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(54) Control of evaporator defrosting in an air-operated heat pump unit

(57) In a heat pump unit that uses a refrigeration cycle and operates between a cold source (Sf) consisting of ambient air and a hot source (Sc), evaporator defrosting is operated on the base of external air temperature (TL) and pressure (PE) and/or temperature (TE) of the coolant gas in the evaporator, as reference parameters

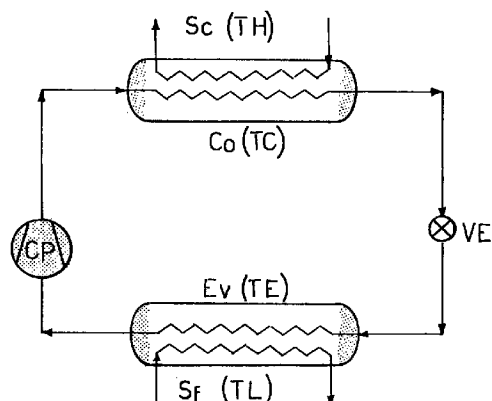


FIG. 1

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Description

Heat pumps are machines that use a cooling or refrigeration cycle (reverse Carnot cycle) to produce heat at medium and high temperatures. The refrigerating machines that follow this cycle use energy in an external mechanical form (work - L), and as a result produce a transfer of heat energy from a low-temperature heat source (TL) to a high-temperature heat source (TH).

The efficiency of a heat pump is indicated as COP (Coefficient of Performance), and is defined by the ratio:

$$\text{COP} = \text{EH} / \text{L}$$

wherein EH is the heat energy yielded to the high temperature heat source TH.

As $\text{EH} = \text{L} + \text{EL}$, wherein EL is the heat energy withdrawn from the low temperature heat source TL,

$$\text{COP} = (\text{EL} + \text{L}) / \text{L} = 1 + \text{EL}/\text{L}$$

In an ideal Carnot refrigeration cycle:

$$\text{COP} = \text{TH} / (\text{TH} - \text{TL})$$

TH and TL are expressed in degrees Kelvin. This relationship indicates that the lower the difference in temperature between the two heat sources, the greater the COP of the heat pump, for a same temperature TH of the hot source.

An elementary cooling circuit used as a heat pump is shown in diagram form in Figure 1.

It basically consists of a compressor CP, a high-temperature heat exchanger (Condenser C_o on hot source S_o), a low-temperature heat exchanger (Evaporator E_v on cold source S_i) and an expansion valve VE.

During operation:

- the cooling machine receives heat from cold source S_i in that heat energy EL flows from cold source S_i at temperature TL towards the evaporator at temperature TE ($\text{TE} \leq \text{TL}$ in order for a flow of heat to take place)
- the compressor supplies mechanical energy L to the cooling cycle
- the machine yields heat EH to hot source S_o ; heat flows from the condenser at temperature TC to the hot source at temperature TH ($\text{TH} \leq \text{TC}$)
- the temperature of the cooling fluid is reduced through the expansion valve.

Compared with an ideal machine, in which the transformations at the condenser and evaporator take place at the same temperature as the sources, the real machine has a worse COP because (for reasons due to heat flow) it has to operate with greater temperature dif-

ferences.

$$\text{a) } \text{TC} - \text{TE} > \text{TH} - \text{TL}$$

$$\text{in which: b) } \text{TC} > \text{TH} \quad \text{c) } \text{TE} < \text{TL}$$

In the construction of refrigerating or cooling machines, the primary objective is to reduce the difference between the first and second terms of expression a) by reducing the individual differences between the temperatures in expressions b) and c).

The temperature differences indicated by expressions b) and c) depend on the dimensioning of the heat exchangers and the technical and financial factors involved in the design of cooling machines. An infinitely large heat exchanger would obviously operate with a nil difference between the temperatures of the heating fluid and the heated fluid.

Every cooling machine therefore has its own operating values TL - TE and TC - TH, based on its design.

If these temperature differences are maintained at the minimum values during operation, certainly the cooling machine is operating with the highest possible COP.

In air-operated heat pumps, the cold source is external ambient air and the hot source is the hot water produced at the condenser or the air in the space to be heated.

Heat exchange at the evaporator takes place between the coolant fluid, which evaporates, and the external air, whose enthalpic content declines. This is described as variation in enthalpic content, because the air cooling phenomenon during transit in the evaporator depends on parameters such as temperature and relative humidity.

Air evaporators used in heat pumps consists of sets of finned pipes. Coolant fluid flows inside the pipes, and the external ambient air flows outside them. When the air meets the cold surfaces of the set of finned pipes it deposits part of its moisture content on them in the form of condensate. The higher the absolute humidity of air entering the set of pipes, the greater the amount of condensate deposited.

Figure 2 shows a psychrometric chart for air. In the cooling transformation shown as 1-2 in the psychrometric chart, under the conditions prevailing at point 1 (start of cooling), the absolute humidity of the air is high, while at point 2 (end of cooling), the humidity content of air is lower; transformation 1-2 takes place with condensate depositing on the surface of the set of pipes. In cooling transformation 3-4, the humidity content of the air before cooling is low, and does not vary up to the output; transformation 3-4 therefore takes place without that the condensate deposits.

Below given external air temperature and relative humidity values, the refrigerant or coolant fluid in the set of finned pipes (evaporator) acquires negative temperature values, which reduce the temperature of the outer surface of the pipes and fins to values of 0°C and below.

Under these conditions, the condensate freezes

and accumulates on the fins in the form of compact ice or frost. Ice increases the heat resistance and worsens the heat exchange between air and coolant fluid; the difference $TL - TE$ increases, and the COP of the heat pump worsens. During frost formation, evaporation temperature TE falls, although external air temperature TL remains constant.

The ice deposited on the evaporating pipes must therefore be removed in order to keep the COP of the machine high.

In heat pump cooling machines, a function called the "defrosting cycle" is periodically activated to melt the ice or frost deposited on the finned pipes. Defrosting can be performed in various ways (by reversal of cycle, injection of hot gas or ventilation, with electrical resistors, etc.). During the defrosting cycle the machine is inactive in the sense that the production of high-temperature heat energy is completely or partly interrupted.

It is essential to quantify and forecast frost formation and activate the defrosting cycles promptly in order to guarantee correct operation of the heat pump. If the defrosting cycles are too frequent or too infrequent, the COP of the heat pump and the hourly output of high-temperature heat energy will be reduced.

The phenomenon of moisture deposit on the fins of an evaporating unit in the form of condensate depends on the external air conditions. These conditions are associated with the climatic, meteorological, seasonal and environmental variables in which the heat pump operates. The relationship between these variables is so complex that it is not usable in practice to activate optimum defrosting cycles.

The heat pumps now known commonly use timed defrosting systems, temperature-operated systems, negative pressure systems, and mixed systems which combine all or some of the first three.

In timed systems, the defrosting cycle runs periodically after a preset time has elapsed. The machine control system usually allows this time to be set. The heat pumps can be suitably preset on the basis of the climatic conditions in which they are intended to operate. However, this system fails to take account of the influence of the other three variables (meteorological, seasonal and environmental conditions) in the formation of ice or frost on the finned pipes. Account must be taken of the worst-case condition of all three variables, which means that the defrosting cycles will be more frequent than necessary in intermediate seasons or when meteorological conditions are favourable.

In temperature-operated systems, a thermometric probe on the evaporating unit detects temperature conditions that can give rise to ice formation, and controls defrosting. This system requires each individual machine to be calibrated and set. It can be used for mass-produced machines or in combination with other systems. It presents the drawback of assuming that a close relationship exists between output temperature and the presence of ice on the unit. However, when the

air temperature is low but the humidity content of the air is also low, no ice will form on the unit, but the system will still order the machine to defrost.

In negative pressure systems, a calibrated differential pressure switch triggers the defrosting cycle. Ice formation on the evaporating unit causes not only an increase in heat resistance, but also an increase in resistance to the air flow crossing the unit. This system presents the drawback of being influenced by wind; it is also difficult to apply to heat pumps with axial fans on the evaporating unit.

The purpose of this invention is to eliminate the drawbacks of the previous technique and ensure that defrosting only takes place as and when necessary.

This purpose has been achieved with the method described in claim 1. Such method will be described below.

In the figures, as already mentioned:

figure 1 schematically illustrates a heat pump machine

figure 2 is a psychrometric chart of air, which shows the temperature in °C on the x axis and the absolute humidity in g/kg on the y axis.

The new method forming the subject of this invention uses two temperatures to control heat pump defrosting cycles in the optimum manner for any climatic, meteorological, seasonal or environmental situation. One of the temperatures can be detected by pressure measurement.

As already mentioned, one of the pre-requisites for efficient operation of a heat pump is that the term $TL - TE$ must always be maintained within minimum values.

The method of management and control of heat pumps in accordance with the invention involves continual measurement of external air temperature TL and pressure PE of the coolant gas in the evaporator. As in the case of any fluid, vapour pressure PE and saturation temperature TE are in a univocal relationship during change of phase; as a result, evaporation temperature TE can be obtained from a pressure gauge reading. By monitoring difference $TL - TE$ (or introducing systematic detection), it is possible to establish when frost forms on the unit. For a few minutes immediately after a defrosting cycle, frost has not yet accumulated on the surface of the evaporating unit, and value $TL - TE$ is the minimum value possible, namely δTi . This value incorporates all the information relating to the climatic, meteorological, seasonal and environmental situation in which the machine operates.

On activation of the machine (first start-up), the new method of management and control of the heat pumps provides for a first forced defrosting cycle. When this initial cycle is over, mean value δTi , which takes place between the 4th and 5th minutes after defrosting, is detected and stored. Under these conditions ice has not yet formed, or at most the amount of ice is so modest as

not to affect the behaviour of the machine. As frost builds up on the unit, $TL - TE$ gradually increases over initial value δTi . When the probes on the machine detect that:

$$TL - TE > \delta Ti + \delta T_{\text{Increment}}$$

a defrosting cycle is triggered. When defrosting is over, the new mean δTi value found between the 4th and 5th minutes is again detected and stored. The monitoring system continually updates the δTi value in this way, and thus follows the behaviour of the machine in accordance with developments in the meteorological situation (rain, fog, wind), and the seasonal and environmental situation (day/night, sun/shade). The COP of the heat pump is always maintained at the highest possible values, and the number of defrosting cycles is minimised. The new method and equipment eliminate the drawbacks of conventional systems. The number of operating hours being equal, the annual heat energy output of a heat pump controlled by the new method is 20% higher than that of the same machine with the conventional type of defrosting system.

The value of $\delta T_{\text{Increment}}$ is usually 8°C but this figure can be modified; field tests demonstrate that whereas higher values have no adverse effect on the operation of the machine, values under 8°C can cause an unnecessary increase in the frequency of defrosting cycles.

Claims

1. Method of control and management of evaporator defrosting in a heat pump unit operating between a cold source (S_f) consisting of environmental air and a hot source (S_c), characterised in that the control parameters used are external air temperature (TL), and pressure (PE) and/or temperature (TE) of the coolant gas in the evaporator.
2. Method as claimed in claim 1, characterised in that detection of the coolant gas pressure in the evaporator (PE) is used to detect the evaporation temperature (TE).
3. Method as claimed in claim 2, characterised in that the difference ($TL - TE$) between the external air temperature and the temperature in the evaporator is monitored to detect frost formation on the evaporator unit.
4. Method as claimed in claim 3, characterised in that an initial mean δTi value is detected and stored equal to the difference ($TL - TE$) between the external air temperature (TL) and the evaporation temperature (TE) of the coolant gas in the evaporator at a preset interval after a reference defrosting cycle,

following which monitoring of the difference ($TL - TE$) between the external air temperature (TL) and the evaporation temperature (TE) continues; when the said difference is $< \delta T + \delta T_{\text{Increment}}$, a defrosting cycle is activated; when defrosting is over, a new mean δT value is detected and stored after a given interval, so that the δT value is continually updated.

5. Method as claimed in claim 4, characterised in that the mean δTi value is detected 4 or 5 minutes after defrosting.
6. Method as claimed in claim 4, wherein $\delta T_{\text{Increment}}$ is approx. 8°C .

