device which is designed as an air-conditioning system, in particular for a motor vehicle, or as a heat pump, in particular for a motor vehicle.

[0038] As an alternative or in addition, the lubricant is particularly preferably used in a compressor of a combined heat and power device which produces a temperature difference of at least 60° C. to 100° C., preferably of at least 70° C. to at most 90° C., particularly preferably of 80° C., between a cold heat reservoir and a hot heat reservoir.

[0039] In this context, the lubricant is particularly preferably used in a compressor of a combined heat and power device which is operated at a temperature of the cold heat reservoir of less than −8° C., preferably less than −15° C., preferably less than −20° C., particularly preferably −30° C. or less. In particular, the cold heat reservoir preferably has a temperature of −30° C., wherein the hot heat reservoir preferably has a temperature of 55° C.

[0040] Preference is also given to a use which is distinguished by the fact that a lubricant with a density of at most 1100 g/l, preferably of at least 1010 g/l to at most 1080 g/l, preferably of at least 1020 g/l to at most 1070 g/l, preferably of at least 1030 g/l to at most 1060 g/l, preferably of at least 1040 g/l to at most 1050 g/l, particularly preferably of 1044 g/l, is formed.

[0041] Finally, preference is given to a use which is distinguished by the fact that use is made of a lubricant designed as a synthetic oil based on polyalkylene glycols, namely a PAG oil, preferably with a density of 1044 g/l.

[0042] As a particularly preferred option, use is made of a lubricant which is characterized by the following parameters: a density of 1044 g/l at 15° C., a Cleveland flashpoint of 250° C., a kinematic viscosity at 40° C. of 70 mm2/s, a kinematic viscosity at 100° C. of 14.0 mm2/s, a viscosity index of 210 and a pour point of −52° C.

[0043] In respect of the use, the same advantages are obtained as have already been explained in connection with the method and the combined heat and power device.

[0044] In other respects, the description of the method, of the combined heat and power device and of the use are to be understood as being complementary to one another. In particular, preference is given here to a use which is characterized by at least one feature which is determined by at least one feature of the combined heat and power device and/or at least one feature of the method, preferably combinations of such features. Accordingly, the lubricant is, in particular, preferably used in a refrigerant device according to one of the illustrative embodiments described here or in the context of a method according to one of the embodiments described here.

[0045] Further areas of applicability will become apparent from the description provided herein. The description and specific examples in this summary are intended for purposes of illustration only and are not intended to limit the scope of the present disclosure,

DRAWINGS

[0046] The invention is explained in greater detail below by means of the drawing, in which:

[0047] FIG. **1** shows a diagrammatic representation of the density of the refrigerant carbon dioxide in the liquid state plotted against temperature, and of the density of a lubricant, likewise plotted against temperature; and

[0048] FIG. **2** shows an illustrative embodiment of a collecting vessel of a combined heat and power device.

DETAILED DESCRIPTION

[0049] Example embodiments are provided so that this disclosure will be thorough, and will fully convey the scope to those who are skilled in the art. Numerous specific details are set forth such as examples of specific components, devices, and methods, to provide a thorough understanding of embodiments of the present disclosure. It will be apparent to those skilled in the art that specific details need not be employed, that example embodiments may be embodied in many different forms and that neither should be construed to limit the scope of the disclosure. In some example embodiments, well-known processes, well-known device structures, and well-known technologies are not described in detail.

[0050] FIG. **1** shows a diagrammatic representation in which the density ρ is plotted against temperature θ. The density profile of liquid carbon dioxide is entered in the diagram as a solid line **1**. The typical density profile of a lubricant against temperature is entered in the diagram as a chain-dotted line **3**. It is apparent that the straight lines represented by lines 1 and 3 have different gradients, both gradients being negative, i.e. the densities both of the liquid carbon dioxide and of the lubricant increase with decreasing temperature. Here, the gradient of the density profile of liquid carbon dioxide is steeper than that of the lubricant. Accordingly, there is a point of intersection of the two straight lines at a temperature θ_s. At a temperature θ that is greater than the temperature θ_s at the point of intersection, the density of the lubricant is always greater than the density of the liquid carbon dioxide. In this case, there is phase stratification in a collecting vessel of a combined heat and power device, in which—as seen in the direction of gravity—the lubricant is arranged underneath and the liquid carbon dioxide on top.

[0051] At a temperature which is less than the temperature θ_s at the point of intersection, on the other hand, the conditions are reversed: here, the density of the liquid carbon dioxide is always greater than the density of the lubricant, and therefore when the temperature in the collecting vessel falls below the temperature θ_s at the point of intersection there is a reversal in the phase stratification, in which case—as seen in the direction of gravity—the liquid phase of the carbon dioxide is arranged at the bottom, while the lubricant is arranged on top.

[0052] Depending on which lubricant is being considered in the particular case, the straight line described by line **3** shifts substantially in parallel and/or the gradient of the straight lines changes, thereby resulting also in a shift in the temperature at the point of intersection. In particular, it is readily apparent from FIG. **1** that the temperature θ_s at the point of intersection falls when line **3** is shifted in parallel towards higher densities.

[0053] As already explained, the lubricants that are typically used to lubricate the compressor in combined heat and power devices operated with carbon dioxide as a refrigerant have a density of about 1004 at 15° C. The temperature θ_s at the point of intersection of the density profile of such a lubricant with the density profile of carbon dioxide is approximately at −8° C. Accordingly, there is a reversal in the phase stratification in the collecting vessel when the temperature there fails below −8° C., as a result of which return of lubricant to the compressor is no longer guaranteed.

[0054] It is assumed that the temperature in the collecting vessel corresponds approximately to the temperature of the cold heat reservoir. Ultimately, the relationships discussed here depend on the temperature in the collecting vessel.

[0055] Use is now preferably made of a lubricant which has a density of 1044 g/l at 15° C. Since this density is greater than the density of the lubricant that is conventionally used, the straight line illustrated by line **3** in FIG. **1** shifts in parallel towards higher densities, with the result that the temperature θ_s at the point of intersection falls. In the case of the lubricant that is preferably used, the temperature θ_s at the point of intersection is preferably −30° C. Accordingly, there is a reversal in the phase stratification in the collecting vessel only below a temperature of −30° C., with the result that—assuming that the temperature in the collecting vessel corresponds substantially to the temperature of the cold heat reservoir but is at most warmer than the latter—the area of application of the combined heat and power device is extended to temperatures of the cold heat reservoir of up to −30° C.

[0056] FIG. **2** shows an illustrative embodiment of a collecting vessel **5** for a combined heat and power device. The collecting vessel **5** is designed as a cylindrical hollow body **7**, into which a feed line **9** opens. As indicated by an arrow P, a mixture of liquid refrigerant, gaseous refrigerant and lubricant flowing in from a second heat exchanger of the combined heat and power device enters an interior **11** of the hollow body **7** through the feed line **9**. In the interior, the liquid components collect in what is the lower area of the vessel **5**—as seen in the direction of gravity—on a bottom **13**, wherein the specific conditions for the operation of the combined heat and power device are chosen in such a way that the lubricant has a higher density at the temperature prevailing in the collecting vessel **5** than the liquid refrigerant, with the result that liquid lubricant **15** is arranged below a phase of liquid refrigerant **17**—as seen in the direction of gravity. The gaseous refrigerant components collect in the gas space above a surface **19** of the liquid refrigerant **17** in the interior **11**.

[0057] To return the gaseous refrigerant and the liquid lubricant **15** to the compressor, use is made of a U-shaped tube **21**, which has a first leg **23** extending substantially parallel to the direction of gravity and a second leg **25** extending substantially parallel to the first leg **23**. The first leg **23** and the second leg **25** are connected to one another by a curved region **27**.

[0058] Both the first leg **23** and the second leg **25** project above the surface **19**. In this arrangement, the first leg **23** has, at its end removed from the curved region **27**, an opening **29**, through which gaseous refrigerant can enter it. At its end removed from the curved region **27**, in a second curved region **31**, the second leg **25** merges into a line **33**, which extends substantially perpendicular to the direction of gravity and penetrates a wall **35** of the hollow body **7**.

[0059] In the curved region **27**—preferably at its lowermost point—the U-shaped tube **21** has an opening, in particular a hole **37**, through which the lubricant **15** can enter the U-shaped tube **21**. Thus, said lubricant is carried back to the compressor along the second leg **25** and the line **33** together with the gaseous refrigerant, this being indicated schematically by an arrow P'.

[0060] It is obviously essential for the ability to function of the lubricant return that the lubricant **15** should always be arranged under the liquid phase of the refrigerant **17**. There must therefore be no reversal in the phase stratification of the liquid phases during the operation of the combined heat and power device because, otherwise, the lubricant **15** will no longer be able to enter the U-shaped tube **21** via the hole **37** and consequently it will also no longer be possible for it to be delivered back to the compressor.

[0061] Conventional heat and power devices, which are operated with carbon dioxide as a refrigerant, can therefore only be operated up to a temperature of the cold heat reservoir or up to a temperature in the collecting vessel **5** which is above or at least −8° C. Hitherto, it has not been possible to use a lubricant with a higher density which has a lower temperature θ_s at the point of intersection with carbon dioxide in order to extend the area of application of the combined heat and power device towards low temperatures because it is known that such lubricants are not stable, especially at hot gas temperatures occurring in transcritical or supercritical carbon dioxide circuits, and overheat or age. Instead, such lubricants have been used in subcritical refrigerant circuits comprising ammonia or propane as a refrigerant, said lubricants incidentally being less expensive.

[0062] It has now been recognized that the temperature in the electric motor and ultimately also the hot gas temperature in a compressor unit driven by the electric motor can be reduced in such a way, by temperature limitation, open-loop or closed-loop temperature control in the region of the compressor, in particular by a cooling system preferably provided in the form of a liquid cooling jacket of the electric motor of the compressor and involving liquid coolant, preferably a water/glycol mixture, that it is possible to use the less expensive lubricants of relatively high density, which are otherwise provided for ammonia and/or propane circuits, with a carbon dioxide circuit as well, in particular a transcritical or supercritical carbon dioxide circuit.

[0063] It is thus possible to use a lubricant of relatively high density but of relatively low thermal stability which is not normally suitable for use in a carbon dioxide circuit, in particular a transcritical or supercritical carbon dioxide circuit (R744 circuit). Through the use of this lubricant, it is possible to shift the reversal in the phase stratification of the liquid phases of the lubricant, on the one hand, and of the refrigerant, on the other hand, in the collecting vessel **5** towards low temperatures, thereby making it possible to operate the combined heat and power device even at a temperature in the collecting vessel of less than −8° C., preferably less than −15° C., preferably less than −2° C., preferably −30° C. or less. In this case, the temperature of the cold heat reservoir is substantially equal to this temperature or lower.

[0064] Overall, it is thus found that it is possible, with the aid of the method of operating a combined heat and power device by monitoring the hot gas temperature and limiting said temperature, in particular by closed-loop control of a coolant flow of the compressor, with the aid of the combined heat and power device and with the aid of the use of a corresponding lubricant, to extend the area of application of the combined heat and power device towards significantly lower temperatures while simultaneously enabling cost savings because a less expensive lubricant of higher density can be used.

[0065] The foregoing description of the embodiments has been provided for purposes of illustration and description. It is not intended to be exhaustive or to limit the disclosure. Individual elements or features of a particular embodiment are generally not limited to that particular embodiment, but, where applicable, are interchangeable and can be used in a selected embodiment, even if not specifically shown or described. The same may also be varied in many ways. Such variations are not to be regarded as a departure from the disclosure, and all such modifications are intended to be included within the scope of the disclosure.

What is claimed is:

1. A method for operating a combined heat and power device, comprising:

compressing carbon dioxide as a refrigerant (**17**) in a compressor;

carrying the carbon dioxide along a refrigerant circuit and routing the carbon dioxide back to the compressor via a collecting vessel (**5**); and

lubricating the compressor with a lubricant (**15**) which has a density of more than 1004 g/l, and holding a hot gas temperature in the compressor below a predetermined value, above which overheating and/or ageing of the lubricant occurs.

2. The method according to claim **1**, wherein the combined heat and power device is operated in a transcritical range, preferably as an air-conditioning system, especially in a motor vehicle, or as a heat pump, especially in a motor vehicle, wherein the cold heat reservoir preferably has a temperature of less than −8° C., preferably less than −15° C., preferably less than −20° C., preferably −30° C.

3. The method according to claim **1** wherein the the lubricant (**15**) with a density of at most 1100 g/l, preferably of at least 1010 g/l to at most 1080 g/l, preferably of at least 1020 g/l, to at most 1070 g/l, preferably of at least 1030 g/l to at most 1060 g/l, preferably of at least 1040 g/l to at most 1050 g/l, particularly preferably of 1044 g/l, is used.

4. The method according to claim **3** wherein a PAG oil with a density of 1044 g/l is used as the lubricant (**15**).

5. The method according to claim **1** wherein the compressor is cooled by a liquid coolant, wherein the compressor used is preferably one which has a compressor unit and an electric motor that drives the compressor unit, wherein the electric motor is cooled by the liquid coolant, preferably by a water/glycol mixture.

6. The method according to claim **6**, wherein a flow of the liquid coolant through the compressor, preferably through a liquid cooling jacket of the electric motor, is subjected to open-loop and/or closed-loop control in such a way that the hot gas temperature in the compressor is held below the predetermined value.

7. The method according to claim **5**, wherein a flow of the liquid coolant through the compressor is subjected to closed-loop control in such a way that the carbon dioxide is compressed isentropically in the compressor.

8. A combined heat and power device, comprising:

a refrigerant circuit, which has a collecting vessel (**5**);

a compressor for compressing a refrigerant (**1**) and for delivering the refrigerant (**17**) along the refrigerant circuit wherein the combined heat and power device has carbon dioxide as a refrigerant (**17**);

a lubricant (**15**) for the compressor which has a density of more than 1004 g/l; and

a temperature limiting device for limiting the hot gas temperature in the compressor, said device being designed to hold the hot gas temperature below a predetermined value.

9. The combined heat and power device according to claim **8** wherein the lubricant (**15**) has a density of at most 1100 g/l, preferably of at least 1010 g/l to at most 1080 g/l, preferably of at least 1020 g/l to at most 1070 g/l, preferably of at least 1030 g/l to at most 1060 g/l, preferably of at least 1040 g/l to at most 1050 g/l, particularly preferably of 1044 g/l.

10. The combined heat and power device according to claim **9** wherein the lubricant (**15**) is a PAG oil with a density of 1044 g/l.

11. The combined heat and power device according to claim **8** wherein the compressor is cooled by a liquid coolant, wherein it preferably has a compressor unit and an electric motor that drives the compressor unit, wherein the liquid coolant flows around the electric motor, at least locally, wherein the electric motor preferably has a liquid coding jacket, through which the liquid coolant flows.

12. The combined heat and power device according to one of claim **8** wherein the temperature limiting device comprises a feed pump, preferably a controllable feed pump, for delivering the liquid coolant.

13. Use of a lubricant (**15**) with a density of more than 1004 g/l in a compressor of a combined heat and power device, which comprises carbon dioxide as a refrigerant (**17**), wherein the compressor has a temperature limiting device for limiting the hot gas temperature in the compressor, which is designed to hold the hot gas temperature below a predetermined value, wherein the compressor is preferably cooled by means of a liquid coolant.

14. Use according to claim **13**, characterized in that a lubricant (**15**) with a density of at most 1100 g/l, preferably of at least 1010 g/l to at most 1080 g/l, preferably of at least 1020 g/l to at most 1070 g/l, preferably of at least 1030 g/l to at most 1060 g/l, preferably of at least 1040 g/l to at most 1050 g/l, particularly preferably of 1044 g/l, is used.

15. Use according to claim **14**, characterized in that a PAG oil with a density of 1044 g/l is used as a lubricant (**15**).

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