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A METHOD FOR CONTROLLING A VAPOUR COMPRESSION SYSTEM AT LOW SUPERHEAT

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A method for controlling a vapour compression system (1) is disclosed, the vapour compression system (1) comprising a compressor unit (2), a heat rejecting heat exchanger (3), an expansion device (4) and an evaporator (5) arranged in a refrigerant path. A superheat value of refrigerant leaving the evaporator (5) is derived, and a quantity being representative for a variance of the

derived superheat value is calculated. A reference superheat value is calculated, based on the calculated quantity and on a minimum acceptable superheat value. The expansion device (4) is operated in accordance with the calculated reference superheat value, and in order to obtain a superheat of refrigerant leaving the evaporator (5) which is equal to the reference superheat value.

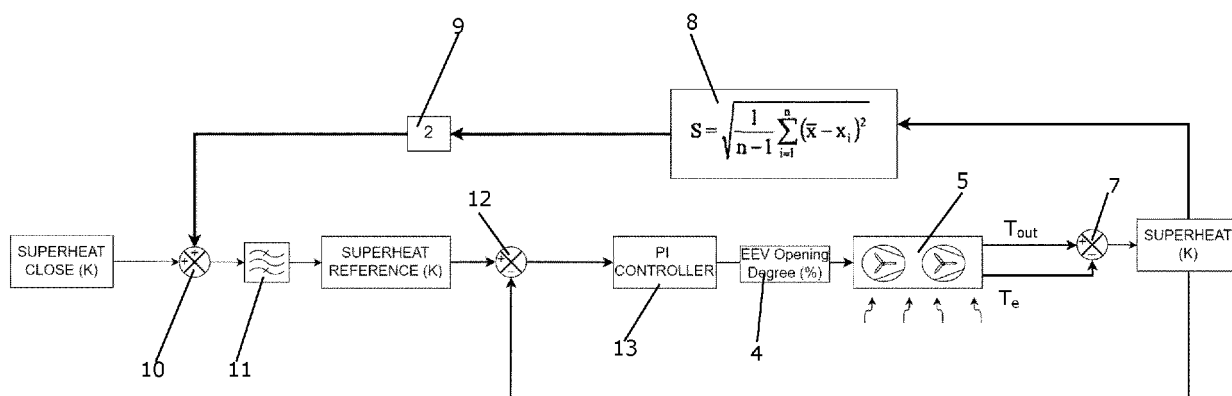


Fig. 3

Description

FIELD OF THE INVENTION

[0001] The present invention relates to a method for controlling a vapour compression system, such as a refrigeration system, an air condition system or a heat pump, in a manner which allows a superheat value of refrigerant leaving the evaporator to be lower than is the case in prior art control methods.

BACKGROUND OF THE INVENTION

[0002] Vapour compression systems, such as refrigeration systems, air conditions systems or heat pumps, normally comprise a compressor unit with one or more compressors, a heat rejecting heat exchanger, at least one expansion device and at least one evaporator arranged in a refrigerant path. Refrigerant flowing in the refrigerant path is compressed by the compressors of the compressor unit before being supplied to the heat rejecting heat exchanger. In the heat rejecting heat exchanger, heat exchange takes place between the refrigerant and the ambient or a secondary fluid flow across the heat rejecting heat exchanger, in such a manner that heat is rejected from the refrigerant.

[0003] The refrigerant leaving the heat rejecting heat exchanger is supplied to the expansion device, where it undergoes expansion before being supplied to the evaporator. The refrigerant being supplied to the evaporator is in the form of a mixture of liquid and gaseous refrigerant. When passing through the evaporator, the liquid part of the refrigerant is at least partly evaporated, while heat exchange takes place with the ambient or a secondary fluid flow across the evaporator, in such a manner that heat is absorbed by the refrigerant. Finally, the refrigerant is once again supplied to the compressor unit.

[0004] Thus, refrigerant flowing in the refrigerant path is alternately compressed by the compressors and expanded by the expansion device, while heat exchange takes place in the heat rejecting heat exchanger and the evaporator, respectively.

[0005] It is desirable that liquid refrigerant is presents along the entire length of the evaporator, because thereby the entire length of the evaporator is used for evaporating refrigerant, and thereby the potential capacity of the evaporator for providing cooling is fully utilised. This provides an energy efficient operation of the vapour compression system.

[0006] On the other hand, it should be avoided that liquid refrigerant passes through the evaporator, because this may result in liquid refrigerant reaching the compressor unit, and this may cause damage to the compressors.

[0007] Therefore, it is normally attempted to control the vapour compression system, in particular an opening degree of the expansion device, in such a manner that all of the liquid refrigerant has been evaporated shortly be-

fore reaching the outlet of the evaporator.

[0008] In order to obtain this, the superheat value of refrigerant leaving the evaporator may be monitored. The superheat is defined as the temperature difference between the evaporating temperature and the temperature of the refrigerant leaving the evaporator. Thus, a high superheat value indicates that the temperature of the refrigerant leaving the evaporator is significantly higher than the evaporating temperature. This is an indication that all of the liquid refrigerant has been evaporated well before reaching the outlet of the evaporator, and that energy is therefore used for heating the gaseous part of the refrigerant passing through the evaporator, that the heat exchange taking place in the evaporator is not optimal, and that the vapour compression system is therefore not operated in an energy efficient manner.

[0009] On the other hand, zero superheat indicates that the temperature of the refrigerant leaving the evaporator is equal to the evaporating temperature. This is an indication that liquid refrigerant is present along the entire length of the evaporator, and that the potential capacity of the evaporator is thereby fully utilised and the vapour compression system is operating in an energy efficient manner. However, at zero superheat it is not possible to determine whether all of the refrigerant has been evaporated exactly when the outlet of the evaporator is reached, or if a significant amount of liquid refrigerant is in fact allowed to pass through the evaporator and potentially reach the compressors.

[0010] Accordingly, it is normally attempted to control the vapour compression system in such a manner that a superheat value is obtained, which is small, but positive, i.e. greater than zero. Thereby it is obtained that the vapour compression system is operated in an energy efficient manner without risking that liquid refrigerant reaches the compressors.

[0011] For low superheat values, the superheat signal may become unstable, in the sense that the variance of the superheat signal increases. This is due to chaotic processes taking place in the evaporator at the point where the last part of the liquid refrigerant is evaporated. In order to avoid that the superheat value decreases to zero, due to a high variance, a superheat setpoint may be selected which ensures that the superheat value is within the stable region.

[0012] The boundary between stable and unstable superheat control, sometimes referred to as Minimum Stable Superheat (MSS), varies as a function of operating conditions, load variations, etc. Thereby, when a superheat setpoint has been selected, which is within the stable region, this may result in the superheat value being well above zero, thereby causing the vapour compression system to be operated in a non-optimal manner.

[0013] US 6,018,959 discloses a method for controlling the superheat temperature of the refrigerant in an evaporator arrangement of a refrigeration system or heat pump system. The superheat temperature is controlled in dependence on a comparison between desired and

actual values. The desired value of the superheat temperature is varied automatically in dependence on the difference from a reference value of a periodically determined function of a number of sampled values of a temperature of the refrigerant with the aim of stable control of the superheat temperature.

DESCRIPTION OF THE INVENTION

[0014] It is an object of embodiments of the invention to provide a method for controlling a vapour compression system in a more energy efficient manner than prior art control methods.

[0015] The invention provides a method for controlling a vapour compression system, the vapour compression system comprising a compressor unit, a heat rejecting heat exchanger, an expansion device and an evaporator arranged in a refrigerant path, the method comprising the steps of:

- deriving a superheat value of refrigerant leaving the evaporator,
- calculating a quantity being representative for a variance of the derived superheat value,
- calculating a reference superheat value, based on the calculated quantity and on a minimum acceptable superheat value, and
- operating the expansion device in accordance with the calculated reference superheat value, and in order to obtain a superheat of refrigerant leaving the evaporator which is equal to the reference superheat value.

[0016] Thus, the method according to the invention is a method for controlling a vapour compression system. 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 alternately 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.

[0017] The vapour compression system comprises a compressor unit comprising one or more compressors, a heat rejecting heat exchanger, an expansion device and an evaporator arranged in a refrigerant path. Refrigerant circulating the refrigerant path is compressed by the compressors of the compressor unit before being supplied to the heat rejecting heat exchanger. In the heat rejecting heat exchanger heat exchange takes place between the refrigerant and the ambient or a secondary fluid flow across the heat rejecting heat exchanger, in such a manner that heat is rejected from the refrigerant. The heat rejecting heat exchanger may be in the form of a condenser, in which case the refrigerant is at least partly

condensed when passing through the heat rejecting heat exchanger. As an alternative, the heat rejecting heat exchanger may be in the form of a gas cooler, in which case the refrigerant passing through the heat rejecting heat exchanger is cooled, but remains in a gaseous or trans-critical state.

[0018] Refrigerant leaving the heat rejecting heat exchanger is supplied to the expansion device, where it undergoes expansion before being supplied to the evaporator. The refrigerant being supplied to the evaporator is in a mixed state of gaseous and liquid refrigerant. In the evaporator, the liquid part of the refrigerant is at least partly evaporated, 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. Finally, the refrigerant leaving the evaporator is supplied to the compressor unit, via a suction line.

[0019] The vapour compression system may comprise two or more expansion devices and two or more evaporators. In this case each expansion device supplies refrigerant to one of the evaporators, and the evaporators, along with their respective expansion devices, are arranged fluidly in parallel between the heat rejecting heat exchanger and the suction line. This is, e.g., relevant in refrigeration systems with several cooling entities, such as a supermarket refrigeration system with several display cases or cabinets. In this case each evaporator is arranged in thermal contact with a refrigerated volume of one of the cooling entities.

[0020] Thus, the refrigerant circulating the refrigerant path is alternately compressed by the compressors of the compressor unit and expanded by the expansion device, while heat exchange takes place in the heat rejecting heat exchanger and the evaporator.

[0021] In the method according to the invention, a superheat value of refrigerant leaving the evaporator is initially derived. As described above, the superheat value of refrigerant leaving the evaporator is defined as the temperature difference between the evaporating temperature of the refrigerant and the actual temperature of the refrigerant leaving the evaporator. Furthermore, as described above, the superheat value is a relevant control parameter for ensuring energy efficient operation of the vapour compression system, and for preventing that liquid refrigerant reaches the compressor unit. The superheat value may be measured directly, or it may be derived from two measured parameters. This will be described in further detail below.

[0022] Next, a quantity being representative for a variance of the derived superheat value is calculated. The quantity may, e.g., be an appropriate variance of the derived superheat value. As an alternative, it may be a variance of another parameter which is related to the superheat value, e.g. the temperature of refrigerant leaving the evaporator. This will be described in further detail below.

[0023] In any event, the calculated quantity is representative for the variance of the derived superheat value,

and thereby it reflects in which manner and how much the superheat value varies. A low variance indicates that the superheat value is stable, whereas a high variance indicates that the superheat value is unstable. As described above, an unstable superheat, and thereby a high variance, may be expected when the vapour compression system is operated at low superheat values.

[0024] The variance of the superheat value provides a measure for how much the superheat value may be expected to deviate from a mean superheat value, at least for most of the time. In particular, the variance of the superheat defines a range of superheat values below the mean superheat value, within which it is likely to find the actual superheat value. The higher the variance, the more the superheat value may be expected to deviate, and thereby the larger the defined range of superheat values. Accordingly, at high variances there is a significant risk that the actual superheat value is significantly lower than the mean superheat value. Therefore, if the mean superheat value is low and the variance of the superheat value is high, then there is a risk that zero superheat is reached sufficiently often and for sufficiently long time periods to introduce a risk of liquid refrigerant reaching the compressor unit.

[0025] For instance, the quantity being representative for the variance of the derived superheat value may be of a kind which represents that the superheat value is within a range around the mean superheat value defined by the variance, for at least 95% of the time.

[0026] Next, a reference superheat value is calculated, based on the calculated quantity and on a minimum acceptable superheat value. The minimum acceptable superheat value is a superheat value below which it is undesirable to go. Thus, the minimum acceptable superheat value constitutes a lower boundary for a range of superheat values which ensures appropriate operation of the vapour compression system, in particular with respect to preventing that liquid refrigerant reaches the compressor unit. The minimum superheat value is typically a small, but positive value, such as 1-5 K, e.g. approximately 2 K or 3 K, thereby ensuring that the superheat remains positive.

[0027] Accordingly, the reference superheat value is calculated with due consideration to the minimum acceptable superheat value, and while taking the variance of the superheat value into account. Thereby the reference superheat value can be selected in such a manner that the variance of the superheat value will not cause the superheat value to decrease below the minimum acceptable superheat value, possibly except on rare occasions and/or briefly. It may be acceptable that zero superheat is reached rarely and briefly, since small amounts of liquid refrigerant may not harm the compressors. Furthermore, a limited amount of liquid refrigerant which enters the suction line may be evaporated before it reaches the compressor unit. This may, e.g., be the case in vapour compression systems comprising two or more evaporators, where hot gaseous refrigerant enter-

ing the suction line from the other evaporators may cause evaporation of the liquid refrigerant.

[0028] Thereby the reference superheat value is calculated in accordance with the prevailing operating conditions, and in such a manner that it is as close as possible to the minimum acceptable superheat value without risking that the prevailing variance of the superheat value causes it to decrease below the minimum acceptable superheat value to an extent which would introduce an unacceptable risk of liquid refrigerant reaching the compressor unit.

[0029] Finally, the expansion device is operated in accordance with the calculated reference superheat value, and in order to obtain a superheat of refrigerant leaving the evaporator which is equal to the reference superheat value. Accordingly, the expansion device is operated in order to control the refrigerant supply to the evaporator in such a manner that the reference superheat value is obtained. This may, e.g., include adjusting an opening degree of the expansion device or modulating a duty cycle of the expansion device. The control of the expansion device may, thus, be a standard setpoint control with the reference superheat value as the setpoint value.

[0030] Accordingly, the vapour compression system is controlled in accordance with the reference superheat value which was calculated in the manner described above. Thereby it is obtained that the superheat of refrigerant leaving the evaporator is as low as possible, thereby ensuring energy efficient operation of the vapour compression system, while preventing liquid refrigerant from reaching the compressor unit. Thereby the method according to the invention strikes an appropriate balance between energy efficient operation of the vapour compression system and protecting the compressors.

[0031] The method according to the present invention relies on the realisation that it may be acceptable to operate the vapour compression system at a superheat value which is within the unstable operating range, as long as it is ensured that the elevated variance of the superheat value, which is caused by the unstable conditions, will not cause the superheat value to reach zero superheat to an extent which introduces a risk of damage to the compressors.

[0032] Thus, the method according to the invention allows the vapour compression system to be safely operated at lower superheat values than prior art control methods, thereby increasing the energy efficiency of the vapour compression system.

[0033] The step of calculating a quantity being representative for a variance of the derived superheat value may comprise calculating the variance of the derived superheat value.

[0034] According to this embodiment, the actual variance of the superheat value is calculated and applied when the reference superheat value is calculated. As an alternative, another suitable quantity may be calculated, e.g. a variance of the temperature of refrigerant leaving the evaporator. As described above, the superheat value

is the temperature difference between the evaporating temperature and the actual temperature of the refrigerant leaving the evaporator. The temperature of the refrigerant leaving the evaporator may be expected to vary to a greater extent than the evaporating temperature. Therefore, the variance of the temperature of refrigerant leaving the evaporator may be regarded as a suitable representation of the variance of the superheat value. As another alternative, the calculated quantity may be a quantity which is proportional to the variance of the superheat value or the variance of the temperature of refrigerant leaving the evaporator.

[0035] The step of calculating a reference superheat value may comprise adding the minimum acceptable superheat value and the calculated quantity.

[0036] According to this embodiment, the reference superheat value is selected as a value which is above the minimum acceptable superheat value by an amount which corresponds to the calculated quantity, and thereby to the variance of the superheat. Thereby, when the expansion device is subsequently operated in order to obtain a superheat which is equal to the reference superheat, it is ensured that, at the current variance, the superheat will not decrease below the minimum acceptable superheat value, even at a lower extreme of the superheat range defined by the variance. Furthermore, this is a simple and reliable way of calculating the reference superheat value.

[0037] The step of calculating a quantity being representative for a reference superheat value may further comprise applying a low pass filter. According to this embodiment, any fast varying components of variance of the superheat value are removed from the calculated quantity before it is applied for calculating the reference superheat value. Thereby it is ensured that the calculated reference superheat value varies in a smooth manner.

[0038] The time constant of the low pass filter may be larger than a time constant of a controller used during operation of the expansion device. Thereby it is ensured that adjustments of the expansion device, e.g. in the form of adjustments of an opening degree of the expansion device, are performed in accordance with true and slow variations in the reference superheat value, thereby ensuring smooth operation of the expansion device.

[0039] The step of calculating a quantity being representative for a variance of the derived superheat value may comprise deriving a standard deviation of the derived superheat value and multiplying the standard deviation by an impact factor.

[0040] According to this embodiment, the variance of the superheat value is in the form of a standard deviation of the derived superheat value. Assuming that the derived superheat values follow a normal distribution, approximately 68% of the derived superheat values will be within a range defined by the mean superheat value $\pm$ the standard deviation.

[0041] The impact factor determines to which extent the variance of the superheat should be taken into ac-

count when calculating the reference superheat value. The impact factor may be 1, in which case the quantity being representative for the variance of the derived superheat is simply the standard deviation of the derived superheat value. Alternatively, the impact factor may be larger than 1. In this case, the quantity is correspondingly larger than the standard deviation, thereby creating a larger margin between the reference superheat value and the minimum acceptable superheat value, and thereby reducing the risk of the superheat value decreasing to zero.

[0042] The impact factor may, e.g., be selected during initial configuration of the vapour compression system. For instance, the selection of the impact factor may be performed with due consideration to the design and expected operating conditions of the vapour compression system. It may further be taken into account to which extent it may be accepted that zero superheat is reached. If the vapour compression system is very sensitive with regard to liquid refrigerant entering the suction line, then a high impact factor may be selected, thereby reducing the risk that the superheat decreases to zero. If, on the other hand, the vapour compression system is less sensitive to liquid refrigerant entering the suction line, e.g. because the vapour compression system comprises several evaporators, then a lower impact factor may be selected.

[0043] As an alternative to deriving a standard deviation of the derived superheat value, a mean deviation of the derived superheat value, or another suitable measure for the variance of the superheat value, may be derived.

[0044] The step of operating the expansion device may be performed by means of a proportional integral (PI) controller. According to this embodiment, the expansion device is operated in accordance with a standard PI control strategy with the reference superheat value as the setpoint value. Alternatively, another suitable control strategy may be applied.

[0045] The step of deriving a superheat value of refrigerant leaving the evaporator may comprise measuring a temperature of refrigerant leaving the evaporator and an evaporating temperature of the evaporator, and calculating the superheat value from the measured temperatures.

[0046] As described above, the superheat value is the temperature difference between the evaporating temperature and the temperature of refrigerant leaving the evaporator. Therefore, if the temperature of refrigerant leaving the evaporator and the evaporating temperature are measured, the superheat value can readily be derived by subtracting the measured evaporating temperature from the measured refrigerant temperature.

[0047] The temperatures may, e.g., be measured by means of temperature sensors arranged in the refrigerant path at the outlet of the evaporator and inside the evaporator, respectively.

[0048] As an alternative, the step of deriving a superheat value of refrigerant leaving the evaporator may com-

prise measuring a temperature of refrigerant leaving the evaporator and a pressure of refrigerant leaving or entering the evaporator, and calculating the superheat value from the measured temperature and pressure.

[0049] For a given refrigerant, the evaporating temperature depends on the pressure inside the evaporator. Thus, knowing the type of refrigerant applied in the vapour compression system, the evaporating temperature can be derived from the pressure prevailing in the evaporator. The pressure at the inlet or at the outlet of the evaporator provides a suitable measure for the pressure prevailing in the evaporator. Accordingly, the evaporating temperature can be at least approximately derived from a refrigerant pressure measured at the inlet or at the outlet of the evaporator. This allows the superheat value to be derived in the manner described above.

[0050] As another alternative, the step of deriving a superheat value of refrigerant leaving the evaporator may comprise measuring a temperature of refrigerant leaving the evaporator and a temperature of refrigerant entering the evaporator, and calculating the superheat value from the measured temperatures.

[0051] Similarly to the embodiment described above, the evaporating temperature can also be derived from the temperature of refrigerant entering the evaporator. As described above, the refrigerant entering the evaporator is in a mixed liquid and gaseous state, i.e. it is in a two-phase state. Therefore, for pure substances, the refrigerant temperature measured at the inlet of the evaporator is in fact the evaporation temperature. However, some refrigerants consist of more substances which means that the temperature depends on the quality (fraction of liquid and gas) known as glides. For such refrigerants, it is still possible to derive the evaporating temperature from the refrigerant temperature at the inlet of the evaporator. Thus, it is also possible to derive the superheat value, based on the derived evaporating temperature, in the manner described above.

[0052] The method may further comprise the steps of:

- opening the expansion device and subsequently operating the expansion device in accordance with a previously stored reference superheat value,
- monitoring the superheat value of refrigerant leaving the evaporator, and
- in the case that the superheat value of refrigerant leaving the evaporator decreases below a predefined threshold value, performing the steps of calculating a quantity being representative for a variance of the derived superheat value, calculating a reference superheat value, based on the calculated quantity and on a minimum acceptable superheat value, and operating the expansion device in accordance with the calculated reference superheat value, and in order to obtain a superheat of refrigerant leaving the evaporator which is equal to the reference su-

perheat value.

[0053] According to this embodiment, the vapour compression system may be controlled in the following manner. Following a period where the vapour compression system has been stopped, or the expansion device has simply been closed for other reasons, thereby preventing a refrigerant flow to the evaporator, the expansion device is opened in order to once again allow refrigerant to be supplied to the evaporator. To this end the expansion device is operated in accordance with a reference superheat value, which has previously been stored. For instance, the previously stored reference superheat value may be a reference superheat value which was applied before the expansion device was closed, and it may have been derived in the manner described above. Thus, the expansion device is operated in accordance with the last known operating conditions, i.e. in accordance with conditions which were prevailing the last time the expansion device was open. Assuming that the operating conditions vary slowly, this may be regarded as an appropriate starting point, in particular the previously stored reference superheat may be regarded as appropriate.

[0054] During this operation of the expansion device, the superheat value of refrigerant leaving the evaporator is monitored and compared to a predefined threshold value.

[0055] In the case that the superheat value decreases below the predefined threshold value, the method steps described above are initiated, i.e. a reference superheat value is calculated in the manner described above, and the expansion device is subsequently operated in accordance therewith.

[0056] Thus, according to this embodiment, following an opening of the expansion device, as long as the superheat value is above the predefined threshold value, the expansion device is simply operated in accordance with the previously stored reference superheat value. However, when the superheat value decreases to a certain low level, defined by the predefined threshold value, this is an indication that the superheat value may be approaching the unstable region, and that it may therefore be relevant to adjust the reference superheat value in accordance with the method according to the present invention. Therefore the method steps described above are initiated when this occurs.

[0057] The predefined threshold value may be a predefined offset above the previously stored reference superheat value. According to this embodiment, the method steps described above are initiated when the superheat value approaches the previously stored reference superheat value.

BRIEF DESCRIPTION OF THE DRAWINGS

[0058] The invention will now be described in further detail with reference to the accompanying drawings in which

Fig. 1 is a diagrammatic view of a vapour compression system being controlled in accordance with a method according to an embodiment of the invention,

Fig. 2 is a diagrammatic view of a vapour compression system being controlled in accordance with a method according to an alternative embodiment of the invention,

Fig. 3 is a block diagram illustrating a control loop of a method according to an embodiment of the invention,

Fig. 4 is a graph illustrating stable and unstable superheat regions for a vapour compression system, and

Fig. 5 is a graph illustrating reference superheat values as a function of evaporator capacity for a prior art control method and for a method according to an embodiment of the invention.

DETAILED DESCRIPTION OF THE DRAWINGS

[0059] Fig. 1 is a diagrammatic view of a vapour compression system 1 being controlled in accordance with a method according to an embodiment of the invention. The vapour compression system 1 comprises a compressor unit 2, a heat rejecting heat exchanger 3, an expansion device 4 and an evaporator 5 arranged in a refrigerant path. A fan 6 is arranged to drive a secondary fluid flow across the heat rejecting heat exchanger 3.

[0060] During operation of the vapour compression system 1, refrigerant flowing in the refrigerant path is compressed by means of the compressor(s) of the compressor unit 2 before being supplied to the heat rejecting heat exchanger 3. When the refrigerant passes through the heat rejecting heat exchanger 3, heat exchange takes place between the refrigerant and the secondary fluid flow driven by the fan 6, in such a manner that heat is rejected from the refrigerant.

[0061] The refrigerant leaving the heat rejecting heat exchanger 3 is supplied to the expansion device 4, where it undergoes expansion before being supplied to the evaporator 5. When passing through the evaporator 5, heat exchange takes place between the refrigerant and air inside a refrigerated volume arranged in thermal contact with the evaporator 5, in such a manner that heat is absorbed by the refrigerant, while the liquid part of the refrigerant is at least partly evaporated. Accordingly, cooling is thereby provided to the refrigerated volume. Finally, the refrigerant is once again supplied to the compressor unit 2.

[0062] The supply of refrigerant to the evaporator 5 is controlled by means of the expansion device 4. The supply of refrigerant is controlled in order to obtain a superheat value of refrigerant leaving the evaporator 5 which

is equal to a reference superheat value. To this end, an opening degree or a duty cycle of the expansion device 4 is adjusted, e.g. according to a setpoint control strategy, e.g. applying a PI controller.

[0063] The reference superheat value which is applied for the control of the expansion device 4 may be calculated in the following manner. While the vapour compression system 1 operates as described above, the superheat value of refrigerant leaving the evaporator 5 is derived. The superheat value is required for the setpoint control of the expansion device 4 described above. However, it is also used for the calculation of the reference superheat value, as will be described below.

[0064] The superheat value may be derived from measurements of the temperature of refrigerant leaving the evaporator 5 and one or more of the evaporating temperature in the evaporator 5, the pressure of refrigerant leaving the evaporator 5, the pressure of refrigerant entering the evaporator 5 and the temperature of refrigerant entering the evaporator 5.

[0065] Next, a quantity being representative for a variance of the derived superheat value is calculated. The calculated quantity may be a variance of the actual superheat value, e.g. in the form of a standard deviation or a mean deviation, or it could be a variance of another parameter which is related to the superheat value, e.g. the temperature of refrigerant leaving the evaporator 5.

[0066] Finally, a reference superheat value is calculated, based on the calculated quantity and on a minimum acceptable superheat value. The minimum acceptable superheat value is a superheat value below which there is a considerable risk that liquid refrigerant passes the evaporator 5 and reaches the compressor unit 2.

[0067] Thus, the reference superheat value is calculated with due respect to the minimum acceptable superheat value, and the variance of the superheat value, i.e. to expected variations of the superheat value, and thereby expected deviations from the reference superheat value.

[0068] Accordingly, it is accepted that the vapour compression system 1 is operated with high variance of the superheat value, and thereby in an unstable region, as long as it is ensured that the variance of the superheat will not cause the superheat to decrease below the minimum acceptable superheat value, to an extent which introduces a risk of liquid refrigerant reaching the compressor unit 2. This allows the vapour compression system 1 to be operated at a lower superheat value than prior art control methods, and thereby in a more energy efficient manner.

[0069] Fig. 2 is a diagrammatic view of a vapour compression system 1 being controlled in accordance with a method according to an alternative embodiment of the invention. The vapour compression system 1 of Fig. 2 is very similar to the vapour compression system 1 of Fig. 1, and it will therefore not be described in detail here.

[0070] The vapour compression system 1 of Fig. 2 comprises a number of expansion devices 4, two of which

are shown, each being arranged to supply refrigerant to a separate evaporator 5. Each of the evaporators 5 is arranged in thermal contact with a separate refrigerated volume. Thus, each of the expansion devices 4 is controlled in order to allow or prevent a flow of refrigerant to the respective evaporators 5, in order to obtain a respective reference superheat value for refrigerant leaving the respective evaporators 5. The reference superheat value is calculated essentially in the manner described above with reference to Fig. 1.

[0071] Fig. 3 is a block diagram illustrating a control loop of a method according to an embodiment of the invention. In the control loop of Fig. 3, an opening degree of an expansion device 4 supplying refrigerant to an evaporator 5 of a vapour compression system is controlled.

[0072] The temperature, T_{out} , of refrigerant leaving the evaporator 5 is measured and supplied to subtraction unit 7. Furthermore, the evaporating temperature, T_e , of the evaporator 5 is obtained and supplied to the subtraction unit 7. The evaporating temperature, T_e , may be measured directly, or it may be derived from measurements of one or more other measured parameters, e.g. the pressure of refrigerant leaving the evaporator 5, the pressure of refrigerant entering the evaporator 5 and/or the temperature of refrigerant entering the evaporator 5.

[0073] In the subtraction unit 7, the evaporating temperature, T_e , is subtracted from the refrigerant temperature, T_{out} , thereby obtaining the superheat of refrigerant leaving the evaporator 5.

[0074] At calculation block 8, a variance of the superheat value, in the form of a standard deviation of the superheat value, is calculated. The variance is multiplied by an impact factor at block 9, thereby obtaining a quantity being representative for the variance of the superheat value, before being supplied to a summation unit 10. In the embodiment of Fig. 3, the impact factor is 2.

[0075] Furthermore, a minimum acceptable superheat value (superheat close) is supplied to the summation unit 10. The minimum acceptable superheat value is a superheat value below which a risk of liquid refrigerant reaching the compressor unit is introduced, and it is therefore undesirable that the superheat of refrigerant leaving the evaporator 5 decreases below the minimum acceptable superheat value.

[0076] In the summation unit 10, the quantity being representative for the variance of the superheat value is added to the minimum acceptable superheat value. The resulting value represents a superheat level which is above the minimum superheat value by an amount corresponding to the calculated quantity, i.e. to the variance of the superheat value multiplied by the impact factor.

[0077] The value is supplied to a low pass filter 11, thereby obtaining a reference superheat value which is supplied to a subtraction unit 12, which also receives the superheat value. In the subtraction unit 12, the superheat value is subtracted from the reference superheat value, thereby obtaining an error signal, which is supplied to a PI controller 13. The PI controller 13 then controls the

opening degree of the expansion device 4, based on the error signal, and in accordance with a standard PI control strategy.

[0078] Fig. 4 is a graph illustrating stable and unstable superheat regions for a vapour compression system. More particularly, the graph of Fig. 4 illustrates superheat of refrigerant leaving the evaporator of a vapour compression system as a function of evaporator capacity.

[0079] The superheat value which represents that all of the liquid refrigerant in the evaporator has been evaporated exactly at the outlet of the evaporator constitutes a boundary between a stable control region and an unstable control region, in the sense that superheat values above this boundary results in a stable superheat signal, and superheat values below the boundary results in an unstable superheat signal. The boundary superheat value may be referred to as a 'minimum stable superheat' (MSS). Thus, the minimum stable superheat represents the best trade-off between optimal efficiency and robust control.

[0080] The minimum stable superheat changes as a function of design of the vapour compression system, operating conditions and loads on the evaporator, as illustrated by the curve marked 'MSS'. Since the evaporator load changes constantly during operation of the vapour compression system, e.g. due to frosting, changes in temperature in the refrigerated volume, evaporation pressure, etc., operation dynamics of the evaporator may change from stable to unstable, or vice versa, if the expansion device is simply operated on the basis of a fixed reference superheat value.

[0081] In one prior art method, it is attempted to calculate the reference superheat value in such a manner that it is as close to the 'MSS' curve as possible. However, as it can be seen from the graph of Fig. 4, for some evaporator loads, this results in a superheat value which is well above a critically low superheat value, and thereby resulting in an operation of the vapour compression system which is less energy efficient than required in order to avoid that liquid refrigerant reaches the compressor unit.

[0082] Fig. 5 is a graph illustrating reference superheat values as a function of evaporator capacity for a prior art control method and for a method according to an embodiment of the invention. Fig. 5 is essentially a detail of the graph of Fig. 4, illustrating the 'MSS' curve.

[0083] The prior art control method is illustrated by dotted area 14. A reference superheat value is selected which follows the 'MSS' curve as closely as possible, thereby ensuring that the unstable control region is avoided. Thereby the variance of the superheat signal is relatively low, and the actual superheat value deviates only in a limited manner from the reference superheat value, illustrated by the relatively narrow area 14, following the 'MSS' curve.

[0084] The control method according to an embodiment of the invention is illustrated by dashed area 15. In the control method according to the invention, the refer-

ence superheat value is calculated in the manner described above, e.g. with reference to Fig. 1, i.e. based on the variance of the superheat value and a minimum acceptable superheat value. This has the consequence that it is accepted that the vapour compression system is operated in the unstable control region, as long as it is ensured that the superheat value remains safely above a critically low superheat value. As a result, the superheat value is allowed to deviate significantly more from the reference superheat value than is the case in the prior art control method, as illustrated by the broader area 15. However, it can also be seen that the superheat value is not allowed to approach the critically low superheat value, indicated as 3 K.

[0085] Accordingly, the vapour compression system can be operated based on a lower reference superheat value, and thereby in a more energy efficient manner, without risking that liquid refrigerant reaches the compressor unit.

Claims

1. A method for controlling a vapour compression system (1), the vapour compression system (1) comprising a compressor unit (2), a heat rejecting heat exchanger (3), an expansion device (4) and an evaporator (5) arranged in a refrigerant path, the method comprising the steps of:
 - deriving a superheat value of refrigerant leaving the evaporator (5),
 - calculating a quantity being representative for a variance of the derived superheat value,
 - calculating a reference superheat value, based on the calculated quantity and on a minimum acceptable superheat value, and
 - operating the expansion device (4) in accordance with the calculated reference superheat value, and in order to obtain a superheat of refrigerant leaving the evaporator (5) which is equal to the reference superheat value.
2. A method according to claim 1, wherein the step of calculating a quantity being representative for a variance of the derived superheat value comprises calculating the variance of the derived superheat value.
3. A method according to claim 1 or 2, wherein the step of calculating a reference superheat value comprises adding the minimum acceptable superheat value and the calculated quantity.
4. A method according to any of the preceding claims, wherein the step of calculating a quantity being representative for a reference superheat value further comprises applying a low pass filter (11).
5. A method according to any of the preceding claims, wherein the step of calculating a quantity being representative for a variance of the derived superheat value comprises deriving a standard deviation of the derived superheat value and multiplying the standard deviation by an impact factor.
6. A method according to any of the preceding claims, wherein the step of operating the expansion device (4) is performed by means of a proportional integral (PI) controller (13).
7. A method according to any of the preceding claims, wherein the step of deriving a superheat value of refrigerant leaving the evaporator (5) comprises measuring a temperature of refrigerant leaving the evaporator (5) and an evaporating temperature of the evaporator (5), and calculating the superheat value from the measured temperatures.
8. A method according to any of claims 1-6, wherein the step of deriving a superheat value of refrigerant leaving the evaporator (5) comprises measuring a temperature of refrigerant leaving the evaporator (5) and a pressure of refrigerant leaving or entering the evaporator (5), and calculating the superheat value from the measured temperature and pressure.
9. A method according to any of claims 1-6, wherein the step of deriving a superheat value of refrigerant leaving the evaporator (5) comprises measuring a temperature of refrigerant leaving the evaporator (5) and a temperature of refrigerant entering the evaporator (5), and calculating the superheat value from the measured temperatures.
10. A method according to any of the preceding claims, further comprising the steps of:
 - opening the expansion device (4) and subsequently operating the expansion device (4) in accordance with a previously stored reference superheat value,
 - monitoring the superheat value of refrigerant leaving the evaporator (5), and
 - in the case that the superheat value of refrigerant leaving the evaporator (5) decreases below a predefined threshold value, performing the steps of calculating a quantity being representative for a variance of the derived superheat value, calculating a reference superheat value, based on the calculated quantity and on a minimum acceptable superheat value, and operating the expansion device (4) in accordance with the calculated reference superheat value, and in order to obtain a superheat of refrigerant leaving the evaporator (5) which is equal to the reference superheat value.

11. A method according to claim 10, wherein the predefined threshold value is a predefined offset above the previously stored reference superheat value.

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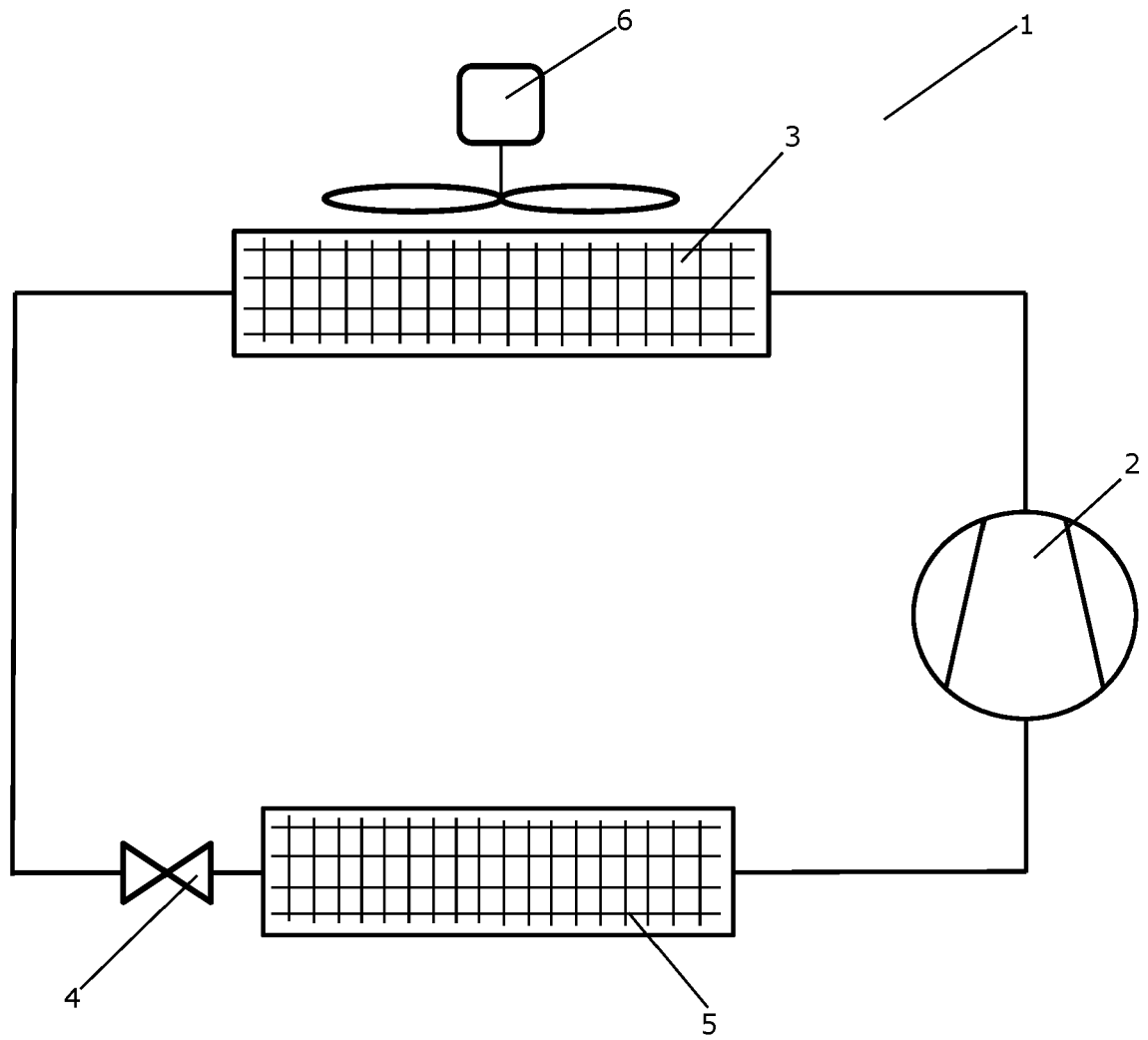


Fig. 1

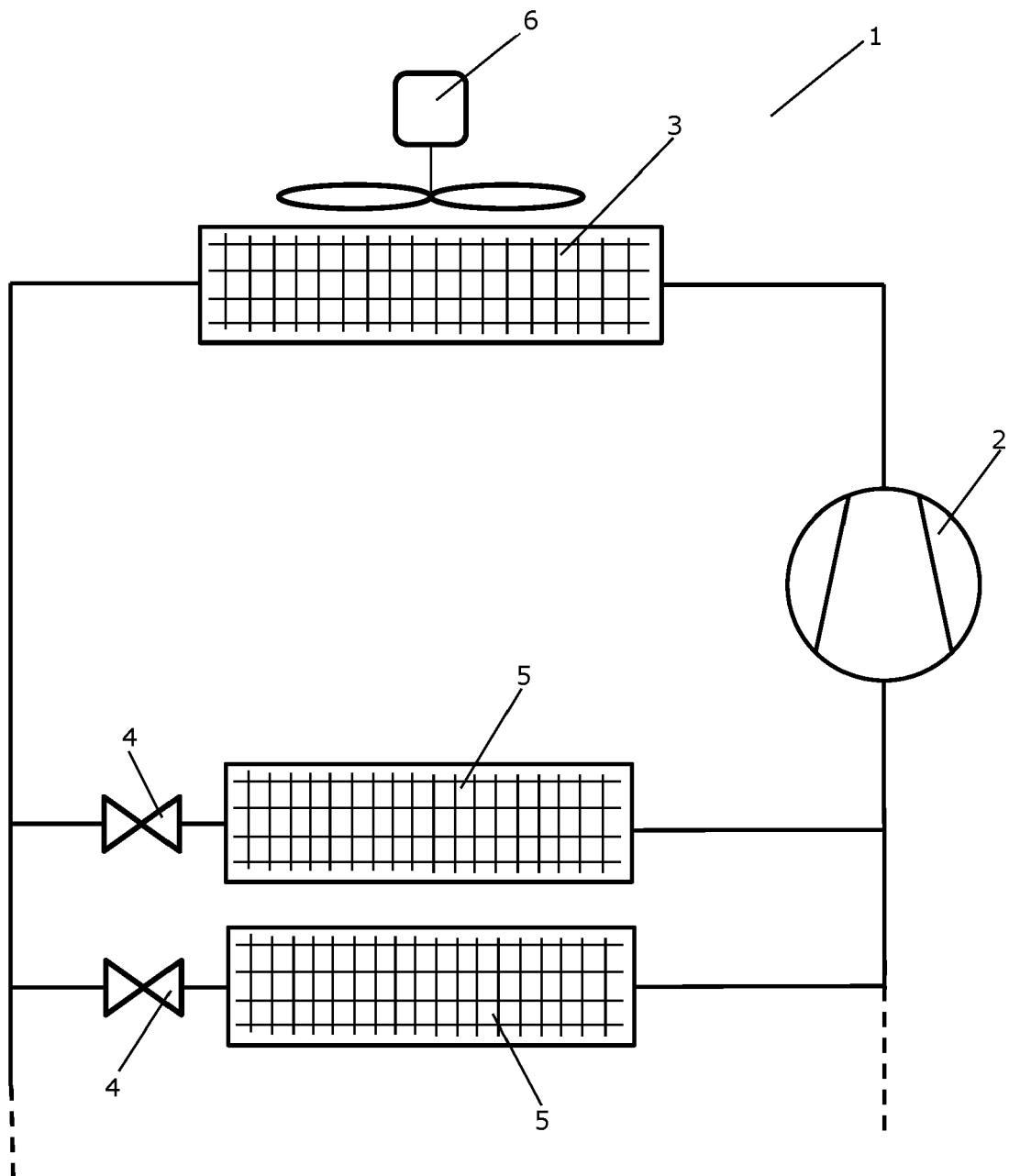


Fig. 2

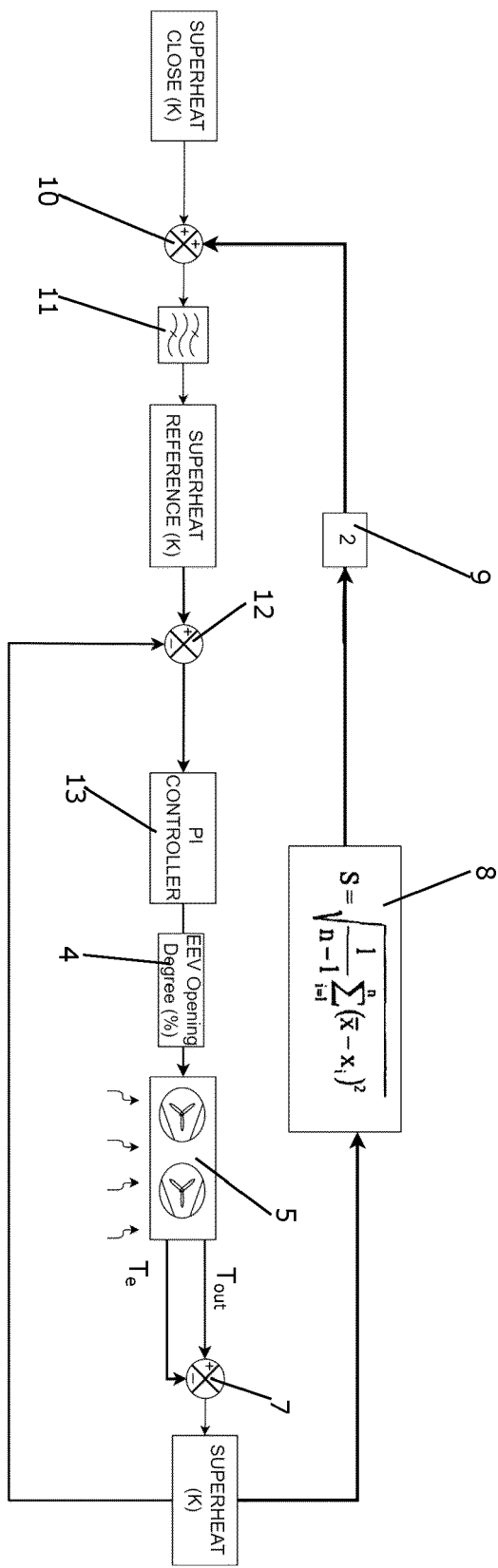


Fig. 3

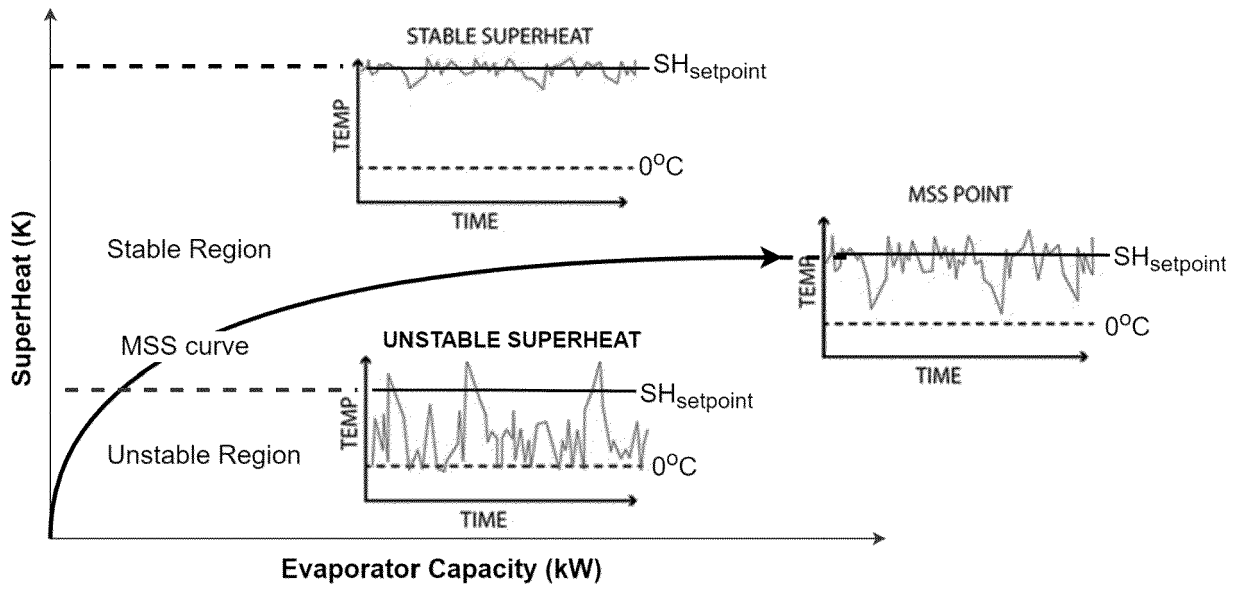


Fig. 4

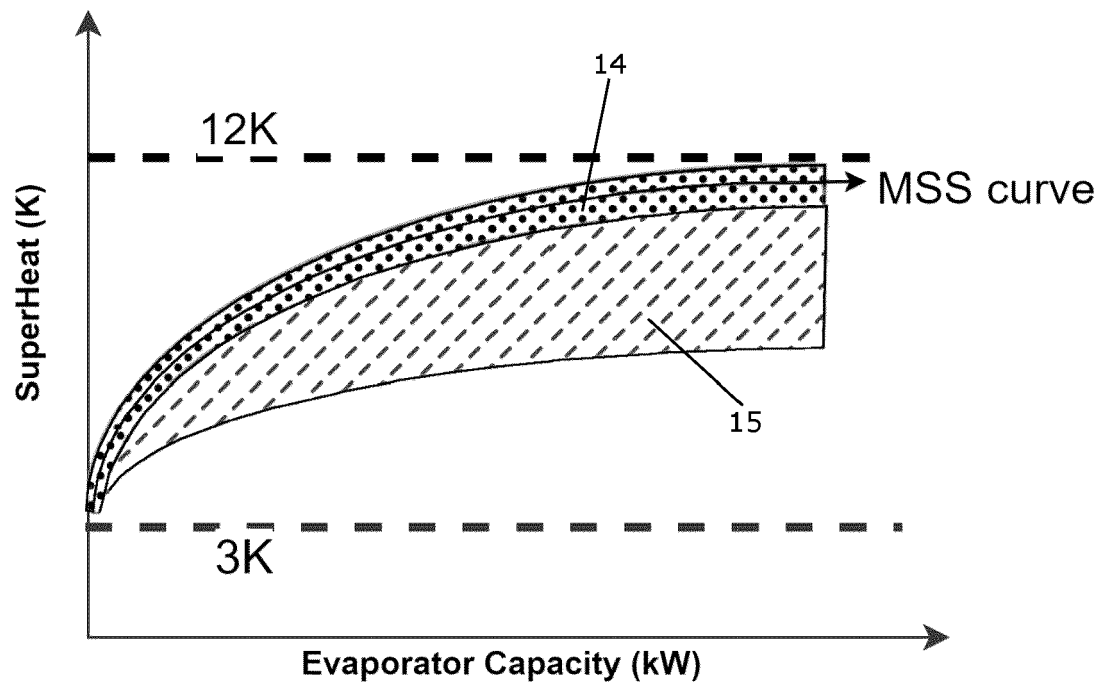


Fig. 5



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Y	* paragraphs [0028] - [0048]; figure 1 *	2, 3	F25B49/00
A	-----	10, 11	F25B49/02
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The present search report has been drawn up for all claims			
Place of search Munich		Date of completion of the search 29 August 2022	Examiner Gaspar, Ralf
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