(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) **EP 3 587 963 A1**

(12) **EUROPEAN PATENT APPLICATION**

(43) Date of publication:
01.01.2020 Bulletin 2020/01

(21) Application number: **18179422.3**

(22) Date of filing: **22.06.2018**

(51) Int Cl.:
F25B 49/02 *(2006.01)*
F25B 47/00 *(2006.01)*
F25B 47/02 *(2006.01)*

(84) Designated Contracting States:
AL AT BE BG CH CY CZ DE DK EE ES FI FR GB GR HR HU IE IS IT LI LT LU LV MC MK MT NL NO PL PT RO RS SE SI SK SM TR
Designated Extension States:
BA ME
Designated Validation States:
KH MA MD TN

(71) Applicant: **Danfoss A/S**
6430 Nordborg (DK)

(72) Inventors:
- **IZADI-ZAMANABADI, Roozbeh**
  6430 Nordborg (DK)
- **THOMSEN, Carsten Mølhede**
  6430 Nordborg (DK)
- **PRINS, Jan**
  6430 Nordborg (DK)

(74) Representative: **Petersen, Frank**
Danfoss A/S
Nordborgvej 81
6430 Nordborg (DK)

(54) A METHOD FOR INITIATING DEFROSTING OF AN EVAPORATOR

(57) A method for detecting ice accumulation on an evaporator (104) of a vapour compression system (100) is disclosed. The evaporator (104) is part of a vapour compression system (100). The vapour compression system (100) further comprises a compressor unit (101), a heat rejecting heat exchanger (102), and an expansion device (103). The compressor unit (101), the heat rejecting heat exchanger (102), the expansion device (103) and the evaporator (104) are arranged in a refrigerant path, and an air flow is flowing across the evaporator (104). At least one temperature of air leaving the evaporator (104) is measured and a control value based on the measured temperature is derived. Determining whether ice has accumulated on the evaporator (104) by comparing the derived control value and a setpoint value.

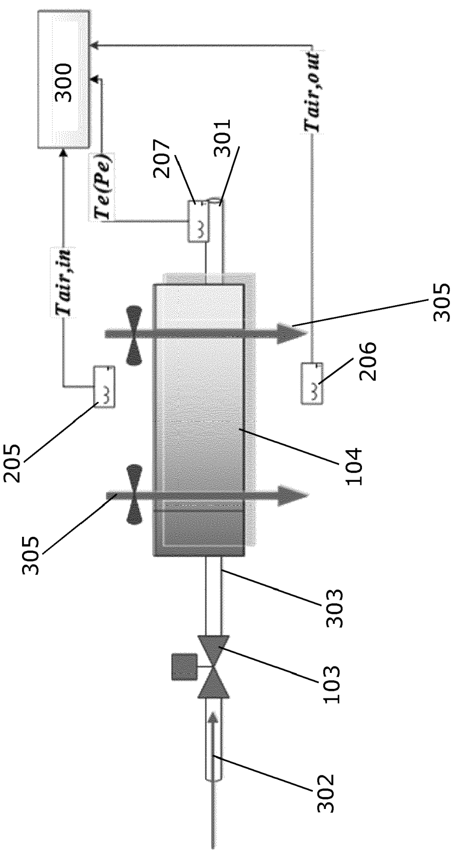


Fig. 3

EP 3 587 963 A1

Description

FIELD OF THE INVENTION

[0001] The present invention relates to a method for detecting ice accumulation on an evaporator of a vapour compression system by measuring at least one temperature of air leaving the evaporator and comparing it with a setpoint value. Defrosting is initiated when the temperature of air deviates from the setpoint value.

BACKGROUND OF THE INVENTION

[0002] Vapour compression systems, such as refrigeration systems, heat pumps or air condition systems, are normally controlled in order to provide a required cooling or heating capacity in an as energy efficient manner as possible. In some scenarios, the operation of the vapour compression system may become energy inefficient, and the system may even become unstable or the system may become unable to provide the required cooling or heating capacity. In particular, during operation of a vapour compression system, such as a refrigeration system with a cooled chamber, ice or frost will deposit on the heat transfer surfaces of an evaporator. Namely, condensation of moisture in the cooled chamber leads to ice accumulation over time on the evaporator in the refrigeration system. Ice buildups disturb air circulation inside the system. This leads to a decrease in cooling efficiency and hence negatively impacts the heat transfer performance. Frost and ice buildups must be recognized before the cooling efficiency of the system has been significantly reduced. Once frost and ice has been identified defrosting needs to be initiated. During defrosting, the evaporator is heated in order to melt ice buildups. It is desired that this defrosting mode starts as soon as ice buildups are identified for a number of reasons. One of the reasons is again energy efficiency and energy consumption. The system does not work optimally when ice covers the evaporator. Furthermore, if defrosting is initiated too late, it can become extremely difficult to remove the ice from the evaporator as it may become excessively thick.

[0003] In commercial and industrial refrigeration systems, initiation of defrosting is typically performed by scheduling it periodically, e.g., once a week or once in several days. This may not be the most efficient way to perform defrosting. In one example, scheduled defrosting may be scheduled too early, when it is not really necessary. In another example, defrosting may be initiated too late, i.e., when a lot of ice has been already accumulated and in such a case, the system is not under optimal conditions for a too long period of time.

[0004] US 2015/0204589 disclose a method including initiating a defrost of a frozen evaporator coil of a refrigerant vapour compression system before ice buildup on the evaporator coil becomes so excessive as to result in an on-off cycling of the refrigerant vapour compression system compressor when operating to a frozen temperature maintenance mode. The defrost of the evaporator heat exchanger coil is initiated if a magnitude of an air flow temperature differential across the evaporator heat exchanger coil at least equals a set point threshold magnitude for the air flow temperature differential, and the magnitude of the evaporator heat exchanger coil refrigerant pressure condition at least equals a set point threshold magnitude for the refrigerant pressure condition.

DESCRIPTION OF THE INVENTION

[0005] It is an object of embodiments of the invention to provide a method for timely detecting ice accumulation on an evaporator of a vapour compression system and initiating defrosting of ice simultaneously.

[0006] The invention provides a method for detecting ice accumulation on an evaporator of a vapour compression system, the vapour compression system further comprising a compressor unit, a heat rejecting heat exchanger and an expansion device, the compressor unit, the heat rejecting heat exchanger, the expansion device and the evaporator being arranged in a refrigerant path, and an air flow flowing across the evaporator, the method comprising the steps of:

- measuring at least a temperature, $T_{air,out}$, of air leaving the evaporator,
- deriving a control value based at least on the measured temperature, $T_{air,out}$,
- comparing the derived control value to a setpoint value, and
- determining that ice has accumulated on the evaporator in the case that the comparing step reveals that the derived control value deviates from the setpoint value.

[0007] The temperature $T_{air,out}$ of air leaving the evaporator is directly affected by ice accumulation and therefore it can either directly or indirectly be used as a control value in detection of ice accumulation on an evaporator. By monitoring the temperature of air leaving the evaporator, while the evaporator operates in a stable, i.e. constant, operating conditions, ice buildups can be timely identified and defrosting can be simultaneously initiated.

[0008] The vapour compression system comprises an evaporator, a compressor unit, a heat rejecting heat exchanger and an expansion device. There may be more than one evaporator and more than one expansion device. The compressor unit may comprise one or more compressors. In the present context the term 'vapour compression system' should be interpreted to mean any system in which a flow of fluid medium, such as refrigerant, circulates and is alternatingly compressed and expanded, thereby providing either refrigeration or heating of a volume. Thus, the vapour compression system may be a refrigeration system, an air condition system, a heat pump, etc.

[0009] The evaporator is arranged in the refrigerant path. Evaporation of a liquid part of the refrigerant takes place in the evaporator, while heat exchange takes place between the refrigerant and the ambient or a secondary fluid flow across the evaporator, in such a manner that heat is absorbed by the refrigerant passing through the evaporator.

[0010] The compressor unit receives the refrigerant from the evaporator. The refrigerant is then normally in gaseous phase and the compressor unit compresses it and supplies it further to the heat rejecting heat exchanger.

[0011] The heat rejecting heat exchanger may, e.g., be in the form of a condenser, in which refrigerant is at least partly condensed, or in the form of a gas cooler, in which refrigerant is cooled, but remains in a gaseous or trans-critical state. The heat rejecting heat exchanger is also arranged in the refrigerant path.

[0012] The expansion device may, e.g., be in the form of an expansion valve. The expansion device is arranged in the refrigerant path, supplying refrigerant to the one or more evaporator. In a vapour compression system, such as a refrigeration system, an air condition system, a heat pump, etc., a fluid medium, such as refrigerant, is thereby alternatingly compressed by means of one or more compressors and expanded by means of one or more expansion devices, and heat exchange between the fluid medium and the ambient takes place in one or more heat rejecting heat exchangers, e.g. in the form of condensers or gas coolers, and in one or more heat absorbing heat exchangers, e.g. in the form of evaporators.

[0013] During ice detection, at least a temperature of air leaving the evaporator, $T_{air,out}$, is measured. The temperature of air leaving the evaporator is directly affected by ice accumulation on the evaporator and therefore it is of relevance to measure at least this temperature. If ice is accumulated on the evaporator, heat transfer through the evaporator gets affected in such a manner that the cooling of the air is not as efficient as in the ice free conditions. Due to a change in the heat transfer, a temperature of cooled air is increased as compared to the ice free conditions, i.e., it is directly affected by the change. If the evaporator operates under the stable conditions, by monitoring the air temperature ice accumulated on the evaporator can be detected.

[0014] The temperature $T_{air,out}$ may be measured by a sensor placed at the air outlet of the evaporator. The temperature of air leaving the evaporator may be monitored all times during the operation of the evaporator. In some cases, this temperature may not be measured during the times when the evaporator is in a defrosting mode.

[0015] The measurement may start from the moment when the defrosting mode is terminated, following a previous defrosting cycle. Alternatively, the temperature measurement may start after a certain period of time upon the termination of the defrosting mode, as upon the defrosting mode temperature, $T_{air,out}$, may go through a transitional phase when its value is not stable. Preferably, the temperature, $T_{air,out}$, may be measured only after a predefined initialization time period, once the evaporator and its tubes reach stable operation, i.e., once a transition phase is over. The predefined initialization time period may be less than an hour, or it may be longer than an hour, such as two hours, or such as three or more hours. In the transition phase, the system dynamics have not settled yet and registered data may not be representative to the expected steady state operating condition the transition phase typically occurs when the evaporator have just finished a defrost period. During the transition period, measurements are typically not carried out, or if the measurements are performed they are not used. Termination of the transition phase may be determined either by defining a predefined waiting period, or by directly analysing the dynamics and comparative behaviour of the measured temperature.

[0016] The temperature, $T_{air,out}$, may be continuously monitored over time during operation of the system. Alternatively, the temperature, $T_{air,out}$, may be measured intermittently, with a certain frequency. The temperature sensor may be placed on the structural support of the evaporator near the air outlet, e.g. directly in the air flow through the evaporator. By placing the temperature sensor directly in the air flow, the measured temperature is the one which is dynamically affected by the heat transfer in the evaporator. The measured temperature $T_{air,out}$ may be communicated to a control unit or a processor.

[0017] The measured temperature, $T_{air,out}$, then serves for derivation of a control value. The control value may also be additionally based on other temperatures related to the evaporator, as well as on other relevant parameters. The control unit or the processor may perform derivation of the control value as a function, f, of various parameters:

$$T_{air,out-ControlValue} = f(T_{air,out-actual}, T_{air,in,,mean,original}, T_{e,mean,original}, T_{air,in,actual}\ , T_{e,actual})$$

[0018] In this case $T_{air,out-ControlValue}$ becomes a control value. When using the above mentioned transformation there is no need to do any manipulation on the original setpoint value, as it may be kept constant.

[0019] A setpoint value is to be interpreted as a value that may be set by a processor or control unit of the vapour compression system representing the system operating in steady state conditions. The setpoint is then compared to the derived control value. The derived control value may be based on prevailing operating conditions of the vapour compression system, such as an outdoor temperature. Alternatively, it could be a fixed value which is set initially when the vapour compression system is installed or it may be calculated under ice free conditions. In any event, the setpoint value should be a value which reflects an expected air temperature during operation under ice free conditions. If operating conditions change, the setpoint may change and therefore may need to be recalculated. In one example, if evaporating pressure changes then measured air temperature changes as well, and if the setpoint is not recalculated ice may erroneously be detected.

[0020] To determine whether ice has accumulated on the evaporator the control value is compared with the setpoint value. In the case that the comparing step reveals that the derived control value deviates from the setpoint value, it may be an indication that ice is accumulated on the evaporator. As mentioned above, the setpoint value reflects the ice free conditions. Therefore, any deviations from the setpoint value indicate deviation from the ice free conditions.

[0021] The method may further comprise the step of deriving the setpoint value from measurements of at least one temperature related to the evaporator under ice free conditions. The setpoint value may be determined based on obtained measurements during a certain time period under the ice free conditions and when the system is operating under the steady state conditions. This time period may be after the transition period. By determining the setpoint value under ice free conditions it is ensured that the ice detection will be accurate as it is performed by comparing the setpoint value, derived under ice free conditions, and the control value, which is obtained from temperature measured at any time during the operation.

[0022] The step of deriving the setpoint value may be repeated, while keeping the control value, $T_{air,out}$, constant. When the operating conditions change, e.g., when pressure levels change, for instance due to changes in outdoor temperature, the air temperature may also change. Then the setpoint value calculated previously for one air temperature may need to be recalculated for the new operating conditions. Alternatively, the setpoint value may be recalculated after a certain time interval, to make sure that the setpoint value corresponds to the current operating conditions and to the ice free evaporator. In one example, the setpoint value derivation may be repeated when sufficient amount of data is registered.

[0023] To derive the setpoint value, energy transfer through the evaporator is considered. The heat transferred from air flowing across the evaporator to the refrigerant can be defined in two ways. One way is to use a log mean temperature difference (LMTD):

$$Q_{air,1} = UA * LMTD, \qquad (1)$$

where U is the heat transfer coefficient [W/(K·M^2)], A is the evaporator area [m^2] and

$$LMDT = \frac{\Delta T_1 - \Delta T_2}{\ln\left(\frac{\Delta T_1}{\Delta T_2}\right)}$$

where $\Delta T_1 = T_{air,in} - T_e$ and $\Delta T_2 = T_{air,out}$ - Te. Te is the evaporation temperature, $T_{air,in}$ is the inlet air temperature, $T_{air,out}$ is the outlet air temperature.

[0024] Another way of defining the heat transfer is by using a given mass flow of air, i.e.:

$$Q_{air,2} = \dot{m}_{air}\, c_{p,air}(T_{air,in} - T_{air,out}), \qquad (2)$$

where $Q_{air,2}$ is the heat transferred through the evaporator for the given mass flow of air $\dot{m}_{air}$. $C_{p,air}$ is the specific heat of the air at constant pressure, $C_{p,air}$ = 1.004 kJ/(kg·K).

[0025] Energy transfer through the evaporator may be defined through energy transferred from the evaporator to the refrigerant. Assuming that the evaporator is a plate separating two media, the refrigerant flowing through the evaporator and the air flowing across the evaporator, the refrigerant having a given temperature, T_e, and the air having a temperature, $T_{air,in}$, the potential heat transferred between these two media and through the evaporator body can be described as:

$$Q_{Tranport} = \mu A(T_{air,in} - T_e), \qquad (3)$$

where μ is the overall heat transfer coefficient calculated by integrating a heat coefficient of the evaporator material over the entire surface of the evaporator.

[0026] Energy consideration and the heat transfer can additionally be described for a given mass flow of refrigerant, $\dot{m}_{ref}$, i.e.:

$$Q_{ref} = \dot{m}_{ref} . \Delta h_{ref}, \qquad (4)$$

where Q_{ref} is the heat transferred through the evaporator for the given mass flow of refrigerant, $\dot{m}_{ref}$, and Δh_{ref} represents enthalpy difference over the evaporator, and where

$$\dot{m}_{ref} = f_{OD}(OD). \sqrt{\rho_l(P_c)(P_c - P_e)} \cong f_{OD}(OD). \rho_l. \sqrt{\Delta P}$$

[0027] The given mass flow of refrigerant, $\dot{m}_{ref}$, is described by a polynomial function f_{OD} related to a density of liquid refrigerant at condensing pressure, P_c, and evaporation pressure, P_e.
and

$$\Delta h_{ref} = h_{2,ref} - h_{1,ref}$$

with

$$h_{1,ref} = f_{h,ref}(P_c, SC) \quad \text{or } h_{1,ref} \cong f_{h,ref}(T_c)$$

and

$$h_{2,ref} = h(P_e, SH)$$

where, Δh_{ref} is the enthalpy difference over the evaporator on the refrigerant side, $h_{1,ref}$, indicates the enthalpy of the refrigerant as the inlet of the evaporator and can be calculated as a function of condensing pressure, P_c and sub-cooling temperature of refrigerant entering the evaporator, SC. Alternatively, it can be calculated as a function of condensing temperature, T_c. $h_{2,ref}$ is enthalpy of the refrigerant at the outlet of the evaporator and is a function of the evaporating pressure, P_e and the superheat temperature of refrigerant leaving the evaporator, SH.

[0028] The above equations (1), (2), (3), and (4) can be used to establish setpoints or residual signals that can be used for ice buildup detection.

[0029] In one embodiment of the invention, equations (1) and (2), describing the energy transfer between air and refrigerant, may be considered. In steady state condition $Q_{air,2} = Q_{air,1}$, i.e.,

$$UA * LMTD = \dot{m}_{air}\, c_{p,air}(T_{air,in} - T_{air,out}).$$

[0030] By isolating the temperatures, the above equation becomes

$$\frac{UA. LMTD}{\dot{m}_{air}\, c_{p,air}(T_{air,in} - T_{air,out})} \cong 1$$

which can be further simplified to:

$$r_{12} = \ln\left(\frac{T_{air,in} - T_e}{T_{air,out} - T_e}\right) \cong \frac{\dot{m}_{air}\, c_{p,air}}{UA}$$

[0031] The above equation can be used to calculate a resulting residual for outlet air temperature, which may be used for detecting ice buildup. Alternatively, the equation may be directly used as a residual signal which may be then used as the control value. The control value may also be $\exp(r_{12})$

[0032] Utilizing equations (2) and (3) a residual value having another form may be derived.

$$\dot{m}_{air}\, c_{p,air}(T_{air,in} - T_{air,out}) = \mu A(T_{air,in} - T_e),$$

$$\frac{\mu A}{\dot{m}_{air}\, c_{p,air}} = \frac{T_{air,in} - T_{air,out}}{T_{air,in} - T_e},$$

$$r_{23} = g_{r23}(T_{air,in}, T_{air,out}, T_e) = \frac{T_{air,in} - T_{air,out}}{T_{air,in} - T_e}$$

[0033] Both r_{12} and r_{23} use the same set of measurements.

[0034] Under steady state conditions the energy delivered by the air should be equal to the energy received by the refrigerant. Comparing equations (2) and (4), i.e. the energy delivered by air to the energy obtained by the refrigerant in the evaporator we have:

$$\dot{m}_{air}\, c_{p,air}(T_{air,in} - T_{air,out}) = \dot{m}_{ref} . \Delta h_{ref},$$

resulting in a residual in the following form

$$r_{24} = g_{r24}(T_{air,in}, T_{air,out}, T_e(P_e), P_c(T_c), SH, SC, OD)$$

r_{12} and r_{23}, r_{24} use the same set of measurements.

[0035] In one embodiment of the invention, the step of deriving a control value may comprise selecting the measured temperature, $T_{air,out}$, as the control value. Ice buildup on fins of the evaporator may result in the deterioration of a heat transfer coefficient with the consequence that the amount of heat transferred to the refrigerant decreases when compared with the ice free operation. The variable that will be directly affected by ice accumulation may be $T_{air,out}$ and therefore it may be directly selected as the control value. Setting the measured temperature of air at the outlet of the evaporator for the control value simplifies the method to great extend and ease requirements for the processor which controls the vapour compression system. Also, by using the residuals r_{12} or r_{23} as the control value, the method is simplified as the residuals depend only on temperatures which can be directly obtained.

[0036] The step of comparing the derived control value to the setpoint value may comprise calculating a residual signal as the difference between the measured temperature, $T_{air,out}$, and the setpoint value, and monitoring the residual value. The residual signal is defined as the deviation of the actual outlet air temperature from its corresponding calculated setpoint value $T_{air,out,SP}$:

$$r = T_{air,out,SP} - T_{air,out}$$

[0037] The corresponding setpoint value may be calculated by using the measured air temperatures at the outlet over a given period of time. The residual signal may then be used in one-sided CUSUM algorithm where statistical information of the air temperature measurements at the outlet is considered and the result of the CUSUM may be used to indicate whether there is ice on the evaporator or not. As mentioned above, ice buildups on the evaporator directly affect the temperature of air leaving the evaporator and by comparing the temperature, $T_{air,out}$, with the setpoint value, presence of ice may be detected. By simple comparison of the measured air temperature and the setpoint value the whole method is simplified as there is no need for particular calculation of the control value from the measured air temperature. If the operation conditions change, the setpoint value may need to be recalculated. The recalculated value may be computed from a function, f, with the following parameters:

$$T_{air,out-setpoint} = f(T_{air,out-setpoint,original}, T_{air,in,,mean,original}, T_{e,mean,original}, T_{air,in,actual}, T_{e,actual})$$

[0038] The updated value of the setpoint involves measurements of the $T_{air,in}$ and T_{e}., i.e., $T_{air,in,actual}$ and $T_{e,actual}$.

[0039] In one embodiment of the invention, the method may further comprise the step of measuring a temperature, $T_{air,in}$, of air entering the evaporator and an evaporation temperature, T_e, of the evaporator, and the step of deriving a control value may be based on the measured temperatures, $T_{air,out}$, $T_{air,in}$ and T_e. The air temperature entering the evaporator, $T_{air,in}$, may be measured with a temperature sensor placed at the inlet of the evaporator and which can monitor the temperature in the same manner as $T_{air,out}$ is monitored. The evaporation temperature, T_e, can be obtained through various sensor measurements. In one example, T_e may be obtained by placing a temperature measurement device at a refrigerant inlet of the evaporator. In another example, T_e may be obtained by use of a pressure measurement at a refrigerant outlet of the evaporator and computing it from the measured pressure. In yet another example, the evaporation temperature may be obtained by a temperature measurement device placed at the refrigerant outlet of the evaporator, if the evaporator is in a flooded state. This temperature is not directly affected by ice buildups, unlike the temperatures of air leaving the evaporator. By measuring at least these three temperatures heat transfer in the evaporator may be precisely monitored.

[0040] In one embodiment of the invention, the step of deriving the control value may comprise calculating the control value, f_r, as a value dependent on all the three measured temperatures, i.e., temperature of air entering the evaporator, temperature of air leaving the evaporator, and the evaporation temperature. The control value may be defined as:

$$\mathrm{fr} = \frac{\mathrm{T_{air,in}} - \mathrm{T_{air,out}}}{\mathrm{LMTD}},$$

where *LMTD* is a log mean temperature difference defined as:

$$\mathrm{LMDT} = \frac{\Delta \mathrm{T_1} - \Delta \mathrm{T_2}}{\ln\left(\frac{\Delta \mathrm{T_1}}{\Delta \mathrm{T_2}}\right)}.$$

where $\Delta T_1 = T_{air,in} - T_e$, and $\Delta T_2 = T_{air,out} - T_e$. The control value f_r then becomes:

$$\mathrm{f}_r = \ln\left(\frac{\Delta \mathrm{T_2}}{\Delta \mathrm{T_1}}\right).$$

[0041] Alternatively, the control value can be chosen to be

$$\mathrm{f'}_r = \mathrm{e}^{\mathrm{f_r}} = \frac{\Delta \mathrm{T_2}}{\Delta \mathrm{T_1}}.$$

[0042] The control value may not be linearly dependent on the temperature difference ΔT_1, or ΔT_2 as it can be seen from the above definition of the control value. The control value may be used for determining whether ice has accumulated on the evaporator or not. Nonlinear dependency between the control value and the temperature difference means that the change in air mass flow is not linearly dependent on the change in the heat flow during the frost generation. In fact, the heat transfer coefficient may be dependent on the evaporator shape, material, and how the ice is accumulated thereon. Furthermore, the accumulated ice may influence the air flow across the evaporator in different ways. These may all be reasons for nonlinear dependency between the control unit and temperatures related to the evaporator.

[0043] The method for detecting ice accumulation on an evaporator of a vapour compression system, may further comprise the step of initiating defrost of the evaporator in the case that it is determined that ice has accumulated on the evaporator. If the control value deviates from the setpoint value, the ice has accumulated on the evaporator and a defrost mode may be initiated. Accumulated ice degrades cooling performance of a cooling system and a timely initiated defrost is of a high importance if energy efficiency is required.

BRIEF DESCRIPTION OF THE DRAWINGS

[0044] The invention will now be described in further detail with reference to the accompanying drawings in which

Fig. 1 shows a simplified diagram of a vapour compression system,

Fig. 2 shows a perspective view of an evaporator (a), (b) and an air flow through the evaporator in a cooling mode (c),

Fig. 3 shows a part of the vapour compression system and its use in the method for ice detection, and

Fig. 4 shows a flow chart with the steps of a method according to an embodiment of the invention for detecting ice accumulation on an evaporator.

DETAILED DESCRIPTION OF THE DRAWINGS

[0045] Fig. 1 shows a simplified diagram of a vapour compression system 100 comprising a compressor unit 101, a heat rejecting heat exchanger 102, an expansion device 103 and an evaporator 104. The compressor unit 101 shown in Fig. 1 comprises two compressors. It is noted that it is within the scope of the present invention that the compressor unit 101 comprises only one compressor, e.g. a variable capacity compressor, or that the compressor unit 101 comprises three or more compressors. Refrigerant flowing through the system 100 is compressed by the compressor unit 101 before being supplied to the heat rejecting heat exchanger 102. In the heat rejecting heat exchanger 102, heat exchange takes place with a secondary fluid flow across the heat rejecting heat exchanger 102 in such a manner that heat is rejected from the refrigerant. In the case that the heat rejecting heat exchanger 102 is in the form of a condenser, the refrigerant passing through the heat rejecting heat exchanger 102 is at least partly condensed. In the case that the heat rejecting heat exchanger 102 is in the form of a gas cooler, the refrigerant passing through the heat rejecting heat exchanger 102 is cooled, but it remains in a gaseous state.

[0046] The refrigerant leaving the heat rejecting heat exchanger 102 is then passed through the expansion device 103 which may, e.g., be in the form of an expansion valve. The refrigerant passing through the expansion device 103 undergoes expansion and is further supplied to the evaporator 104. In the evaporator 104, heat exchange takes place with a secondary fluid flow across the evaporator 104 in such a manner that heat is absorbed by the refrigerant, while the refrigerant is at least partly evaporated. The refrigerant leaving the evaporator 104 is then supplied to the compressor unit 101.

[0047] Figs. 2(a) and 2(b) show perspective views of a generic model of an evaporator 104. In the evaporator 104 the liquid refrigerant is evaporated into a gaseous form/vapour. The evaporator 104 of Fig. 2 comprises a plurality of tubes 201 which guide the liquid refrigerant there through and which are enclosed in an evaporator structural support 202. The tubes 201 may typically be arranged in a horizontal manner. The length of the tubes 201 may vary and that length may define one dimension of the evaporator 104. The evaporator 104 comprises a fan 203 which drives a secondary air flow across the evaporator 104 and over the evaporator tubes 201 as indicated by arrows 204 in Fig. 2(c). In case of a refrigeration system, the liquid refrigerant absorbs heat from the air passing through the evaporator 104, thereby reducing the temperature of the air and providing cooling for a closed volume being in contact with the evaporator 104. The closed volume may, e.g., be a refrigeration chamber. Various temperature sensors 205-207 may be placed on the evaporator. Sensor 205 is placed at the air inlet of the evaporator 104 measuring a temperature, $T_{air,in}$, of air entering the evaporator 104. Sensor 206 is placed at the air outlet of the evaporator 104 measuring a temperature, $T_{air,out}$, of air leaving the evaporator 104. Sensor 207 is placed inside the evaporator 104 measuring an evaporation temperature, T_e, of the evaporator 104. Sensor 207 can be placed on the outside of one of the evaporator tubes 201. Namely, sensor 207 is placed in a way such that it measures surface temperature of the evaporator.

[0048] Measuring at least a temperature, $T_{air,out}$, of air leaving the evaporator (104) by sensor 206 both the control value and the setpoint value are derived. These two values based on the measured temperatures are further compared and outcome of the comparison is used in determination whether ice has accumulated on the evaporator (104) or not. In the case that the comparing step reveals that the derived control value deviates from the setpoint value it is determined that ice has accumulated on the evaporator 305.

[0049] Fig. 3 shows a part of the vapour compression system 100 showing the evaporator 104 and the expansion device 103 and its use in the method for ice detection. Refrigerant flows through the system 100 in a direction indicated by arrow 302, passing through the expansion device 103 and further enters the evaporator 104 via the inlet 303 of the evaporator 104 and leaves the evaporator through the outlet 301. Air flow through the evaporator 104 is illustrated by arrows 305. The method uses air temperature measurements by temperature sensors 205 and 206 and a temperature of the refrigerant at suction pressure, measured by means of temperature sensor 207, to generate and evaluate a control value for the purpose of identifying the initiation time for the defrost. The air temperatures are measured by the sensor 205 which measures the temperature, $T_{air,in}$, of air at the air inlet of the evaporator 104, and the sensor 206 which measures the temperature, $T_{air,out}$, of air at the air outlet of the evaporator 104. The temperature of the refrigerant at suction pressure, i.e., the evaporation temperature, T_e, is measured by the sensor 207 placed at the outlet 301 of the evaporator 104. Sensor 207 may be placed on the inlet 303. It may also be placed on the outside of one of the evaporator tubes, as well as inside one of the evaporator tubes. Alternatively, a pressure sensor may be placed instead of the temperature sensor 207, measuring pressure from which the evaporation temperature may be calculated. All the measured temperatures, $T_{air,in}$, $T_{air,out}$, T_e, are communicated to a processor 300 configured to perform derivation of the control value. The processor 300 may also be configured to initiate defrosting of the evaporator 104 once ice is detected.

In a large plant with a plurality of evaporators instead of a number of controllers controlling each evaporator individually, the measured temperatures may be communicated to a central plant controller, e.g., a set of program codes running on the central plant controller may monitor each evaporator in the plant.

[0050] Fig. 4 shows a flow chart 400 with the steps of a method for detecting ice accumulation on an evaporator. At the start, i.e., right after the defrosting mode, the system goes through a transition phase 401 during which temperatures related to the evaporator 104 are not stable. During this phase 401, temperatures may be monitored but may not be used in calculations or for controlling the evaporator 104. The transition phase 401 is finished when the monitored temperatures are stable. Once the temperatures are stable, the evaporator 104 is operating in steady state, there is no ice accumulated thereon and, in the step 402, a baseline generation is performed, including calculating a setpoint value based on at least measured temperatures, $T_{air,out}$, of air leaving the evaporator 104. The following step 403 is a diagnosis, i.e., determining whether ice is accumulated on the evaporator 104 or not. During the diagnosis 403, integrity of the measured temperatures is validated, a control value is calculated to adapt to the current operating condition and to perform, e.g., a CUSUM test on the difference between the setpoint value and the control value, or another suitable statistical method.

Claims

1. A method for detecting ice accumulation on an evaporator (104) of a vapour compression system (100), the vapour compression system (100) further comprising a compressor unit (101), a heat rejecting heat exchanger (102) and an expansion device (103), the compressor unit (101), the heat rejecting heat exchanger (102), the expansion device (103) and the evaporator (104) being arranged in a refrigerant path, and an air flow flowing across the evaporator (104), the method comprising the steps of:

   - measuring at least a temperature, $T_{air,out}$, of air leaving the evaporator (104),
   - deriving a control value based at least on the measured temperature, $T_{air,out}$,
   - comparing the derived control value to a setpoint value, and
   - determining that ice has accumulated on the evaporator (104) in the case that the comparing step reveals that the derived control value deviates from the setpoint value.

2. A method according to claim 1, further comprising the step of deriving the setpoint value from measurements of at least one temperature related to the evaporator (104) under ice free conditions.

3. A method according to claim 2, wherein the step of deriving the setpoint value is repeated.

4. A method according to any of the preceding claims, wherein the step of deriving a control value comprises selecting the measured temperature, $T_{air,out}$, as the control value.

5. A method according to claim 4, wherein the step of comparing the derived control value to the setpoint value comprises calculating a residual signal as the difference between the measured temperature, $T_{air,out}$, and the setpoint value, and monitoring the residual value.

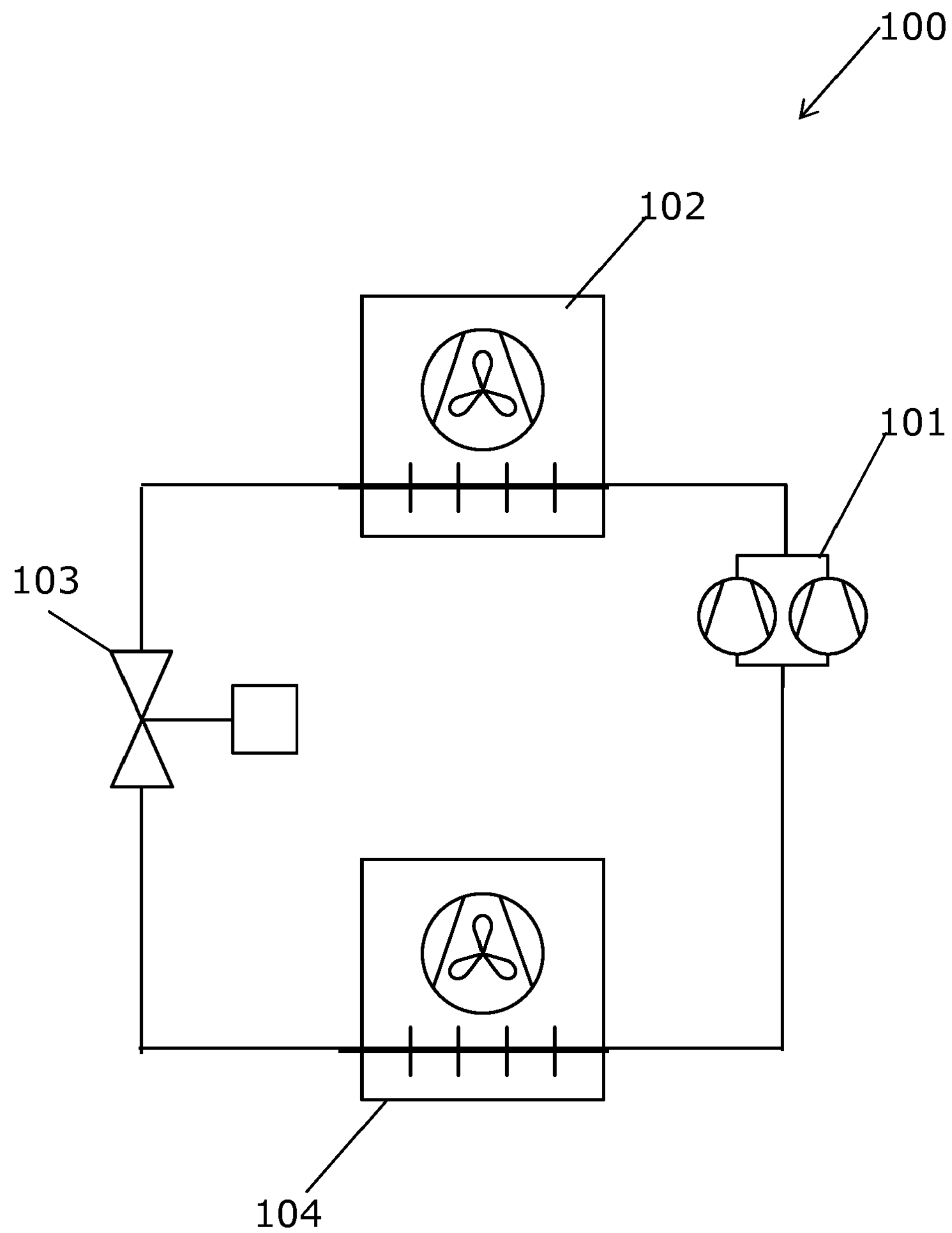
6. A method according to any of claims 1-3, further comprising the step of measuring a temperature, $T_{air,in}$, of air entering the evaporator (104) and an evaporation temperature, T_e, of the evaporator (104), and wherein the step of deriving a control value is based on the measured temperatures, $T_{air,out}$, $T_{air,in}$ and T_e.

7. A method according to claim 6, wherein the step of deriving a control value comprises calculating a control value, f_r, as:

$$fr = \frac{T_{air,in} - T_{air,out}}{LMTD},$$

   where LMTD is a log mean temperature difference.

8. A method according to any of the preceding claims, further comprising the step of initiating defrost of the evaporator (104) in the case that it is determined that ice has accumulated on the evaporator (104).


100
102
101
103
104

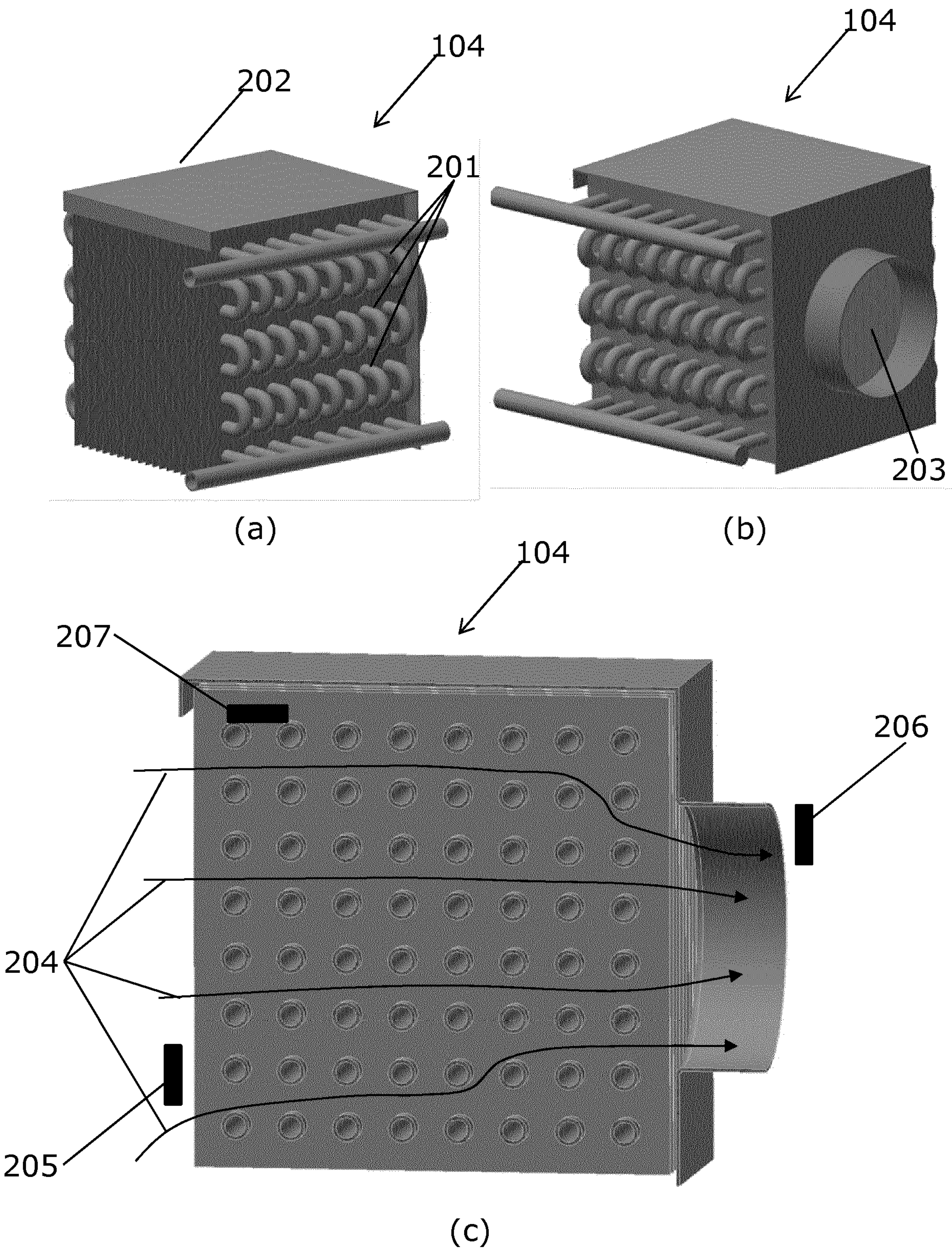


Fig. 2

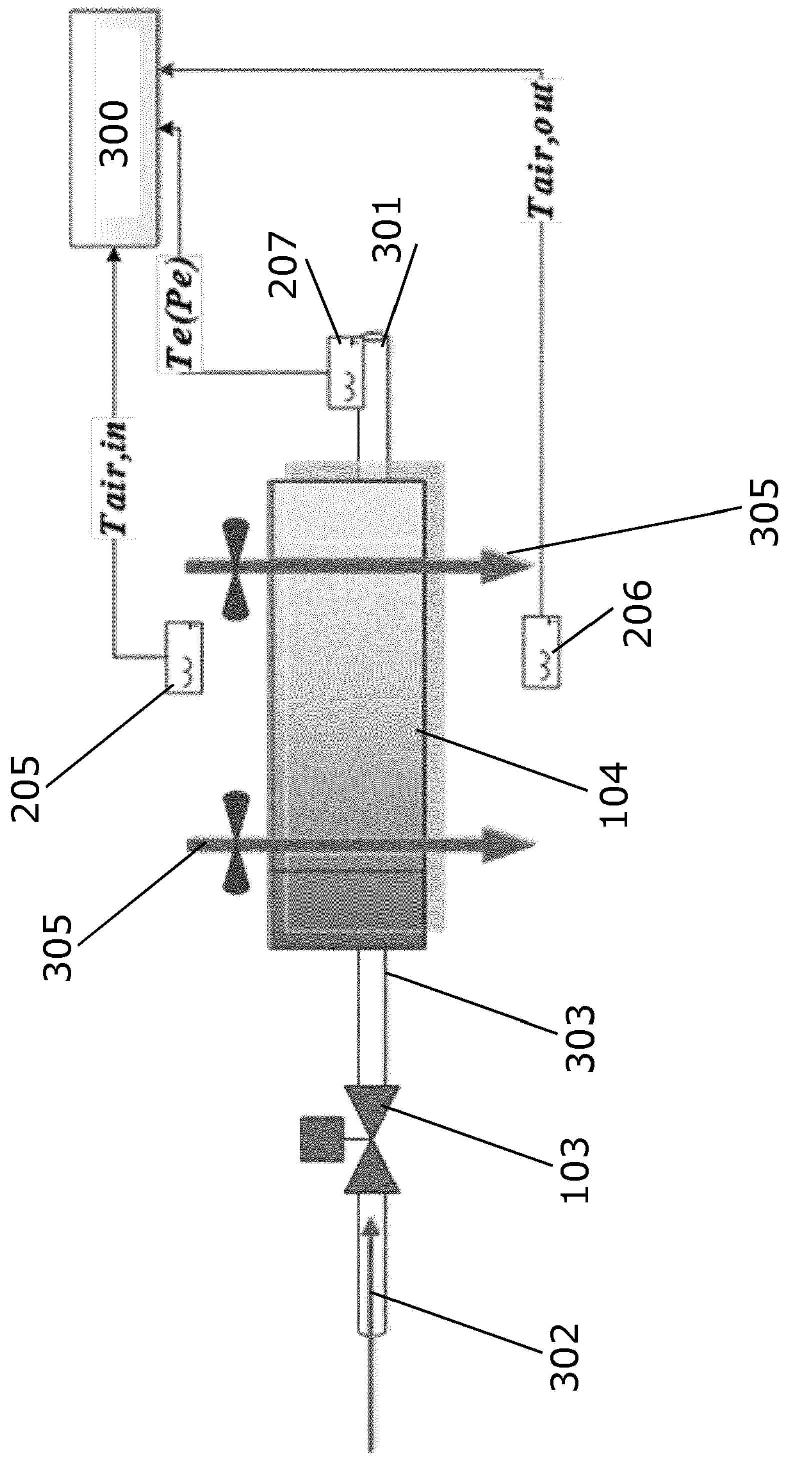

300
Te(Pe)
Tair,in
Tair,out
207
301
305
206
205
104
305
303
103
302

Fig. 3

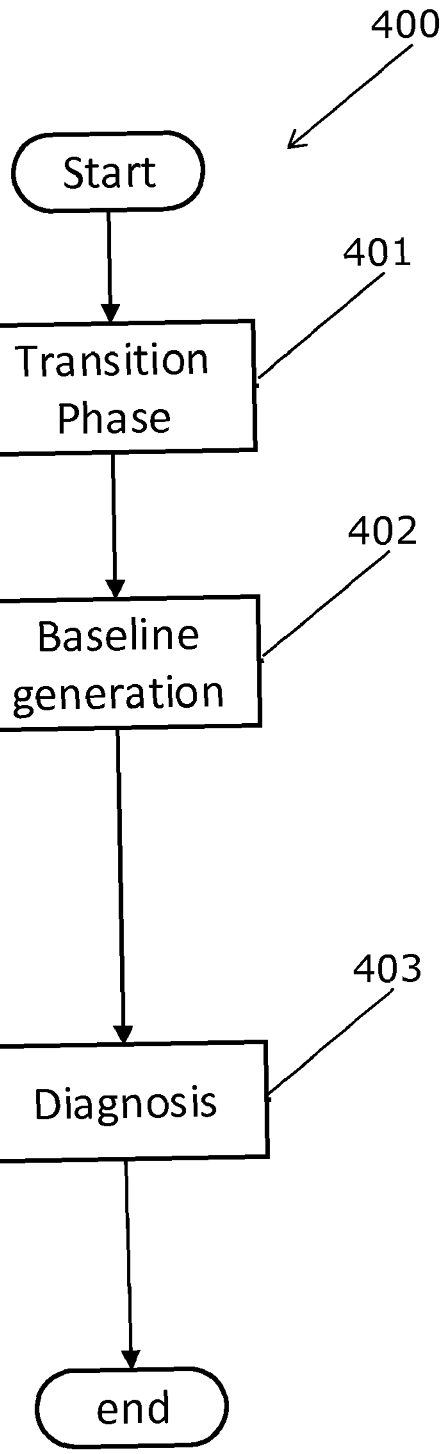

400
Start
401
Transition Phase
402
Baseline generation
403
Diagnosis
end

Fig. 4

Europäisches Patentamt
European Patent Office
Office européen des brevets

EUROPEAN SEARCH REPORT

Application Number
EP 18 17 9422

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
X	WO 2014/022269 A2 (CARRIER CORP [US]; LIU LUCY YI [US]) 6 February 2014 (2014-02-06) * paragraph [0020] - paragraph [0039]; figures 2,3 *	1-8	INV. F25B49/02 F25B47/00 F25B47/02
X	WO 2017/073212 A1 (DENSO CORP [JP]) 4 May 2017 (2017-05-04) * page 3 - page 17; figures 1,2 *	1-8	
A	WO 2016/083858 A1 (CARRIER CORP [US]; CHAMOUN MARWAN [FR]) 2 June 2016 (2016-06-02) * page 6 - page 10; figure 1 *	1-8	
A	EP 0 505 315 A1 (CARRIER CORP [US]) 23 September 1992 (1992-09-23) * column 3 - column 4; figures 1,2 *	1-8	
A	WO 2012/123849 A2 (ECOLOBLUE INC [US]; FERREIRA WAYNE [US]; TIELEMAN HENRI-JAMES [US]) 20 September 2012 (2012-09-20) * page 4 - page 6; figures 1-6 *	1-8	TECHNICAL FIELDS SEARCHED (IPC)
A	WO 2017/121721 A1 (DANFOSS AS [DK]) 20 July 2017 (2017-07-20) * page 9 - page 10; figures 1-4 *	1-8	F25B
A	JP 2000 161821 A (ISUZU CERAMICS RES INST) 16 June 2000 (2000-06-16) * page 2 - page 3; figures 1-4 *	1-8	

The present search report has been drawn up for all claims

2

Place of search	Date of completion of the search	Examiner
Munich	26 November 2018	Amous, Moez

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
Y : particularly relevant if combined with another document of the same category
A : technological background
O : non-written disclosure
P : intermediate document

T : theory or principle underlying the invention
E : earlier patent document, but published on, or after the filing date
D : document cited in the application
L : document cited for other reasons

& : member of the same patent family, corresponding document

EPO FORM 1503 03.82 (P04C01)

ANNEX TO THE EUROPEAN SEARCH REPORT ON EUROPEAN PATENT APPLICATION NO. EP 18 17 9422

This annex lists the patent family members relating to the patent documents cited in the above-mentioned European search report. The members are as contained in the European Patent Office EDP file on
The European Patent Office is in no way liable for these particulars which are merely given for the purpose of information.

26-11-2018

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
WO 2014022269 A2	06-02-2014	CN 104813119 A	29-07-2015
		EP 2880375 A2	10-06-2015
		SG 11201500570W A	29-04-2015
		US 2015204589 A1	23-07-2015
		WO 2014022269 A2	06-02-2014
WO 2017073212 A1	04-05-2017	CN 108027185 A	11-05-2018
		DK 201870232 A1	30-04-2018
		JP WO2017073212 A1	01-03-2018
		US 2018209697 A1	26-07-2018
		WO 2017073212 A1	04-05-2017
WO 2016083858 A1	02-06-2016	CN 107076477 A	18-08-2017
		EP 3224554 A1	04-10-2017
		US 2017276422 A1	28-09-2017
		WO 2016083858 A1	02-06-2016
EP 0505315 A1	23-09-1992	DE 69212356 D1	29-08-1996
		DE 69212356 T2	30-01-1997
		EP 0505315 A1	23-09-1992
		ES 2092079 T3	16-11-1996
		US 5257506 A	02-11-1993
WO 2012123849 A2	20-09-2012	CN 102733451 A	17-10-2012
		CN 202850099 U	03-04-2013
		US 2014053580 A1	27-02-2014
		US 2015033774 A1	05-02-2015
		WO 2012123849 A2	20-09-2012
WO 2017121721 A1	20-07-2017	CN 108463679 A	28-08-2018
		EP 3403035 A1	21-11-2018
		WO 2017121721 A1	20-07-2017
JP 2000161821 A	16-06-2000	NONE	

EPO FORM P0459

For more details about this annex : see Official Journal of the European Patent Office, No. 12/82

REFERENCES CITED IN THE DESCRIPTION

This list of references cited by the applicant is for the reader's convenience only. It does not form part of the European patent document. Even though great care has been taken in compiling the references, errors or omissions cannot be excluded and the EPO disclaims all liability in this regard.

Patent documents cited in the description

- US 20150204589 A **[0004]**