(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
31 May 2019 (31.05.2019)

WIPO | PCT

(10) International Publication Number
WO 2019/100122 A1

(51) International Patent Classification:
F25B 39/04 (2006.01) *F25B 9/00* (2006.01)
F28B 1/06 (2006.01) *F28D 5/00* (2006.01)

(21) International Application Number:
PCT/AU2018/051262

(22) International Filing Date:
27 November 2018 (27.11.2018)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
2017904783 27 November 2017 (27.11.2017) AU

(71) Applicant: **GLACIEM COOLING TECHNOLOGIES** [AU/AU]; 16 Graham Place, Prospect, South Australia 5082 (AU).

(72) Inventor: **HUDSON, Julian**; 16 Graham Place, Prospect, South Australia 5082 (AU).

(74) Agent: **GRIFFITH HACK**; GPO Box 4164, Sydney, New South Wales 2001 (AU).

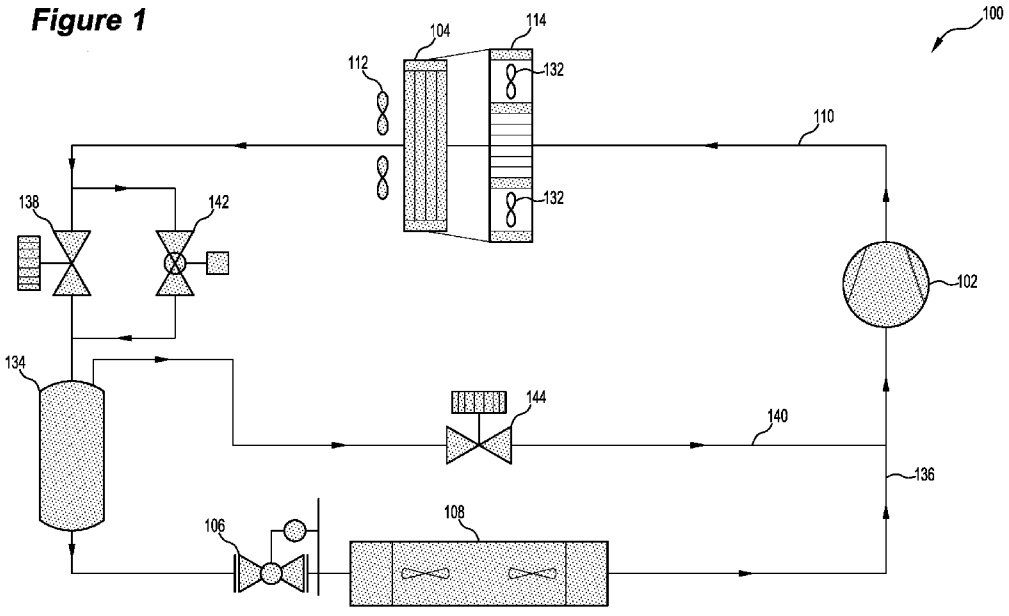
(81) Designated States *(unless otherwise indicated, for every kind of national protection available)*: AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DJ, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IR, IS, JO, JP, KE, KG, KH, KN, KP, KR, KW, KZ, LA, LC, LK, LR, LS, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(84) Designated States *(unless otherwise indicated, for every kind of regional protection available)*: ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, ST, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, KM, ML, MR, NE, SN, TD, TG).

Published:
— *with international search report (Art. 21(3))*

(54) Title: REFRIGERATION SYSTEM

Figure 1



(57) **Abstract:** Disclosed is a CO2 based refrigeration system comprising a condenser for transferring heat from a CO2 refrigerant of the refrigeration system to an air stream. The system further comprises an indirect evaporative cooler arranged to cool an air stream and supply the cooled air to the condenser to facilitate the transfer of heat from the CO2 refrigerant.

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REFRIGERATION SYSTEM

TECHNICAL FIELD

This disclosure relates to refrigeration systems and, in particular, refrigeration systems that make use of carbon dioxide (hereinafter referred to as "CO_2") as a refrigerant.

BACKGROUND ART

The vapour compression cycle has been used extensively in the refrigeration industry for many years. The cycle typically employs the continuous flow of refrigerant between four primary components; a metering device, evaporator, compressor and condenser.

The type of refrigerant employed in this cycle varies depending on the application and the refrigeration temperature required. Typically synthetic refrigerants such as CFC's, HCFC's and HFC's have been used. CFC's and HCFC's are in the process of being banned in many countries under the Montreal Protocol due to the ozone depleting potential (ODP) of such refrigerants. Similarly, HFC's are being phased out in those same countries under the Kigali Amendment to the Montreal Protocol due to their high global warming potential (GWP). This phase out in the use of synthetic refrigerants due to their environmental impact has resulted in increased interest in the use of natural refrigerants such as carbon dioxide (CO_2), ammonia and hydrocarbons.

In low ambient temperature environments, CO_2 refrigeration systems can be more efficient than synthetic refrigerant systems, and for this reason such systems have mostly been used in cooler climates. However, in higher ambient temperatures, the efficiency of CO_2 systems can drop significantly. This reduction in efficiency at higher ambient temperatures is due to the low critical temperature of CO_2 (approximately 31°C) when compared to other refrigerants. The critical

temperature of a refrigerant is the temperature above which that refrigerant exists in a supercritical state. When a refrigerant is in this state, it is unable to be condensed in the condenser and the efficiency of the system drops significantly.

In refrigeration systems the condenser condenses the refrigerant by transferring heat from the refrigerant to a cooling medium (e.g. air or water). This heat exchange is induced by a temperature difference between the cooling medium and the refrigerant. Because the temperature of the cooling medium is often dependent on the ambient temperature of the immediate environment, when ambient temperatures are higher (such as in hotter climates), it is increasingly difficult to maintain CO_2 refrigerant in a subcritical state. For example, ambient temperatures of above 25°C can result in difficulty maintaining the CO_2 refrigerant below its critical temperature.

It is to be understood that, if any prior art is referred to herein, such reference does not constitute an admission that the prior art forms a part of the common general knowledge in the art, in Australia or any other country.

SUMMARY

Disclosed is a CO_2 based refrigeration system comprising a condenser for transferring heat from a CO_2 refrigerant of the refrigeration system to an air stream. The system further comprises an indirect evaporative cooler arranged to cool an air stream and supply the cooled air to the condenser to facilitate the transfer of heat from the CO_2 refrigerant.

As should be appreciated by the skilled person, the term "condenser" encompasses gas coolers. The term gas cooler is used to describe a condenser that is operating under conditions where the refrigerant received by the condenser is supercritical rather than subcritical (i.e. such that it is simply cooled rather than condensed). The condenser, or gas cooler, may be an air-cooled condenser. The condenser may alternatively be a water-cooled condenser and heat may be exchanged between the water and the cooled air.

The provision of cooled (rather than ambient) air to the condenser may allow the CO_2 refrigerant to be maintained in a subcritical state, even under ambient conditions that would otherwise lead to a CO_2 refrigerant temperature above the critical temperature of CO_2 (31°C).

The use of an evaporative cooler for cooling the air can enable the use of CO_2 refrigerant in a broader range of ambient conditions, and can provide an alternative to systems that make use of non-natural refrigerants (such as CFC's, HCFC's and HFC's) that can be harmful to the environment. The use of an evaporative cooler for cooling the air can also be more efficient than other cooling systems, such that the efficiency benefits gained by the use of CO_2 as a refrigerant are not lost within the process of cooling the air supplied to the condenser. The use of an indirect evaporative cooler can, in some circumstances, be more cost effective than other cooling systems.

As should be appreciated, the refrigeration system may also be suitable for (and configured for) various applications, including residential air conditioning, commercial air conditioning (including e.g. cool rooms, chilled cabinets, etc.) and vehicle air conditioning.

In one embodiment, the indirect evaporative cooler may comprise a first channel (e.g. a dry channel) for receipt of a first air stream from an air source and a second channel (e.g. a wet channel) separate to the first channel. The second channel may be for receipt of a second air stream and may comprise a wetted surface for supplying water to the second air stream by way of evaporation. The indirect evaporative cooler may further comprise a heat exchanger for exchanging heat between the first and second channels. As is discussed further below, at least a portion of the first and/or second air stream may be supplied to the condenser to facilitate transfer of heat from the CO_2 refrigerant. Preferably, however, at least a portion of the first air stream may be supplied to the condenser to facilitate transfer of heat from the CO_2 refrigerant.

In this way, the second air stream may be cooled by the evaporation process (i.e. due to energy being transferred from the air and water due to the phase change). Because of a temperature difference between the cooled second air stream and the first air stream (which is initially at the temperature of the air source), heat is transferred from the first air stream to the cooler second air stream. The evaporation process reduces the dry bulb temperature of the second air stream, but the wet bulb temperature generally remains the same (because of the increase in the moisture entrained in the air). However, in the case of the first air stream, both the wet bulb and dry bulb temperatures are reduced, because the heat loss is a result of heat exchange with the second air stream rather than due to an evaporative process. Hence, the moisture content of the first air stream remains the same.

For brevity, only one pair of first and second channels is discussed, but the refrigeration system may comprise a plurality of first channels and a plurality of second channels that are arranged in various configurations. For example, each first channel may be adjacent (and may exchange heat with) a plurality of second channels and vice versa.

As should be apparent, the system as disclosed herein requires minimal energy input. The minimal energy input is mostly required by and limited to the energy required to move the air through the channels, but also includes energy for e.g. supply of the water to the second channel.

In one embodiment, the indirect evaporative cooler may comprise a diverter to divert at least a portion of the first air stream into the second channel such that the second air stream comprises the diverted portion of the first air stream. The entire first air stream may be diverted, or only a portion of the air stream may be diverted. This may allow the air supplied to the condenser to be cooled to a temperature that is below the wet bulb temperature of the air source (which is not possible with a direct evaporative process). This is because, the cooling (by heat exchange) of the first air stream lowers both the dry bulb and wet bulb

temperature. Thus, the diverted portion of the first air stream (which becomes the second air stream) has a lower wet bulb temperature than the air source. This reduces the minimum temperature to which the second air stream can be cooled and, in turn, reduces the temperature to which the first air stream can be cooled (by heat exchange with the second air stream).

This arrangement may improve the ability of the system to maintain the temperature of the CO_2 below the critical temperature, so as to maintain the CO_2 refrigerant leaving the condenser in a subcritical state. To an extent, the arrangement may allow the CO_2 refrigerant to be maintained in this state regardless of the ambient air conditions (e.g. temperature and humidity). Hence, the system may be suitable for use in locations that are otherwise unsuitable for CO_2 refrigeration systems.

In one embodiment, the first air stream of the indirect evaporative cooler may comprise the cooled air supplied to the condenser for condensing of the CO_2 refrigerant. In another embodiment, the second air stream may comprise the cooled air supplied to the condenser for condensing of the CO_2 refrigerant. In another embodiment the first and second air streams may comprise the cooled air supplied to the condenser for condensing of the CO_2 refrigerant.

In one embodiment, the system may further comprise a controller arranged to control the supply of cooled air to the condenser. The controller may be a programmable logic controller (PLC). The system may further comprise a fan to move air through the indirect evaporative cooler. The fan may be a centrifugal fan. The fan may be a backward curved centrifugal fan.

In one embodiment, the controller may be configured to control the fan to control movement of air through the indirect evaporative cooler. In this way, the power input to the fan may be controlled, and the temperature and pressure of the air supplied by the indirect evaporative cooler may be controlled so as to maximise the efficiency of the refrigeration system.

In one embodiment, the controller may be configured to control a condenser fan for moving air across coils of the condenser. The condenser fan may be a centrifugal fan. The fan may alternatively be a backward curved centrifugal fan. In some circumstances, a centrifugal fan may provide lower operating power requirements than an axial fan, because of the pressure drop induced by the indirect cooler.

In one embodiment, the controller may be configured to control the supply of cooler air to the condenser based on the relative humidity and temperature of the air source. Again, this may allow the controller to control the system so as to maximise the efficiency of the system. The relative humidity and temperature may be used to determine a condition of the air (e.g. temperature) being supplied to the condenser.

In one embodiment, the controller may be configured to maintain the temperature of the refrigerant in the condenser below a predetermined threshold temperature. The controller may be configured to maintain the temperature of the refrigerant below the critical temperature of the refrigerant. The controller may be configured to maintain the temperature of the refrigerant below a temperature of at least between 30°C.

In one embodiment, the refrigeration system may comprise one or more sensors for measuring the temperature and relative humidity of the air source. The sensors may be positioned at an inlet of the indirect evaporative cooler. The sensors may communicate sensed data to the controller in a wired or wireless manner.

In one embodiment, the refrigeration system may further comprise a metering device (e.g. a high pressure expansion valve) downstream of the condenser. The metering device may be configured to cause supercritical refrigerant, when received from the condenser, to condense. The metering device may, for example, liquefy the supercritical refrigerant by way of throttling. The metering

device may provide a backup solution for when the indirect evaporative cooler is unable to maintain the CO_2 in a subcritical state.

In one embodiment, the refrigeration system may further comprise a bypass valve. The bypass valve may be configurable between a first position and a second position. In the first position refrigerant may bypass the metering device. In the second position, the refrigerant may pass through the metering device. The bypass valve may be controlled by the controller to move to the first position when the refrigerant is maintained in a subcritical state. The bypass valve may be controlled by the controller to move to the second position when the refrigerant is not maintained in a subcritical state. Such an arrangement may maximise the efficiency of the system when the refrigerant is able to be maintained in a subcritical state, but also allows the system to continue to operate (in a less efficient but useable manner) when the CO_2 refrigerant is not subcritical (e.g. due to conditions of the air source (e.g. extreme conditions) or a system fault).

In one embodiment, the refrigeration system may further comprise a receiver vessel, an expansion valve, an evaporator and a compressor. These components may be disposed in this order (i.e. in the direction of flow of the refrigerant). The refrigeration system may further comprise a bypass line for flash gases formed at the metering device. The bypass line may fluidly connect the receiver vessel to the compressor. Flash gases may form at the metering device due to the pressure drop at the metering device. The flash gases may be separated from the CO_2 refrigerant in the receiver vessel, and can then be directed to the bypass line to bypass the expansion valve and the evaporator. This can avoid a system efficiency loss that could otherwise occur if flash gases pass through the expansion valve.

In one embodiment, the bypass line may comprise a bypass line valve for selectively restricting the flow of flash gases through the bypass line. The bypass line valve may be opened when the refrigerant is in a supercritical state, and may be closed when the refrigerant is in a subcritical state. The bypass valve may be

operated in conjunction with the bypass valve for bypassing the metering device, such that one is closed when the other is open (i.e. to reflect the state of the refrigerant).

In one embodiment, the refrigerant circuit of the refrigeration system may be a closed system.

Also disclosed is a method of operating a CO_2 based refrigeration system. The method comprises supplying a first air stream from an air source and cooling a second air stream by moving the second air stream across a wetted surface. The method further comprises transferring heat between the first air stream and the second air stream, and transferring heat between at least a portion of the first air stream and CO_2 refrigerant in a condenser of the refrigeration system to condense the CO_2.

As is provided above, the evaporative cooling of the second air stream, and the transfer of heat from the first air stream to the second air stream can provide an efficient way to maintain the CO_2 below its critical temperature (31°C). In turn, this may allow the system to operate in an efficient manner (e.g. inefficiency associated with the refrigerant being supercritical may be avoided).

In one embodiment, the method may further comprise diverting a portion of the first air stream. The diverted portion may become the second air stream. In this way, the temperature of the air supplied to the condenser (i.e. for the transfer of heat between the CO_2 refrigerant and the air) can be below the wet bulb temperature of the source (e.g. ambient) air. This may otherwise not be the case with direct evaporative cooling. Thus, the present method may not be limited by the wet bulb temperature of the source air and can allow the refrigerant to remain subcritical in locations where this would otherwise not be possible (e.g. due to climatic reasons).

In one embodiment, the method may further comprise controlling the rate at which air is supplied from the air source and/or the rate at which air is supplied to

the condenser based on a condition of the air source. The condition of the air source may be at least one of the relative humidity and the temperature of the air source. As set forth above, this control may allow the efficiency of the refrigeration system to be maximised (for a particular set of conditions).

In one embodiment, the method may further comprise controlling the rate at which air is supplied from the air source and/or the rate at which air is supplied to the condenser to maintain the refrigerant in a subcritical state.

In one embodiment, the method may further comprise determining whether the CO_2 refrigerant is in a subcritical or supercritical state at the step of transferring heat in the condenser. If the CO_2 refrigerant is determined to be supercritical, the method may comprise reducing the pressure of the CO_2 refrigerant by way of a throttling step, to liquefy at least a portion of the CO_2 refrigerant. Thus, even if the CO_2 refrigerant remains supercritical (e.g. due to system fault or extreme ambient conditions), it may still be liquefied such that the method can still be performed.

Also disclosed is a method of retrofitting a CO_2 refrigeration system. The method comprises arranging an indirect evaporative cooler so as to be in fluid connection with an air-cooled condenser of the refrigeration system for supplying cooled air to the air-cooled condenser. This may allow the refrigeration system to operate in a more efficient manner than prior to the retrofitting.

Also disclosed is a CO_2 based refrigeration system comprising a condenser for transferring heat from a CO_2 refrigerant of the refrigeration system to an air stream, and a metering device downstream of the condenser. The metering device (e.g. a high pressure expansion valve) configured to condense refrigerant from the condenser when received in a supercritical state. The refrigeration system further comprises a bypass arrangement to allow the refrigerant to bypass the metering device.

In one embodiment the bypass arrangement may comprise a valve configurable between a first position and a second position. In the first position, the refrigerant may bypass the metering device. In the second position the refrigerant may pass through the metering device.

In some circumstances, the process of condensing the CO_2 refrigerant can result in efficiency losses. By bypassing the metering device (e.g. when such condensing is not required), these efficiency losses may be avoided. The refrigeration system may comprise fittings and components that are formed of a copper or steel alloy able to withstand high pressures. Such high pressures may be experienced when CO_2 refrigerant received from the condenser does not pass through the metering device (which may reduce the pressure of the CO_2 refrigerant).

In one embodiment the bypass arrangement comprises a bypass line on which the valve disposed.

In one embodiment the refrigeration system may be as otherwise defined above

Also disclosed is a method of operating a CO2 based refrigeration system. The method comprises determining whether CO2 refrigerant being discharged from a condenser of the refrigeration system is in a supercritical state. The method further comprises controlling the system so as to condense the CO2 refrigerant by way of a throttling process when the CO2 refrigerant is determined to be in a supercritical state, and so as to bypass the throttling process when the CO2 is determined to not be in a supercritical state.

BRIEF DESCRIPTION OF THE DRAWINGS

Embodiments will now be described by way of example only, with reference to the accompanying drawings in which:

Figure 1 is a schematic showing a refrigeration system as disclosed herein;

Figure 2 schematic illustrates the operation of an indirect evaporative cooler;

Figure 3 is a schematic showing a method of operating the refrigeration system shown in Figure 1A; and

Figures 4A, 4B and 4C are top, side and perspective views of a condenser/indirect evaporative cooler assembly.

DETAILED DESCRIPTION

In the following detailed description, reference is made to accompanying drawings which form a part of the detailed description. The illustrative embodiments described in the detailed description, depicted in the drawings and defined in the claims, are not intended to be limiting. Other embodiments may be utilised and other changes may be made without departing from the spirit or scope of the subject matter presented. It will be readily understood that the aspects of the present disclosure, as generally described herein and illustrated in the drawings can be arranged, substituted, combined, separated and designed in a wide variety of different configurations, all of which are contemplated in this disclosure.

Figure 1 shows a CO_2 based refrigeration system (i.e. that uses CO_2 as a refrigerant or working fluid) comprising, among other components, a compressor 102, condenser 104, expansion valve 106 and evaporator 108. In general, these components operate in the same manner as in known refrigeration systems.

In operation, CO_2 refrigerant is compressed in the compressor 102, which increases the pressure and temperature of the refrigerant. The refrigerant subsequently flows from the discharge side of the compressor, via a discharge line 110, to the condenser 104 for condensing. In the presently described embodiment the condenser 104 is an air cooled condenser (e.g. comprising a coil block and fans 112 that draw air through the coil block to transfer heat from the coil block).

Condensers generally operate by way of heat transfer between a cooling medium and the refrigerant (in this case CO_2). In an air cooled condenser, such as the condenser 104 illustrated in Figure 1, the cooling medium is an air stream (or a

plurality of air streams) that flows across conduits (e.g. tubes or coils) containing flowing refrigerant. The heat exchange is driven by a difference in temperature between the cooling medium (in this case, air) and the refrigerant. As a result, during operation, the temperature of the refrigerant in the condenser 104 is higher (e.g. by 3-8K) than the temperature of the air stream. Thus, even when the ambient temperature is below the critical temperature of CO_2, the refrigerant temperature can be above the critical temperature (31°C for CO_2), such that the refrigerant exists in a supercritical state. As is set forth above, if the refrigerant is unable to be condensed from a supercritical state to a subcritical state, it can be detrimental to the operation and efficiency of the refrigeration cycle.

To avoid this, or to at least reduce the possibility of this occurring, the presently described embodiment further includes an indirect evaporative cooler 114 that supplies an air stream (or a plurality of air streams) to the condenser 104 for the purpose of transferring heat from the refrigerant. As will be described in further detail below, the indirect evaporative cooler 114 is able to receive an air source (i.e. ambient or outside air) and reduce the temperature of the air, before supplying the cooled air to the condenser 104. In this way, the system 100 is no longer reliant on the ambient temperatures remaining below a particular temperature and, as a result, the refrigerant is able to be maintained in a subcritical state even under high ambient temperatures (e.g. up to 40°C). Thus, the present system 100 may be operated in locations that would otherwise be unsuitable for CO_2 based refrigeration systems.

The indirect evaporative cooler 114 can take various forms, but in general it operates by transferring heat between at least one first air stream that is cooled by an evaporative process, and at least one separate second air stream.

Operation of the indirect evaporative cooler 114 is best described by reference to Figure 2. The indirect evaporative cooler 114 of the present embodiment comprises first and second sets of channels that are formed in pads through which the air is drawn. For illustrative purposes, only one first channel 216 and one

second channel 218 is shown in Figure 2 and described below, but one should be aware that in practice a plurality of first channels and a plurality of second channels may be present. The first channel 216 (or the "dry" channel) is separated from the second channel 218 (or the "wet" channel) by a wall 226 that is water impermeable, but that allows heat transfer between the first 216 and second 218 channels.

In operation, the first channel 216 receives a first air stream 220 from an ambient air source (i.e. at ambient temperature). The second channel comprises wetted surfaces 222 and receives a second air stream 224 that causes water on the wetted surfaces 222 to evaporate. The evaporation process results in sensible heat in the air and water becoming latent heat in the vapour, which causes a reduction in temperature of the air and of the water on the wetted surfaces 222. The difference in temperature between the first 216 and second 218 channels drives heat exchange from the first channel 216 to the associated second channel 218 via a heat exchanger in the form of a channel wall 226 (separating the first 216 and second 218 channels). In this way, the first air stream 220 in the first channel 216 is cooled as it flows along the first channel 216. This cooled air stream 228 is then supplied to the condenser (such as the condenser 104 shown in Figure 1 and described above) for the purpose of transferring heat away from refrigerant in coils, tubes, conduits, etc. of the condenser.

The indirect evaporative cooler also comprises a diverter (not shown) that diverts a portion 230 of the first air stream 220 in each first channel 216 into the second channel 218. In this respect, the diverted portion 230 of the first air stream 220 becomes the second air stream 224 that flows over the wetted surfaces 222 in the second channel 218 (and cools the first air stream 220 via heat exchange across the channel wall 226). The cooled air stream 228 (i.e. that is not diverted) is supplied to the condenser, and the remaining diverted portion (the second air stream 224) is exhausted to the atmosphere, subsequent to it flowing over the wetted surfaces 222.

Such an arrangement means that, in practice, the cooled air stream 228 supplied from the evaporative cooler 114 (e.g. to the condenser) can be at a temperature that is below the wet bulb temperature of the ambient air received by the evaporative cooler 114 (this is not the case with direct evaporative cooling). This is because, as the first air stream 220 is cooled, both the dry and wet bulb temperatures of the first air stream 220 are lowered. Thus, the wet bulb temperature of the second air stream 224 (which is a redirected portion of the first air stream 220) is lower than the ambient wet bulb temperature.

Although not shown, the indirect evaporative cooler 114 further comprises a water supply system that supplies water (e.g. via a pump and spray nozzles) to the second channel 218 (or set of second channels). In some cases, second channels of the indirect evaporative cooler 114 may be oriented to facilitate wetting of the wetted surfaces 222.

Returning back to Figure 1, the indirect evaporative condenser 114 comprises fans 132 that move air through the channels (216, 218), exhausts humid air (224) and supplies cooled air (228) to the condenser 104. The condenser 104 also comprises a centrifugal fan 112 that moves the supplied air across the coils to transfer heat from the coils to the air. Each of the evaporative cooler 132 and condenser 112 fans can be controlled (e.g. by a PLC) to maintain the condenser pressure at a desired level.

As is set forth above, because the indirect evaporative cooler 114 is capable of supplying air to the condenser 104 at temperatures below the wet bulb temperature of the air, it is possible to maintain the CO_2 refrigerant in a subcritical state (i.e. in environments where this would otherwise not be possible due to ambient air temperatures). In this way, inefficiencies associated with supercritical CO_2 refrigerant can be avoided.

Under normal operation, the subcritical CO_2 is condensed to a liquid in the condenser 104, and flows via a number of components (discussed further below) to the expansion valve 106, via a receiver vessel 134. At the expansion valve 106,

the CO_2 refrigerant undergoes a pressure drop and lowers in temperature. The refrigerant subsequently passes through the evaporator 108 and heat is transferred to the refrigerant from the surrounding air or process fluid (i.e. so as to cool the surrounding air or process fluid such as milk, wine, water, etc.). Finally, the refrigerant returns to the compressor 102 via a suction line 136 and the cycle is repeated.

The present system 100 also provides means for handling the CO_2 when in a supercritical state (i.e. under non-normal operation). For this purpose, the system 100 further includes a high pressure expansion valve 138 connected between the condenser 104 and the receiver vessel 134. As is described above, when the CO_2 is supercritical it does not condense into a liquid in the condenser 104. The high pressure expansion valve 138 is configured to create a pressure drop that liquefies the refrigerant, which then flows to the receiver vessel 134 (and subsequently to the expansion valve 106 and evaporator 108).

One consequence of the throttling in the high pressure expansion valve 138 is that it forms a flash gas component, which also flows to the receiver vessel 134 (where it separates from the liquid component). To accommodate the flash gas, the present system further comprises a bypass line 140 connecting the receiver vessel 134 (in which the flash gas is separated from the liquid refrigerant) to the compressor 102. As should be apparent, the flash gas is a portion of the refrigerant that is not useful to the cooling function of the refrigeration system 100 and therefore is representative of an efficiency loss. This loss in efficiency means that the system 102 is more efficient when the CO_2 is maintained in a subcritical state.

Nevertheless, even when in a subcritical state, the throttling effect of the high pressure expansion valve 138 results in a reduction in efficiency of the system 100. To avoid this, the present system 100 further includes a first bypass valve 142 that allows the refrigerant to bypass the high pressure expansion valve 138. The first bypass valve 142 may avoid (unnecessary) efficiency losses that would

otherwise be present due to the CO_2 refrigerant passing through the high pressure expansion valve 138. The refrigeration system 100 may comprise fittings and components able to withstand the high pressure of the CO_2 bypassing the high pressure expansion valve 138 (e.g. the fitting and components may comprise a copper or steel alloy).

The system 100 also includes a second bypass valve 144 positioned on the bypass line 140 (between the receiver vessel 134 and the compressor 102) that provides control of refrigerant flow on the bypass line 140.

In this way, when the refrigerant is subcritical (e.g. because the indirect evaporative cooler 114 is operating to maintain it in this state), the first bypass valve 142 can be opened, and the second bypass valve 144 can be closed. This avoids efficiency losses due to throttling in the high pressure expansion valve 138, and closes the bypass line 140 (which is not required, because no flash gases are produced). Conversely, when the refrigerant is supercritical, the first bypass valve 142 can be closed, and the second bypass valve 144 can be opened such that the supercritical refrigerant flows through the high pressure expansion valve 138, and the flash gases (created by the throttling effect) are able to flow from the receiver 134 to the compressor 102 via the bypass line 140.

This operation of the valves is depicted in Figure 3, which is a schematic showing exemplary operation of the refrigeration system 100. The control methodology 346 includes detecting ambient air conditions 348 (i.e. the conditions of the air received by the indirect evaporative cooler 114 for cooling). These conditions may be, for example, the humidity and the temperature of the ambient air and may be detected by suitable sensors (these sensors are discussed in more detail with reference to Figures 4A, B and C).

The detected conditions can then be used to determine the conditions at the condenser inlet 350, which can in turn be used to determine whether the CO_2 refrigerant is in a supercritical state 352.

If the CO_2 refrigerant is supercritical, then the first bypass valve 142 on the high pressure expansion valve bypass (which is normally configured in an open position) is closed 354, which causes refrigerant to flow through the high pressure expansion valve 138. This allows the supercritical CO_2 refrigerant to be liquefied by the high pressure expansion valve 138. At the same time, the second bypass valve 144 on the bypass line 140 is opened 356, which allows the flash gas component (formed at the high pressure expansion valve 138) to bypass the expansion valve 106 and the evaporator 108. That is, the flash gas flows, via the bypass line 140, directly to the compressor 102.

An alert may also be raised 358 to notify an operator that the system 100 is operating in a supercritical state. The operator can then correct any issues that might be causing the system 100 to run in this state (i.e. apart from extreme climate conditions).

If, on the other hand, the CO_2 refrigerant is determined to be in a subcritical state, the indirect evaporative cooler fan 132 and the condenser fan 112 may be controlled 360, 362 (depending on the detected ambient air conditions) to achieve a desired condenser pressure for maximising efficiency of the system 100.

Figure 4 depicts an exemplary indirect evaporative cooler 414 and condenser 404 assembly 464 that may be used in a refrigeration system, such as the refrigeration system 100 described above. The assembly 464 comprises a plurality of sensors that can communicate data to a controller (not shown) so that the condenser 404 and indirect evaporative cooler 414 can be controlled in a manner that e.g. maximises efficiency of the system.

The assembly 464 comprises a humidity and temperature sensor 466 disposed at an inlet of the indirect evaporative cooler 414. This sensor 466 measures the humidity and temperature of the ambient air that is supplied to the indirect evaporative cooler 414. The assembly 464 also comprises condenser outlet 468 and condenser inlet 470 temperature sensors that detect the temperature of air entering and leaving the condenser 404. Also provided is an indirect evaporative

cooler inlet pressure sensor 472, an indirect evaporative cooler exhaust pressure sensor 474, a condenser pressure sensor 476 and a condenser fan pressure sensor 478.

The data from these sensors is transmitted (e.g. wirelessly or via wired connection) to a controller. The controller makes use of this data to control aspects of the assembly, such as the condenser fans 412 and/or indirect evaporative cooler fans 432 to maximise efficiency.

Variations and modifications may be made to the parts previously described without departing from the spirit or ambit of the disclosure.

For example, the system may include additional components not discussed above, or may be configured in an alternative manner.

The indirect evaporative cooler may be arranged alternatively to that described above. For illustrative purposes, Figure 2 shows a single dry (first) channel and a single wet (second) channel, but it should be understood that the indirect evaporative cooler can comprise a plurality of dry channels and a plurality of wet channels. For example, each dry channel may be adjacent to a plurality of wet channels (and vice versa).

Similarly, it may not be necessary that a portion of the first air stream be diverted to form the second air stream. Instead, the first (dry) air stream and second (wet) air stream may remain separate so as to be in a cross-flow arrangement. The first and second air streams may not be parallel to one another, and may instead be e.g. perpendicular to one another.

Further, and as would be appreciated by the skilled person, the means for providing water to the channels may be other than via spray nozzles.

In the claims which follow and in the preceding description, except where the context requires otherwise due to express language or necessary implication, the word “comprise” or variations such as “comprises” or “comprising” is used in an inclusive sense, i.e. to specify the presence of the stated features but not to

preclude the presence or addition of further features in various embodiments of the CO_2 based refrigeration system.

CLAIMS

1. A CO_2 based refrigeration system comprising:

a condenser for transferring heat from a CO_2 refrigerant of the refrigeration system to an air stream; and

an indirect evaporative cooler arranged to cool an air stream and supply the cooled air to the condenser to facilitate the transfer of heat from the CO_2 refrigerant.

2. A refrigeration system according to claim 1 wherein the indirect evaporative cooler comprises:

a first channel for receipt of a first air stream from an air source;

a second channel separate to the first channel, the second channel for receipt of a second air stream and comprising a wetted surface for supplying water to the second air stream by way of evaporation; and

a heat exchanger for exchanging heat between the first and second channels.

3. A refrigeration system according to claim 2 wherein the indirect evaporative cooler comprises a diverter to divert at least a portion of the first air stream into the second channel, whereby the second air stream comprises the diverted portion of the first air stream.

4. A refrigeration system according to claim 2 or 3 wherein the first air stream of the indirect evaporative cooler comprises the cooled air supplied to the condenser for condensing of the CO_2 refrigerant.

5. A refrigeration system according to any one of the preceding claims comprising a controller arranged to control the supply of cooled air to the condenser.

6. A refrigeration system according to claim 5 comprising a fan to move air through the indirect evaporative cooler.

7. A refrigeration system according to claim 6 wherein the controller is configured to control the fan to control movement of air through the indirect evaporative cooler.

8. A refrigeration system according to any one of claim 5 to 7 wherein the controller is configured to control a condenser fan for moving air across coils of the condenser.

9. A refrigeration system according to any one of claims 6 to 8 wherein the controller is configured to control the supply of cooler air to the condenser based on the relative humidity and temperature of the air source.

10. A refrigeration system according to any one of claims 5 to 9 wherein the controller is configured to maintain the temperature of the refrigerant in the condenser below a predetermined threshold temperature.

11. A refrigeration system according to any one of the preceding claims comprising one or more sensors for measuring the temperature and relative humidity of the air source.

12. A refrigeration system according to any one of the preceding claims further comprising a metering device downstream of the condenser, the metering device configured to cause supercritical refrigerant, when received from the condenser, to condense.

13. A refrigeration system according to claim 12 comprising a bypass valve configurable between:

a first position in which refrigerant bypasses the metering device; and

a second position in which the refrigerant passes through the metering device.

14. A method of operating a CO_2 based refrigeration system, the method comprising:

supplying a first air stream from an air source;

cooling a second air stream by moving the second air stream across a wetted surface;

transferring heat between the first air stream and the second air stream;

transferring heat between at least a portion of the first air stream and CO_2 refrigerant in a condenser of the refrigeration system to condense the CO_2.

15. A method according to claim 14 further comprising diverting a portion of the first air stream, the diverted portion comprising the second air stream.

16. A method according to claim 14 or 15 further comprising controlling the rate at which air is supplied from the air source and/or the rate at which air is supplied to the condenser based on a condition of the air source.

17. A method according to claim 16 wherein the condition of the air source is at least one of relative humidity and temperature of the air source.

18. A method according to claim 16 or 17 comprising controlling the rate at which air is supplied from the air source and/or the rate at which air is supplied to the condenser to maintain the refrigerant in a subcritical state.

19. A method according to any one of claims 14 to 18 further comprising determining whether the CO_2 refrigerant is in a subcritical or supercritical state at the step of transferring heat in the condenser.

20. A method according to claim 19 wherein, if the CO_2 refrigerant is determined to be supercritical, the method further comprises reducing the pressure of the CO_2 refrigerant by way of throttling, to liquefy at least a portion of the CO_2 refrigerant.

21. A method of retrofitting a CO_2 refrigeration system, the method comprising arranging an indirect evaporative cooler so as to be in fluid connection with an air-cooled condenser of the refrigeration system for supplying cooled air to the air-cooled condenser.

22. A method according to claim 21 wherein the indirect evaporative cooler is as set forth in any one of claims 1 to 13.

23. A CO_2 based refrigeration system comprising:

a condenser for transferring heat from a CO_2 refrigerant of the refrigeration system to an air stream;

a metering device downstream of the condenser, the metering device configured to condense refrigerant, when received in a supercritical state, from the condenser; and

a bypass arrangement to allow the refrigerant to bypass the metering device.

24. A refrigeration system according to claim 23 wherein the bypass arrangement comprises a valve configurable between:

a first position in which refrigerant bypasses the metering device; and

a second position in which the refrigerant passes through the metering device.

25. A refrigeration system according to claim 24 wherein the bypass arrangement comprises a bypass line on which the valve is disposed.

26. A refrigeration system according to any one of claims 23 to 25 that is as otherwise defined in any one of claims 1 to 13.

27. A method of operating a CO_2 based refrigeration system, the method comprising:

determining whether CO_2 refrigerant being discharged from a condenser of the refrigeration system is in a supercritical state; and

controlling the system so as to:

condense the CO_2 refrigerant by way of a throttling process when the CO_2 refrigerant is determined to be in a supercritical state, and

bypass the throttling process when the CO_2 is determined to not be in a supercritical state.

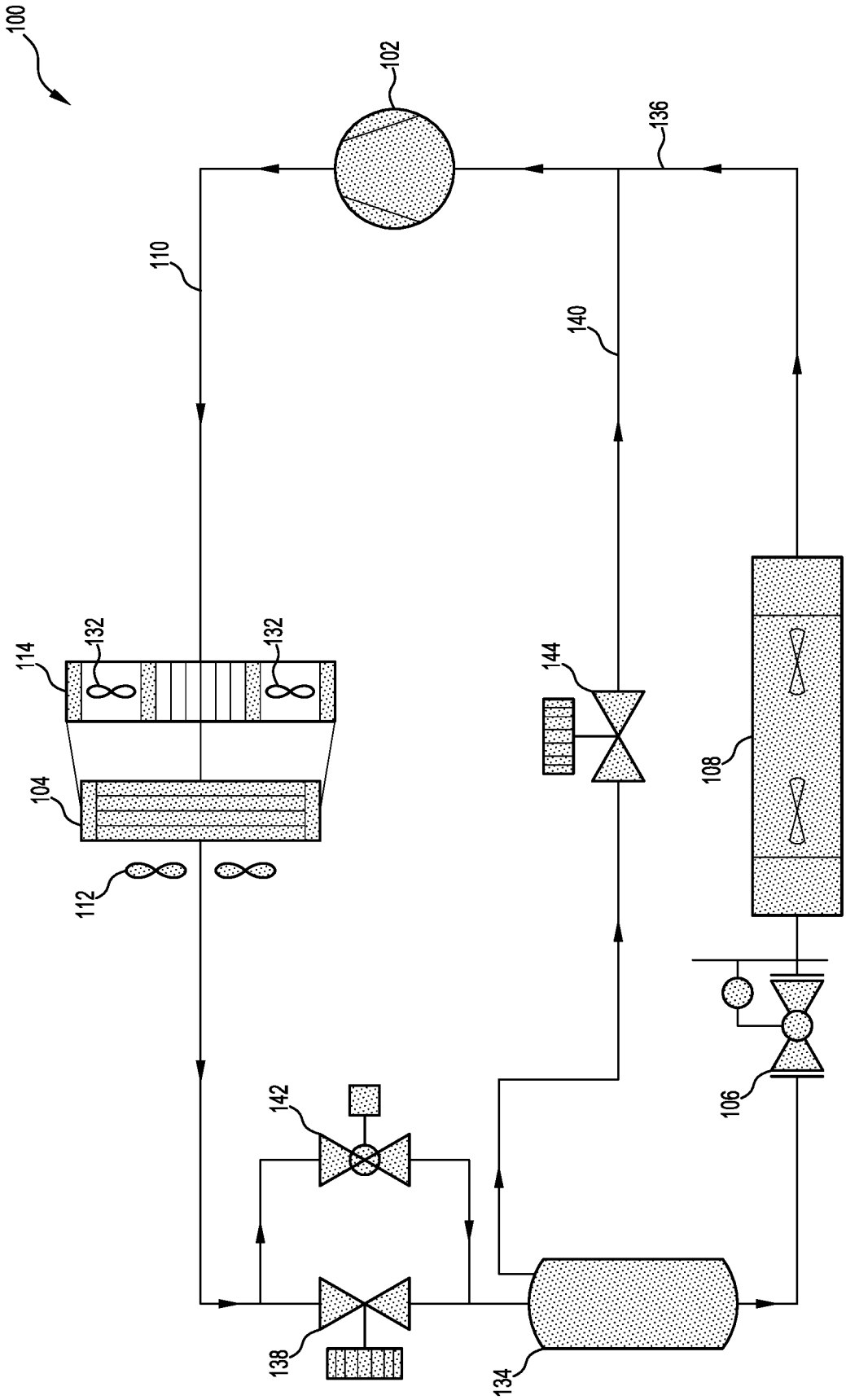


Figure 1

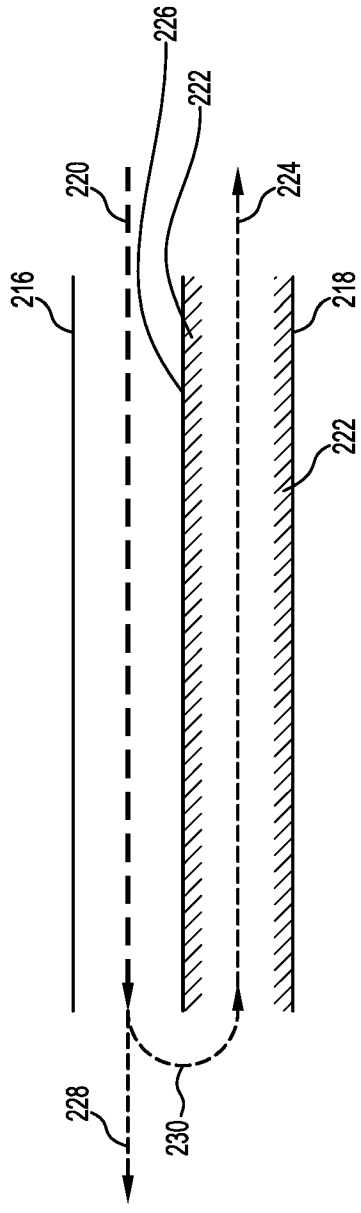


Figure 2

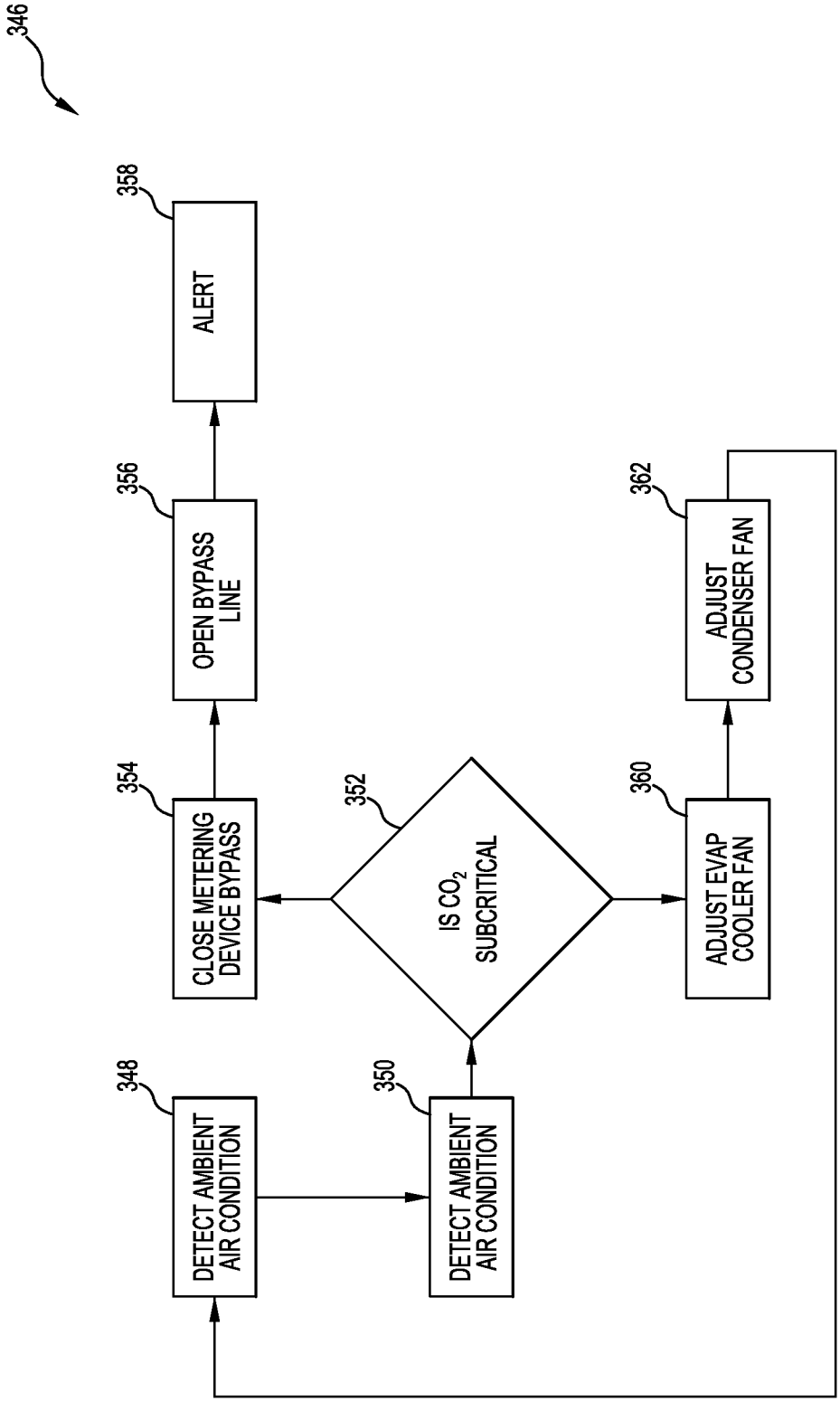

346
358
ALERT
356
OPEN BYPASS LINE
354
CLOSE METERING DEVICE BYPASS
352
IS CO_2 SUBCRITICAL
360
ADJUST EVAP COOLER FAN
362
ADJUST CONDENSER FAN
348
DETECT AMBIENT AIR CONDITION
350
DETECT AMBIENT AIR CONDITION

Figure 3

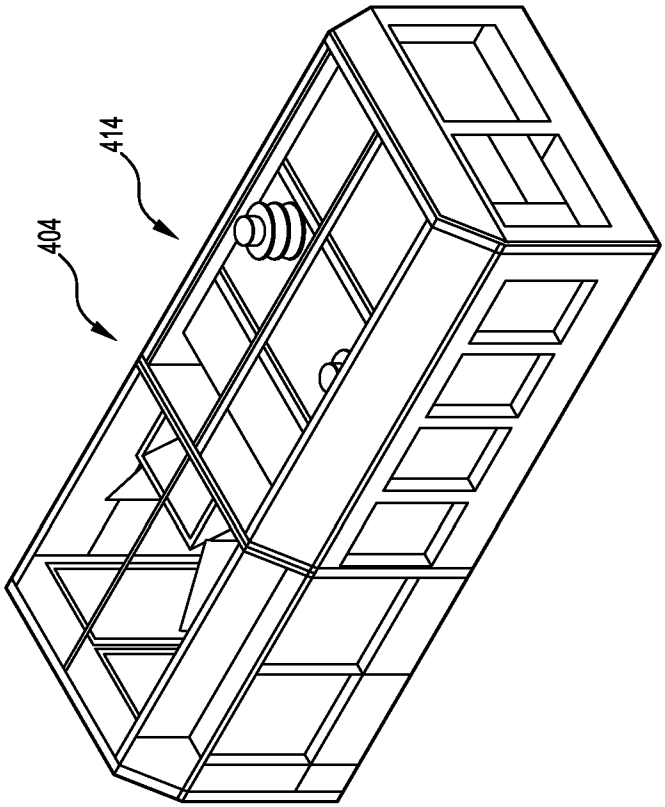


Figure 4C

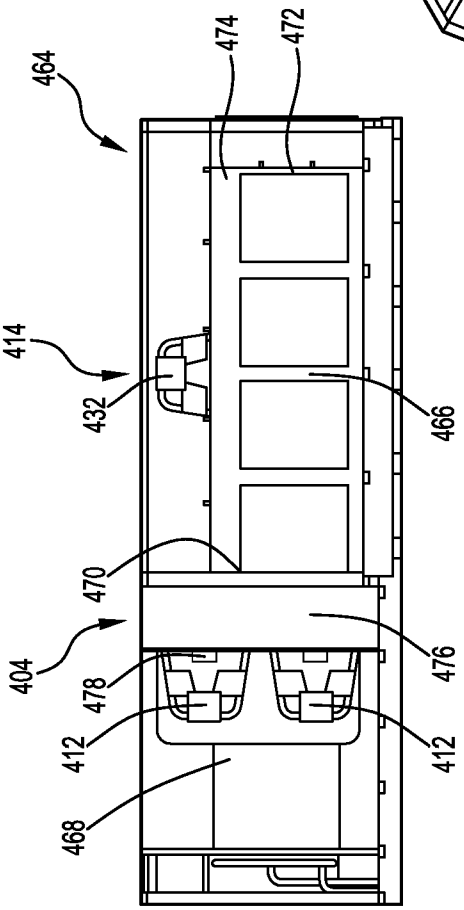


Figure 4A

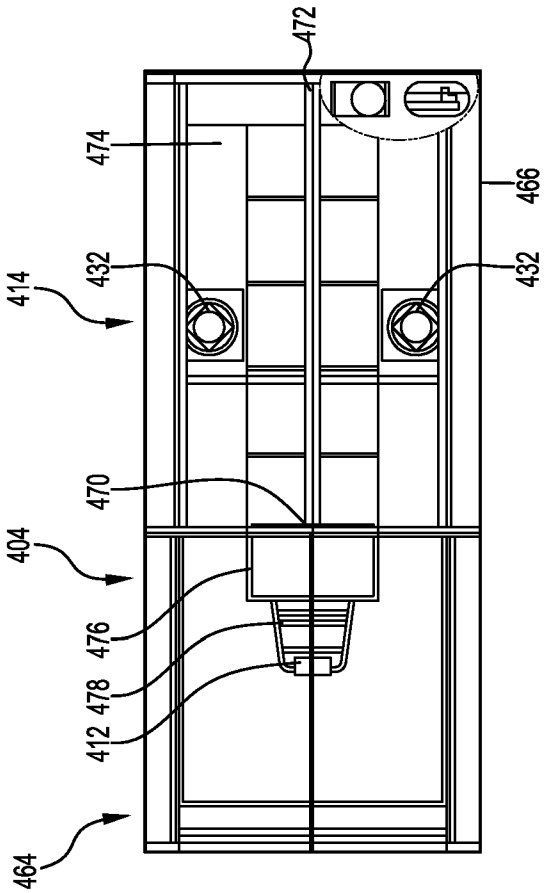


Figure 4B

INTERNATIONAL SEARCH REPORT

International application No.
PCT/AU2018/051262

A. CLASSIFICATION OF SUBJECT MATTER

F25B 39/04 (2006.01) F28B 1/06 (2006.01) F25B 9/00 (2006.01) F28D 5/00 (2006.01)

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

QUE PATENW and XFULL: IPC/CPC marks: F25B, F25B6, F25B7, F25B9, F25B9/008, F25B2309/06, F25B39/04, F25B2339/04, F25B2339/041, F25B2339/047, F28B1/06, F28D5, F24F5, F24F6, F24F12 and keywords (carbon dioxide, air, atmosphere, condenser, radiator, indirect, evaporative, water moisture, wet, tube, conduit, pad, wick, cooling, recycle, supply and like terms); GOOGLE, ESPACENET AND GOOGLE Advanced Patent search with keywords: refrigeration, air condenser, indirect, evaporative, cooling and similar terms Applicant and Inventor name searched using AUSPAT, ESPACENET and internal databases provided by IP Australia.

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
	Documents are listed in the continuation of Box C	

[X] Further documents are listed in the continuation of Box C

[X] See patent family annex

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
6 February 2019	06 February 2019

Name and mailing address of the ISA/AU

AUSTRALIAN PATENT OFFICE
PO BOX 200, WODEN ACT 2606, AUSTRALIA
Email address: pct@ipaustralia.gov.au

Authorised officer

Kosala Gunatillaka
AUSTRALIAN PATENT OFFICE
(ISO 9001 Quality Certified Service)
Telephone No. +61262223652

INTERNATIONAL SEARCH REPORT		International application No.
C (Continuation).	DOCUMENTS CONSIDERED TO BE RELEVANT	**PCT/AU2018/051262**

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	EP 1550829 A1 (MATSUSHITA ELECTRIC INDUSTRIAL CO., LTD.) 06 July 2005 Abstract; Fig. 1; paragraphs [0030] - [0037]	1, 4, 6, 12
X Y	US 4182131 A (MARSHALL et al.) 08 January 1980 Fig. 11 and column 6, lines 17 - 59 As above	1 5, 7 - 11, 21 - 22
X	US 2005/0028545 A1 (HERBERT) 10 February 2005 Figs. 4(a) and 9; paragraphs [0076] and [0085] – [0086]).	1
Y	EP 1688685 A1 (MAYEKAWA MFG. CO. LTD.) 09 August 2006 Abstract; claim 6; Figs. 6 & 11 and paragraphs [0108] - [0113] & [0129]	5, 7 - 11, 21 - 22
A	US 4827733 A (DINH) 09 May 1989 Abstract; Fig. 1; from column 5, line 4 to column 6, line 19	1 - 22
A	EP 1659357 A1 (FUJIKOKI CORPORATION) 24 May 2006 Abstract and Figs. 4 - 5	1 - 22

INTERNATIONAL SEARCH REPORT

International application No.
PCT/AU2018/051262

Box No. II Observations where certain claims were found unsearchable (Continuation of item 2 of first sheet)

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:

because they relate to subject matter not required to be searched by this Authority, namely:

the subject matter listed in Rule 39 on which, under Article 17(2)(a)(i), an international search is not required to be carried out, including

2. ☐ Claims Nos.:

because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:

3. ☐ Claims Nos:

because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a)

Box No. III Observations where unity of invention is lacking (Continuation of item 3 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

See Supplemental Box for Details

1. ☐ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.
2. ☐ As all searchable claims could be searched without effort justifying additional fees, this Authority did not invite payment of additional fees.
3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:

4. ☒ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

1 - 22

Remark on Protest

☐ The additional search fees were accompanied by the applicant's protest and, where applicable, the payment of a protest fee.

☐ The additional search fees were accompanied by the applicant's protest but the applicable protest fee was not paid within the time limit specified in the invitation.

☐ No protest accompanied the payment of additional search fees.

Supplemental Box

Continuation of: **Box III**

This International Application does not comply with the requirements of unity of invention because it does not relate to one invention or to a group of inventions so linked as to form a single general inventive concept.

This Authority has found that there are different inventions based on the following features that separate the claims into distinct groups:

- Group I: Claims 1 – 13, 14 – 20 and 21- 22: Claims 1 – 13 are directed to a CO2 based refrigeration system comprising: a condenser for transferring heat from a CO2 refrigerant of the refrigeration system to an air stream; and an indirect evaporative cooler arranged to cool an air stream and supply the cooled air to the condenser to facilitate the transfer of heat from the CO2 refrigerant. Claims 14 – 20 are directed to a method of operating a CO2 based refrigeration system, the method comprising: supplying a first air stream from an air source; cooling a second air stream by moving the second air stream across a wetted surface; transferring heat between the first air stream and the second air stream; transferring heat between at least a portion of the first air stream and CO2 refrigerant in a condenser of the refrigeration system to condense the CO2. Claims 21 – 22 are directed to a method of retrofitting a CO2 refrigeration system, the method comprising arranging an indirect evaporative cooler so as to be in fluid connection with an air-cooled condenser of the refrigeration system for supplying cooled air to the air-cooled condenser.. The feature of wherein and an indirect evaporative cooler arranged to cool an air stream and supply the cooled air to the condenser to facilitate the transfer of heat from the CO2 refrigerant is specific to this group of claims.

- Group II: Claims 23 – 26 and claim 27: Claims 23 – 26 are directed to CO2 based refrigeration system comprising: a condenser for transferring heat from a CO2 refrigerant of the refrigeration system to an air stream; a metering device downstream of the condenser, the metering device configured to condense refrigerant, when received in a supercritical state, from the condenser; and a bypass arrangement to allow the refrigerant to bypass the metering device. Claim 27 is directed to a method of operating a CO2 based refrigeration system, the method comprising: determining whether CO2 refrigerant being discharged from a condenser of the refrigeration system is in a supercritical state; and controlling the system so as to: condense the CO2 refrigerant by way of a throttling process when the CO2 refrigerant is determined to be in a supercritical state, and bypass the throttling process when the CO2 is determined to not be in a supercritical state. . The feature of the CO2 based refrigerant comprising a condenser, wherein the CO2 refrigerant is received in a supercritical state, and bypassing a metring device or a throttling process is specific to this group of claims.

PCT Rule 13.2, first sentence, states that unity of invention is only fulfilled when there is a technical relationship among the claimed inventions involving one or more of the same or corresponding special technical features. PCT Rule 13.2, second sentence, defines a special technical feature as a feature which makes a contribution over the prior art.

When there is no special technical feature common to all the claimed inventions there is no unity of invention.

In the above groups of claims, the identified features may have the potential to make a contribution over the prior art but are not common to all the claimed inventions and therefore cannot provide the required technical relationship. The only feature common to all of the claimed inventions and which provides a technical relationship among them is a CO2 based refrigeration system comprising, a condenser.

However this feature does not make a contribution over the prior art because it is disclosed in:

D1: EP 1550829 A1 (MATSUSHITA ELECTRIC INDUSTRIAL CO., LTD.) 06 July 2005 (Abstract and paragraphs [0004] - [0010])

Therefore in the light of this document this common feature cannot be a special technical feature. Therefore there is no special technical feature common to all the claimed inventions and the requirements for unity of invention are consequently not satisfied *a posteriori*.

INTERNATIONAL SEARCH REPORT Information on patent family members	International application No. **PCT/AU2018/051262**

This Annex lists known patent family members relating to the patent documents cited in the above-mentioned international search report. The Australian Patent Office is in no way liable for these particulars which are merely given for the purpose of information.

Patent Document/s Cited in Search Report		Patent Family Member/s	
Publication Number	**Publication Date**	**Publication Number**	**Publication Date**
EP 1550829 A1	06 July 2005	EP 1550829 A1	06 Jul 2005
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		JP 2005016779 A	20 Jan 2005
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		WO 2004029516 A1	08 Apr 2004
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US 2005/0028545 A1	10 February 2005	US 2005028545 A1	10 Feb 2005
		US 7150160 B2	19 Dec 2006
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		BR PI0416759 B1	12 Sep 2017
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		EP 1795831 B1	12 Feb 2014
		EP 2570752 A1	20 Mar 2013
		EP 2570752 B1	10 Dec 2014
		JP WO2005050104 A1	07 Jun 2007

Due to data integration issues this family listing may not include 10 digit Australian applications filed since May 2001.

INTERNATIONAL SEARCH REPORT Information on patent family members	International application No. **PCT/AU2018/051262**

This Annex lists known patent family members relating to the patent documents cited in the above-mentioned international search report. The Australian Patent Office is in no way liable for these particulars which are merely given for the purpose of information.

Patent Document/s Cited in Search Report		Patent Family Member/s	
Publication Number	**Publication Date**	**Publication Number**	**Publication Date**
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		TW 200619572 A	16 Jun 2006
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		JP 4494991 B2	30 Jun 2010
		KR 20060052287 A	19 May 2006
		KR 101158802 B1	26 Jun 2012

End of Annex

Due to data integration issues this family listing may not include 10 digit Australian applications filed since May 2001.