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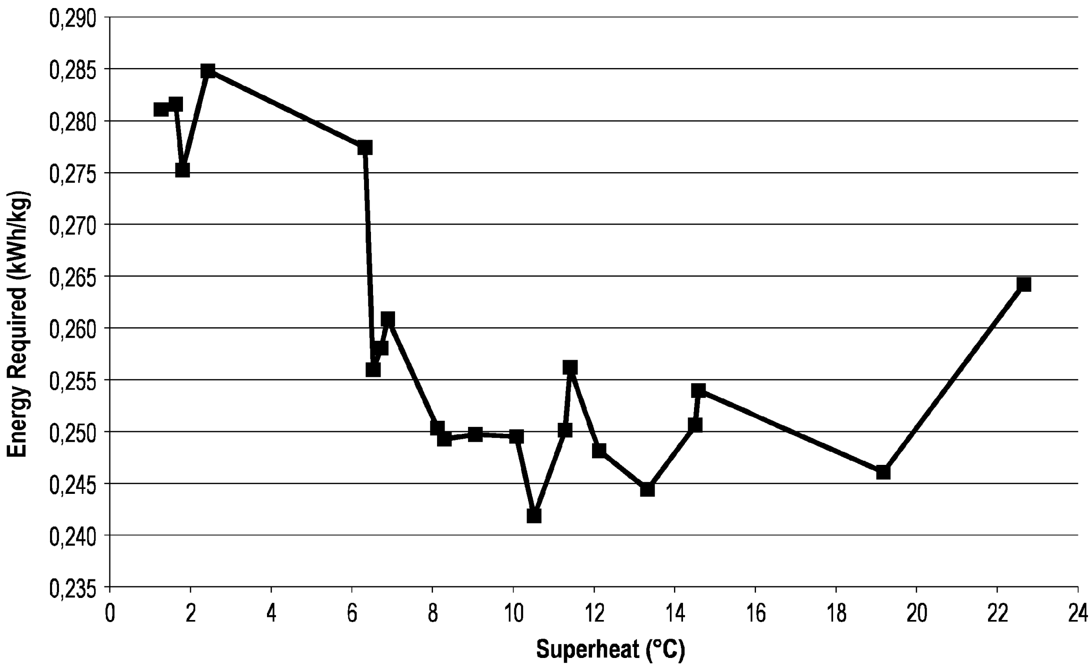
(54) Machine and process for drying humid articles with superheating a refrigerant

(57) The invention relates to a machine (1) comprising a treating chamber (2) for drying humid articles (3) by process air at a pressure substantially equal to an ambient pressure, a process air guide (5) for guiding the process air through said treating chamber (2) in a first circuit substantially closed in itself, said process air guide (5) comprising a first blower (6) for driving the process air, a heater (10) for heating the process air and placed upstream of said treating chamber (2), and a cooler (8) for cooling the process air and placed downstream of said treating chamber (2), wherein said heater (10) and cooler (8) form a heat pump (8,10,12,13) comprising a compressor (12) for driving and compressing the refrigerant through said heat pump and an expander (13) for expanding the refrigerant in a refrigerant circuit (11) and an operating unit (14) for operating said heat pump. Said machine (1) is provided to be operable with superheating the refrigerant to between 6°C and 22°C. Further, the invention relates to a process for execution in such a machine (1).

Fig. 6



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Description

[0001] The invention relates to a machine comprising a treating chamber for drying humid articles by process air at a pressure substantially equal to an ambient pressure, a process air guide for guiding process air through said treating chamber in a first circuit substantially closed in itself, said process air guide comprising a blower for driving the process air, a heater for heating the process air and placed upstream of said treating chamber, and a cooler for cooling the process air and placed downstream of said treating chamber, a heat pump, wherein said heater is a heat source for transferring heat from a refrigerant to the process air by liquefying the refrigerant, and wherein said cooler is a heat sink for transferring heat from the process air to the refrigerant by evaporating and superheating the refrigerant, said heat pump further comprising a compressor for driving and compressing the refrigerant through said heat pump for pumping heat from said heat sink to said heat source, an expander for expanding the refrigerant, and a refrigerant guide for guiding the refrigerant through said heat pump in a second circuit closed in itself, and an operating unit for operating said process air guide and said heat pump in treating the articles.

[0002] Likewise, the invention relates to a machine thus specified and wherein a nominal drying process for drying a nominal amount of the humid articles is scheduled for execution, said nominal process requiring a nominal amount of energy input during execution.

[0003] In addition, the invention relates to a process for drying humid articles by process air at a pressure substantially equal to an ambient pressure in a machine comprising a treating chamber for drying the articles, a process air guide guiding process air through the treating chamber in a first circuit substantially closed in itself, the process air guide comprising a blower driving the process air, a heater heating the process air and placed upstream of the treating chamber, and a cooler cooling the process air and placed downstream of the treating chamber, a heat pump, wherein said heater is a heat source transferring heat from a refrigerant to the process air by liquefying the refrigerant, and wherein the cooler is a heat sink transferring heat from the process air to the refrigerant by evaporating and superheating the refrigerant, the heat pump further comprising a compressor driving and compressing the refrigerant through the heat pump for pumping heat from the heat sink to the heat source, an expander expanding the refrigerant, and a refrigerant guide guiding the refrigerant through the heat pump in a second circuit closed in itself, and an operating unit operating the process air guide and the heat pump in treating the articles.

[0004] Likewise, the invention relates to a process thus specified, wherein, in said machine as specified, a nominal drying process for drying a nominal amount of the humid articles is scheduled for execution, said nominal process requiring a nominal amount of energy input during execution.

[0005] A machine as embodied in a household appliance and a process of this generic type are disclosed in WO 2008/107266 A1. The machine disclosed is a household laundry dryer whose heat pump is a compressor-type heat pump which is characterized by having a refrigerant which is guided in a closed refrigerant guide. To effect an absorption of heat into the associated heat sink, the refrigerant is made to evaporate in the heat sink, and to release heat from the associated heat source, the refrigerant is made to liquefy in the heat source. To transport the heat and have the evaporation and liquefaction processes occur at appropriate temperatures, the gaseous refrigerant is compressed as it passes from the heat sink to the heat source, and the liquid refrigerant is expanded in an expansion system as it returns from the heat source to the heat sink. According to the cited document, special selections of the compressor comprised by the heat pump, and the refrigerant, are made.

[0006] Documents WO 2009/053257 A1 and EP 2 138 627 A1 also disclose machines and processes for drying articles by process air. According to the former document, a special selection of the refrigerant in view of operational and environmental criteria is disclosed. According to the latter document, means are provided to handle condensate which is produced in the heat sink from humidity extracted from the articles being treated, which articles are laundry being dried, in the machine disclosed, and handling concurrently particulate impurities in the form of lint which always occurs upon operating a machine dedicated to drying wet laundry.

[0007] In accordance with each of the cited documents, the process air used for drying the articles is guided in a first circuit that substantially closed in itself, meaning that, on one hand, no substantial and intentional exchange of air between an ambient of the respective machine and the interior of the process air guide is provided, but, on the other hand, there is neither any tight seal which would bar any exchange or any means to change the pressure of the process air in relation to the ambient pressure, except a blower which will create some slight pressure drop through the process air guide to enable the desired flow of air. Yet, some minor exchange of air may be provided by a controllable flap or the like on purpose of enabling to eject excess heat from the process air guide, for example. In accordance with each of the cited documents, the refrigerant circulates in a circuit which is generally closed by the best available means against any leaking of refrigerant. On one hand, most refrigerants commonly used are more or less problematic for reasons of environment protection or even operational safety. On the other hand, the thermodynamic process to be executed by use of the refrigerant requires retaining prerequisite conditions within the refrigerant circuit over a very substantial period of time that may amount to more than ten years in the case of the machine being a household appliance, precluding any substantial loss of refrigerant from the circuit through such amount of years.

[0008] None of the references mentions the feature of superheating the refrigerant that circulates in the heat pump of the respective machine disclosed. Yet, it is to be understood that it is a routine matter of functional safety for every heat pump of the compressor type, to implement a slight superheat of the refrigerant absorbing heat in the heat sink. Thereby, any possibility of refrigerant to reach the compressor in liquid state is eliminated, thus preventing possible damage to the components of the compressor exposed to the refrigerant. Such slight superheating of the refrigerant is provided by having a temperature of the refrigerant upon exiting the evaporator exceed an evaporation temperature of the refrigerant upon exit, meaning the evaporation temperature at the internal pressure prevailing at the exit of the evaporator, by a few degrees, meaning 2 °C to 4 °C as an example. Any superheating in excess of the measure motivated by the safety reasons set out above remains undesired. As a first reason, any superheat implies an increase in outlet pressure at the compressor and a reduced mass flow of refrigerant through the compressor. As a second reason, the temperature prevailing at the exit of the evaporator in a cooling application like a refrigerator or a climate-control appliance marks the local maximum temperature; any increase in superheat would imply an increase in that maximum temperature and a consequential limitation in cooling power offered by the evaporator. As a third reason, cooling of the compressor which is routinely provided by the refrigerant may be reduced as well.

[0009] While none of the references mentions a machine as specified above wherein a nominal drying process for drying a nominal amount of the humid articles is scheduled for execution, said nominal process requiring a nominal amount of energy input during execution, it is to be understood that it is a routine matter of assessing pertinent functional data of such machines to evaluate the performance of a machine in a predetermined nominal drying process, as a matter of comparability between competing machines for customer information and other purposes. Such nominal drying process will be defined by specifying a predetermined amount of laundry consisting of a predetermined type of textile and to be provided in a predetermined state of humidity, and scheduling to dry that amount of laundry in a machine to be assessed by selecting a drying program provided and suitable for drying textiles as present in that amount of laundry.

[0010] In view of the foregoing it is an object of the present invention to provide further developments of the machines and processes for drying articles by process air as specified in the present introduction, to further improve the drying of articles by process air.

[0011] With this and other objects in view there are specified, in accordance with the present invention, machines and processes as defined in the respective attached independent claims. Preferred embodiments of the invention are specified in dependent claims as attached and in the subsequent specification, where each preferred embodiment of an inventive machine implies preferred embodiments of the inventive processes and vice versa, even if not expressly indicated herein.

[0012] Thus, in accordance with a first aspect of the present invention, the inventive machine comprising a treating chamber for drying articles by process air at a pressure substantially equal to an ambient pressure, a process air guide for guiding the process air through said treating chamber in a first circuit substantially closed in itself, said process air guide comprising a blower for driving the process air, a heater for heating the process air and placed upstream of said treating chamber, and a cooler for cooling the process air and placed downstream of said treating chamber, a heat pump, wherein said heater is a heat source for transferring heat from a refrigerant to the process air by liquefying the refrigerant, and wherein said cooler is a heat sink for transferring heat from the process air to the refrigerant by evaporating and superheating the refrigerant, said heat pump further comprising a compressor for driving and compressing the refrigerant through said heat pump for pumping heat from said heat sink to said heat source, an expander for expanding the refrigerant, and a refrigerant guide for guiding the refrigerant through said heat pump in a second circuit closed in itself, and an operating unit for operating said process air guide and said heat pump in treating the articles is provided to be operable with superheating the refrigerant in said heat sink to an exit temperature attained upon exiting said heat sink which exceeds an evaporating temperature of said refrigerant upon exiting said heat sink by a superheat between 6°C and 22°C.

[0013] Likewise, in accordance with a second aspect of the present invention, the inventive machine comprising a treating chamber for drying humid articles by process air at a pressure substantially equal to an ambient pressure, a process air guide for guiding the process air through said treating chamber in a first circuit substantially closed in itself, said process air guide comprising a first blower for driving the process air, a heater for heating the process air and placed upstream of said treating chamber, and a cooler for cooling the process air and placed downstream of said treating chamber, a heat pump, wherein said heater is a heat source for transferring heat from a refrigerant to the process air by liquefying the refrigerant, and wherein said cooler is a heat sink for transferring heat from the process air to the refrigerant by evaporating and superheating the refrigerant, said heat pump further comprising a compressor for driving and compressing the refrigerant through said heat pump for pumping heat from said heat sink to said heat source, an expander for expanding the refrigerant, and a refrigerant guide for guiding the refrigerant through said heat pump in a second circuit closed in itself, and an operating unit for operating said process air guide and said heat pump in treating the articles, wherein a nominal drying process for drying a nominal amount of the humid articles is scheduled for execution, said nominal process requiring a nominal amount of energy input during execution, is provided to be operable with superheating the refrigerant in said heat sink to an exit temperature attained upon exiting said heat sink which exceeds an evaporating temperature of said refrigerant upon exiting said heat sink by a superheat that is defined to yield a minimum in said nominal amount of energy input required by said nominal drying process.

[0014] Likewise, according to the first aspect of the present invention, the inventive process for drying articles by process air at a pressure substantially equal to an ambient pressure in a machine comprising a treating chamber for drying the articles, a process air guide guiding the process air through the treating chamber in a first circuit substantially closed in itself, the process air guide comprising a blower driving the process air, a heater heating the process air and placed upstream of the treating chamber, and a cooler cooling the process air and placed downstream of the treating chamber, a heat pump, wherein said heater is a heat source transferring heat from a refrigerant to the process air by liquefying the refrigerant, and wherein the cooler is a heat sink transferring heat from the process air to the refrigerant by evaporating and superheating the refrigerant, the heat pump further comprising a compressor driving and compressing the refrigerant through the heat pump for pumping heat from the heat sink to the heat source, an expander expanding the refrigerant, and a refrigerant guide guiding the refrigerant through the heat pump in a second circuit closed in itself, and an operating unit operating the process air guide and the heat pump in treating the articles, is characterized by superheating the refrigerant in said heat sink to an exit temperature attained upon exiting said heat sink which exceeds an evaporating temperature of said refrigerant upon exiting said heat sink by a superheat between 6°C and 22°C.

[0015] Likewise, according to the second aspect of the present invention, the inventive process for drying humid articles by process air at a pressure substantially equal to an ambient pressure in a machine comprising a treating chamber for treating the articles, a process air guide guiding the process air through the treating chamber in a first circuit substantially closed in itself, the process air guide comprising a blower driving the process air, a heater heating the process air and placed upstream of the treating chamber, and a cooler cooling the process air and placed downstream of the treating chamber, a heat pump, wherein said heater is a heat source transferring heat from a refrigerant to the process air by liquefying the refrigerant, and wherein the cooler is a heat sink transferring heat from the process air to the refrigerant by evaporating and superheating the refrigerant, the heat pump further comprising a compressor driving and compressing the refrigerant through the heat pump for pumping heat from the heat sink to the heat source, an expander expanding the refrigerant, and a refrigerant guide guiding the refrigerant through the heat pump in a second circuit closed in itself, and an operating unit operating the process air guide and the heat pump in treating the articles, wherein, in the machine, a nominal drying process for drying a nominal amount of the humid articles is scheduled for execution, said nominal process requiring a nominal amount of energy input during execution, is characterized by superheating the refrigerant in the heat sink to an exit temperature attained upon exiting said heat sink which exceeds an evaporating temperature of said refrigerant upon exiting said heat sink by a superheat that is defined to yield a minimum in said nominal amount of energy input required by said nominal drying process.

[0016] In accordance with all aspects of the present invention it has been perceived that the machine and process of the generic type as specified in the present introduction each include two interacting thermodynamic processes, the first process running in the first circuit to evaporate, transport and re-condense humidity from the articles to be dried by circulating process air, and the second process running in the second circuit to pump heat from a heat sink which does the re-condensing of humidity extracted from the articles to a heat source which provides heat to the process air for doing the evaporation of humidity yet prevailing in the articles. In contrast to usual practice which will obtain a quick fixing of process parameters by setting the process temperatures to appropriate values and electing a suitable refrigerant for use in the second circuit, the present invention relies on exploiting additional degrees of freedom in designing a heat pump in a dryer.

[0017] Thus, it has been found in accordance with this invention that considerable improvements in overall expenditure for drying articles are obtained by dedicatedly superheating the refrigerant in the heat sink to temperature levels far away from those required by usual practice. Surprisingly, the disadvantageous effect of increasing the operational loads on the compressor by increasing the refrigerant's temperature upon increasing its superheating is countered, and in fact much more than compensated, by a considerable improvement in transporting humidity from the articles to be dried to the heat sink for condensation. In particular it has been understood that, given a certain flow of process air in a given process air circuit, to increase the transport of humidity by the process air under implies to increase the temperature of the process air as it exits the treatment chamber and enters the heat sink. The reason is that the capability of process air to dissolve steam increases with the temperature of the process air. In increase in temperature of the process air upon entering the heat sink implies, assuming a drying process running in a stationary state, an increase of the maximum temperature According to the invention, the increase in temperature of the process air upon entering the heat sink is accomplished by increasing the maximum temperature of the refrigerant in the heat sink, implying an increase in superheating the refrigerant. In other words, the invention avoids excess cooling of the process air in the process air circuit, to maintain or even increase a maximal capability for transporting humidity from the articles to be dried to the heat sink. An increase in heating the process air in the heat source due to the increased superheat implying an increase in temperature of the refrigerant upon exiting the compressor also contributes to the increase in the capability to transport humidity. This in effect results in substantial savings of energy required for drying a standard load of articles. Thus, savings of 15 % in total energy required for drying could be saved in an inventive machine implemented as a household dryer by increasing the superheat from 2 °C as recommended in prior art to 12 °C.

[0018] According to the invention, the increase in superheating may be implemented by adjusting the restriction of the expander in the heat pump, either as a matter of choice during development, or as a matter of controlling a variable restriction. The increased restriction implies a reduction in temperature of the refrigerant upon exiting the expander and entering the heat sink which is readily utilized to improve condensation of humidity from the process air to contribute even more to increase in the capability to transport humidity.

[0019] Accordingly, a positive effect obtained is that the refrigerant emerges from the expander to enter the heat sink at a reduced temperature, thus increasing the temperature difference between the process air and the refrigerant and increasing the effectivity of heat transfer between these fluids. Another positive effect is an increase in extraction of heat from the process air in the heat sink, resulting in a reduction of process air temperature upon exiting the heat sink and implying an increase in extraction of humidity from the process air. In total, this results in an overall improvement in effectivity as an immediate consequence.

[0020] The decrease in refrigerant temperature entering the heat sink incurs a decrease in refrigerant mass flow, thus limiting the total cooling effect on the process air and keeping its temperature at an advantageous level. As to the temperature of the refrigerant upon leaving the compressor which is the maximum temperature of the refrigerant through the whole heat pump, the increased superheating results in another increase which in turn improves the heat transfer to the process air in the heat source.

[0021] An extended increase of superheating will result in a loss of the advantages just described due to the decrease in mass flow of the refrigerant and the according reduction in cooling power available. If the mass flow of the refrigerant gets too low, the reduction of refrigerant temperature upon entering the heat sink will no longer suffice to retain an according temperature reduction in the process air upon exiting the heat sink, with a resultant loss in overall effectivity. In addition, a temperature limitation imposed on the refrigerant upon exiting the compressor may limit the advantages to be obtained by limiting the total heating power available to heat the process air prior to entering the treatment chamber. Such limitation may be effected by using means for bleeding excess heat from the process air or refrigerant circuit. Such limitation may be necessary to keep the temperature of the refrigerant from exceeding a threshold set from thermodynamic or safety considerations. A limited heating power will keep the process air from absorbing its maximal load of humidity even if its temperature upon exiting the treatment chamber is maintained at a desired level; the problem is that the process air will be less than saturated with humidity, thus restricting the transport of humidity from the treatment chamber to the heat sink. According to an aspect of the present invention the advantages set out above are attained in a range of superheat between a superheat of 6 °C and a superheat of 22 °C, with preferred ranges as specified hereinbelow.

[0022] As to the composition of the heat pump it is to be noted that the mentioning of its components hereinabove is not exhaustive. In addition to the components mentioned above the heat pump may include means for stabilizing the composition of the refrigerant like drying and absorbing agents for catching spurious impurities like residuals from manufacturing and cooling means for bleeding excess heat from the heat pump like an additional heat exchanger. Likewise, the process air circuit may additionally include flaps or valves for partial exchange of process air, or another additional cooling means. The system as a whole may also include control and sensor means, in accordance with pertinent knowledge of a person of ordinary skill in the art.

[0023] As to the refrigerant, agents designated in accordance with usual DIN/ASHRAE practice as R 290, R134a, R152a, R407C, R410A, and R744, may be applied in accordance with the invention. While R290 is the hydrocarbon compound propane which could require dedicated fire hazard protection means for its use, and R744 is carbon dioxide which would possibly require much more complex heat pump circuitry, the other compounds are fluorinated hydrocarbon compounds, or mixtures of such. All of these fluorinated hydrocarbon compounds and mixtures are well suited for the purpose of the invention, and would not require complex heat pump circuitry or fire hazard protection like R290. Yet, some of these compounds and mixtures may be regarded as problematic in view of their impact upon release into the environment.

[0024] In accordance with a preferred embodiment of the invention, the superheat is selected at a value between 8°C and 16°C. In an even more preferred embodiment, the superheat is selected at about 12°C. It has been established, in accordance with the invention, that the advantages referred to above are attained to a particularly great extent if the superheat is selected between 8°C and 16°C, and around 12°C in particular.

[0025] In accordance with another preferred embodiment of the invention, the inventive machine is embodied as a household appliance. In particular, the machine may be a laundry dryer or laundry washer-dryer.

[0026] In accordance with a further preferred embodiment of the invention, at least one of the heat source and the heat sink is a counter flow heat exchanger, with the refrigerant and the process air passing such heat exchanger substantially in counter-flow. It should be noted that the feature of counter-flow will generally not necessarily have to be followed into the smallest detail of the heat exchanger; for example, the feature may be broken to an insubstantial extent by certain minor parts of heat exchanger tubing being arranged to transport refrigerant in a direction more or less vertical to the direction of the process air traversing the heat exchanger around that part of the tubing.

[0027] In accordance with yet another preferred embodiment of the invention, the treating chamber is a rotatable drum. This qualifies the invention for embodying in the form of a tumble dryer according to common laundry drying technology.

[0028] In accordance with yet a further preferred embodiment of the invention, an additional cooling means is associated for cooling said heat pump, and wherein said operating unit is provided to operate said cooling means for limiting a temperature in said heat pump to a maximum temperature. In accordance with this embodiment and in view of the energy input required to operate the heat pump, operation of the heat pump may be stabilized in a controlled manner even if dissipation of heat by reasonably unavoidable thermal losses does not suffice in dissipating an amount equal to such energy input. More preferred, such cooling means comprises a second blower for passing cooling air along the heat pump and operable by the operating unit, and a temperature sensor for sensing the temperature of heat pump to be limited and connected to said operating unit.

[0029] In accordance with still another preferred embodiment of the invention, the process for drying articles is structured into an initialization phase wherein operating temperatures of the refrigerant upon entering and exiting the heat source and the heat sink vary, and a quasi-stationary phase wherein a majority of the operating temperatures remains without major variation.

[0030] In accordance with still a further preferred embodiment of the invention, the process for drying articles is structured in that at least during a quasi-stationary phase, a temperature of the refrigerant upon exiting the compressor is retained near a predetermined maximum temperature by additional cooling applied to the heat pump. Based on observing that the temperature of the refrigerant upon exiting the compressor is the highest temperature within the system containing the interacting thermodynamic processes, it is preferred to impose the thermal limitation to stabilize the system on that highest temperature. Even more preferred, the additional cooling is applied by passing cooling air along the heat pump in general and along the compressor in particular, in addition. Still more preferred, the maximum temperature (applicable to the temperature of the refrigerant upon exiting the compressor, being the highest temperature in the system) is between 90°C and 100°C.

[0031] In accordance with an additional preferred embodiment of the invention, the articles to be dried by application of the invention are items of laundry. Even more preferred these items of laundry are tumbled through the process air, to obtain thorough interaction between the process air and the humidity contained in and to be extracted from the items.

[0032] In the subsequent disclosure, preferred embodiments of the invention are discussed with reference to the drawing attached. In the drawing,

Fig. 1	exhibits a schematic diagram showing a drying machine;
Fig. 2	exhibits an enlarged section of the machine shown in Fig. 1;
Fig. 3	exhibits a graph of temperatures in a drying machine with low superheat;
Fig. 4	exhibits a graph of temperatures in a drying machine with intermediate superheat;
Fig. 5	exhibits a graph of temperatures iin a drying machine with high superheat; and
Fig. 6	exhibits the relation between superheat and energy input required to dry a sample batch of laundry.

[0033] As shown schematically in Fig. 1 and Fig.2, a drying machine 1 comprises, generally disposed in a housing 1, a treating chamber 2 as embodied in a rotatable drum 2 to contain humid articles 3, piece of laundry 3 in particular, to be dried by being tumbled in a flow of warm process air by rotating drum 2 which is drive by electric drive 4. The process air flows through process air guide 5, driven by first blower 6. Like drum 2 the first blower 6 is driven by electric drive 4, as indicated by arrows pointing from drive 4 to drum 2 and first blower 6, respectively.

[0034] In the drum 2, the warm process air heats the pieces of laundry 3 and picks up steam evaporated from water contained in the laundry 3. After exiting drum 2, the humid process air flows through lint filter 7 where the process air is scavenged and lint that is small particulate matter including fibres released from the laundry 3 is retained. Subsequently, the humid process air is subjected to cooling in cooler 8, to condense humidity from the process air. Condensate thus formed precipitates on heat exchanging surfaces of cooler 8 and flows to condensate collector 9 for later disposal. The process air thus stripped of humidity flows to heater 10 to be heated again, and is forwarded to drum 2 again to pick up more humidity from laundry 3 by the first blower 6, and to complete its circulation.

[0035] The cooler 8 and the heater 10 are both heat exchangers which exchange heat between the process air and a refrigerant which circulates in closed circuit through a refrigerant guide 11, and in counter-flow to the process air. The refrigerant is selected from a group comprising agents specified as R 290, R134a, R152a, R407C, R410A, and R744 in accordance with usual DIN/ASHRAE practice, with R407C being the preferred selection. R 407C is a mixture of fluorinated hydrocarbon compounds. The refrigerant enters the cooler 8 at a low internal pressure and in a state partly liquid and partly gaseous. By picking up heat from the process air, the refrigerant is fully evaporated to form a gas and superheated to a predetermined extent for reasons to be elaborated upon subsequently. Due to its function to evaporate the refrigerant, the cooler 8 is also termed the "evaporator" 8 according to usual practice. Having exited cooler 8, the gaseous refrigerant reaches compressor 12, preferredly embodied in a rotary piston compressor 12, and is compressed to an elevated internal pressure. This compression is performed substantially adiabatically, to result in a substantial temperature rise within the refrigerant. After exiting the compressor 12, the gaseous refrigerant enters the heater 10 where heat is picked up from the refrigerant by the process air, thereby condensing the refrigerant into liquid form. Due to its function to condense the refrigerant heater 10 is also termed the "condenser" according to usual practice. Having exited heater 10, the refrigerant flows through an expander 13 as embodied in a capillary 13, an orifice 13 or a valve 13 (which may be controllable), wherein the refrigerant undergoes substantially isenthalpic expansion to reduce both its internal pressure and temperature, to attain again the state partly liquid and partly gaseous as initially, to complete a full circulation through refrigerant guide 11. By circulating the refrigerant extracts heat from the process air in the evaporator 8, has this heat transformed to an elevated temperature by action of compressor 12, and returns this heat (together with some excess heat given by the input of mechanical energy to the compressor 12) to the process air in the heater 10. Thereby cooler 8, heater 10, refrigerant guide 11, compressor 12 and expander 13 form the necessary components of a heat pump 8, 10, 11, 12, 13. As apparent from usual practice the heat pump 8, 10, 11, 12, 13 may contain additional components like a scavenger to absorb undesired impurities from the refrigerant or a storage device to contain an extended amount of refrigerant as well as additional heat exchangers that may be essential for a heat pump 8, 10, 11, 12, 13 that uses R744 which is carbon dioxide as a refrigerant in a so-called trans-critical cycle.

[0036] Functional control of the drying machine 1 including interfacing to a user as well as defining and controlling the overall function of the components of drying machine 1 is performed by the electronic operating unit 14.

[0037] Presently, means to bleed excess heat from heat pump 8, 10, 11, 12, 13 include a second blower 15 which forwards cooling air ingested from an ambient of drying machine 1 to the compressor 12 through coolant guide 16, and returns such cooling air to the ambient. Operation of second blower 15 is effected by operating unit 14 is response to measurements of the refrigerant's temperature upon exiting compressor 12 b temperature sensor 17. signal and control lines connecting operating unit 14 to second blower 15 and sensor 17 are indicated by dashed lines; other connections to operating unit 14 not being shown for the sake of clarity. By these means the temperature of the refrigerant upon exiting compressor 12, which is the highest temperature within the process air and refrigerant circuits in the machine 1, is limited to a predetermined maximum to avoid any undesired overheating.

[0038] In relation to Fig.1, Fig. 2 shows the heat pump part of the machine shown in Fig. 1, with some points shown as black dots indicating where operating temperatures have been registered over time for several superheats during experimental drying processes.

[0039] Special operating features of the drying machine shown in Fig. 1 and Fig. 2 will now be detailed by reference to temperatures of the refrigerant and process air at predetermined locations within their respective circuits. These temperatures are:

- 18 Evap in: Refrigerant upon entering cooler 8
- 19 Evap out: Refrigerant upon exiting cooler 8
- 20 Air evap in: Process air upon entering cooler8
- 21 Air evap out: Process air upon exiting cooler 8
- 22 Comp out: Refrigerant upon exiting compressor 12
- 23 Cond out: Refrigerant upon exiting heater 10
- 24 Air cond out: Process air upon exiting heater 10.

[0040] Data apparent from Fig. 3 have been taken in a machine wherein the superheat had been set to 2 °C by appropriate selection of operational parameters of expander 13. A superheat of 2 °C may be understood to be representative for common practice in heat pump design, selecting the superheat just high enough to rule out any nun-gaseous refrigerant to reach compressor 12. In Fig. 2, the actual superheat is shown as the temperature difference between curves 19, which is the refrigerant temperature upon exiting cooler 8, and 18, which is the refrigerant temperature upon entering cooler 8. Curves 20 and 21 indicate the process air temperatures upon entering (curve 20) and exiting (curve 21) cooler 8. It may be observed that hardly any temperature difference between these curves is discernible until the last third of the drying process, say from 120 minutes onwards. This is due to the fact that the cooling action within cooler 8 results in condensing humidity from the process air only at least for the first two thirds of the drying process. Only as soon as the humidity content of the process air entering cooler 8 becomes lower as the batch of laundry approaches dryness, the process air temperature is also decreased in cooler 8. The temperature level of curve 21 is indicative of the degree of extraction of humidity from the process air reached by the cooling action of the refrigerant. The lower the temperature level is the more humidity has been extracted. Curve 22 indicates the refrigerant temperature upon exiting compressor 12 (and entering heater 10). Curve 23 indicates the refrigerant temperature upon exiting heater 9. Curve 24 indicates the process air temperature upon exiting heater 9. It is noted that that temperature level is indicative of the capability of the process air to absorb humidity from the batch of laundry being dried in drum 2. The higher the temperature level is the more humidity can be extracted from the batch of laundry.

[0041] The sharp and short variation of all temperatures shown in Fig. 3 is caused by pouring cleaning liquid (namely, condensate collected and stored through the previous part of the drying process) over the surfaces of the cooler 8 exposed to the process air, to remove precipitated lint from these surfaces.

[0042] Data apparent from Fig. 4 have been taken with a superheat set to 12 °C, much above a superheat as suggested by common practice. It may be noted that due to the increased restriction of expander 13 all curves show a gradual and extended increase to quasi-stationary levels. Ripples present on the curves indicate activity of second blower 15 which has been actuated upon evaluating signals from temperature sensor 17 to bleed excess heat from the heat pump and keep refrigerant temperature at or below a predetermined maximum. The most striking feature of Fig. 4 is the large increase in refrigerant temperature upon exiting compressor 12 from some 65 °C according to Fig. 3 to some 95 °C according to Fig. 4, resulting in a substantial increase in heating capability to heat the process air. Further, the temperature level of the process air upon exiting cooler 8 (namely, curve 21) has been maintained at the level indicated in Fig. 3 showing that the increased pickup of humidity from the batch of laundry is accompanied by an increased extraction of humidity in cooler 8 resulting in a much faster drying process. Instead of taking 25,2 minutes to dry 1 kg of laundry provided with standard initial humidity, the process shown in Fig. 4 takes 20,5 minutes only. As to related energy input required, the machine configuration of Fig. 4 will require only 0,246 kWh/kg instead of 0,285 kWh/kg for the configuration of Fig. 3.

[0043] Data apparent from Fig. 5 have been taken with a superheat set to 20 °C. while curve 22 confirms that heating effect can be maximized by heating the refrigerant to the predetermined maximum at 95 °C, all curves indicate that the machine is predominantly slow to attain its quasi-stationary mode of operation after initiating a drying process. Further, curves 21 shows that the temperature level of the process air upon exiting cooler 8 has increased from near 20 °C to well above 30 °C, indicating a considerable decrease .in cooling capability. Accordingly, the drying time for 1 kg of laundry heating increases from 20,5 minutes to 22.4 minutes. Likewise, the total energy input required increases to 0,246 kWh/kg.

[0044] Experimental data on total energy input required in relation to superheat are summarized in Fig. 5. Apparent ripples in the data may be attributed to small changes in ambient conditions of the machine in its test environment, and to fluctuations in preset parameters. Yet, these data confirm that a selection of superheat absent from recommendations of normal practice yields very considerable profits in terms of energy input required for a drying process. Accordingly, a range of superheat to attain lowest energy input required is set from 6 °C to 22 °C, with a preferred range from 8 °C to 16 °C, and a particularly preferred value of superheat at or around 12 °C.

LIST OF REFERENCE NUMERALS

[0045]

1	Drying machine
2	Treating chamber, drum
3	Humid articles, laundry
4	Drive
5	Process air guide
6	First blower
7	Lint filter
8	Cooler, heat sink
9	Condensate collector
10	Heater, heat source
11	Refrigerant guide
12	Compressor
13	Expander
14	Operating unit
15	Second blower
16	Coolant guide
17	Temperature sensor
18	Evap in: Refrigerant upon entering cooler 8
19	Evap out: Refrigerant upon exiting cooler 8
20	Air evap in: Process air upon entering cooler8
21	Air evap out: Process air upon exiting cooler 8
22	Comp out: Refrigerant upon exiting compressor 12
23	Cond out: Refrigerant upon exiting heater 10
24	Air cond out: Process air upon exiting heater 10.

Claims

1. Machine (1) comprising a treating chamber (2) for drying humid articles (3) by process air at a pressure substantially equal to an ambient pressure, a process air guide (5) for guiding the process air through said treating chamber (2) in a first circuit substantially closed in itself, said process air guide (5) comprising a first blower (6) for driving the process air, a heater (7) for heating the process air and placed upstream of said treating chamber (2), and a cooler (8) for cooling the process air and placed downstream of said treating chamber (2), a heat pump (7, 8, 9, 10, 11), wherein said heater (7) is a heat source (7) for transferring heat from a refrigerant to the process air by liquefying the refrigerant, and wherein said cooler (8) is a heat sink (8) for transferring heat from the process air to the refrigerant by evaporating and superheating the refrigerant, said heat pump (7, 8, 9, 10, 11) further comprising a compressor (9) for driving and compressing the refrigerant through said heat pump (7, 8, 9, 10, 11) for pumping heat from said heat sink (8) to said heat source (7), an expander (10) for expanding the refrigerant, and a refrigerant guide (11) for guiding the refrigerant through said heat pump (7, 8, 9, 10, 11) in a second circuit closed in itself, and an operating unit (12) for operating said process air guide (5) and said heat pump (7, 8, 9, 10, 11) in treating the articles (3), **characterized by** being provided to be operable with superheating the refrigerant in said heat sink (8) to an exit temperature attained upon exiting said heat sink (8) which exceeds an evaporating temperature of said refrigerant upon exiting said heat sink (8) by a superheat between 6°C and 22°C.

2. Machine (1) comprising a treating chamber (2) for drying humid articles (3) by process air at a pressure substantially equal to an ambient pressure, a process air guide (5) for guiding the process air through said treating chamber (2) in a first circuit substantially closed in itself, said process air guide (5) comprising a first blower (6) for driving the process air, a heater (7) for heating the process air and placed upstream of said treating chamber (2), and a cooler (8) for cooling the process air and placed downstream of said treating chamber (2), a heat pump (7, 8, 9, 10, 11), wherein said heater (7) is a heat source (7) for transferring heat from a refrigerant to the process air by liquefying the refrigerant, and wherein said cooler (8) is a heat sink (8) for transferring heat from the process air to the refrigerant by evaporating and superheating the refrigerant, said heat pump (7, 8, 9, 10, 11) further comprising a compressor (9) for driving and compressing the refrigerant through said heat pump (7, 8, 9, 10, 11) for pumping heat from said heat sink (8) to said heat source (7), an expander (10) for expanding the refrigerant, and a refrigerant guide (11) for guiding the refrigerant through said heat pump (7, 8, 9, 10, 11) in a second circuit closed in itself, and an operating unit (12) for operating said process air guide (5) and said heat pump (7, 8, 9, 10, 11) in treating the articles (3), wherein a nominal drying process for drying a nominal amount of the humid articles (3) is scheduled for execution, said nominal process requiring a nominal amount of energy input during execution, **characterized by** being provided to be operable with superheating the refrigerant in said heat sink (8) to an exit temperature attained upon exiting said heat sink (8) which exceeds an evaporating temperature of said refrigerant upon exiting said heat sink (8) by a superheat that is defined to yield a minimum in said nominal amount of energy input required by said nominal drying process.

3. Machine (1) according to one of claims 1 and 2, wherein said superheat is between 8 °C and 16 °C.

4. Machine (1) according to claim 3, wherein said superheat is about 12°C.

5. Machine (1) according to one of the preceding claims, which is embodied as a household appliance (1).

6. Machine (1) according to one of the preceding claims, wherein at least one of the heat source (7) and the heat sink (8) is a counter flow heat exchanger (7, 8).

7. Machine (1) according to one of the preceding claims, wherein said treating chamber (2) is a rotatable drum (2).

8. Machine (1) according to one of the preceding claims, wherein an additional cooling means (13, 14) is associated for cooling said heat pump (7, 8, 9, 10, 11), and wherein said operating unit (12) is provided to operate said cooling means (13, 14) for limiting a temperature in said heat pump (7, 8, 9, 10, 11) to a maximum temperature.

9. Machine (1) according to claim 8, wherein said cooling means comprises a second blower (13) for passing cooling air along said heat pump (7, 8, 9, 10, 11) and operable by said operating unit (12), and a temperature sensor (14) for sensing the temperature of heat pump (7, 8, 9, 10, 11) to be limited and connected to said operating unit (12).

10. Process for drying humid articles (3) by process air at a pressure substantially equal to an ambient pressure in a machine (1) comprising a treating chamber (2) for treating the articles (3), a process air guide (5) guiding the process air through the treating cham-

ber (2) in a first circuit substantially closed in itself, the process air guide (5) comprising a blower (6) driving the process air, a heater (7) heating the process air and placed upstream of the treating chamber (2), and a cooler (8) cooling the process air and placed downstream of the treating chamber (2), a heat pump (7, 8, 9, 10, 11), wherein said heater (7) is a heat source (7) transferring heat from a refrigerant to the process air by liquefying the refrigerant, and wherein the cooler (8) is a heat sink (8) transferring heat from the process air to the refrigerant by evaporating and superheating the refrigerant, the heat pump (7, 8, 9, 10, 11) further comprising a compressor (9) driving and compressing the refrigerant through the heat pump (7, 8, 9, 10, 11) for pumping heat from the heat sink (8) to the heat source (7), an expander (10) expanding the refrigerant, and a refrigerant guide (11) guiding the refrigerant through the heat pump (7, 8, 9, 10, 11) in a second circuit closed in itself, and an operating unit (12) operating the process air guide (5) and the heat pump (7, 8, 9, 10, 11) in treating the articles (3), **characterized by** superheating the refrigerant in the heat sink (8) to an exit temperature attained upon exiting said heat sink (8) which exceeds an evaporating temperature of said refrigerant upon exiting said heat sink (8) by a superheat between 6 °C and 22 °C.

11. Process for drying humid articles (3) by process air at a pressure substantially equal to an ambient pressure in a machine (1) comprising a treating chamber (2) for treating the articles (3), a process air guide (5) guiding the process air through the treating chamber (2) in a first circuit substantially closed in itself, the process air guide (5) comprising a blower (6) driving the process air, a heater (7) heating the process air and placed upstream of the treating chamber (2), and a cooler (8) cooling the process air and placed downstream of the treating chamber (2), a heat pump (7, 8, 9, 10, 11), wherein said heater (7) is a heat source (7) transferring heat from a refrigerant to the process air by liquefying the refrigerant, and wherein the cooler (8) is a heat sink (8) transferring heat from the process air to the refrigerant by evaporating and superheating the refrigerant, the heat pump (7, 8, 9, 10, 11) further comprising a compressor (9) driving and compressing the refrigerant through the heat pump (7, 8, 9, 10, 11) for pumping heat from the heat sink (8) to the heat source (7), an expander (10) expanding the refrigerant, and a refrigerant guide (11) guiding the refrigerant through the heat pump (7, 8, 9, 10, 11) in a second circuit closed in itself, and an operating unit (12) operating the process air guide (5) and the heat pump (7, 8, 9, 10, 11) in treating the articles (3), wherein, in the machine (1), a nominal drying process for drying a nominal amount of the humid articles (3) is scheduled for execution, said nominal process requiring a nominal amount of energy input during execution, **characterized by** superheating the refrigerant in the heat sink (8) to an exit temperature attained upon exiting said heat sink (8) which exceeds an evaporating temperature of said refrigerant upon exiting said heat sink (8) by a superheat that is defined to yield a minimum in said nominal amount of energy input required by said nominal drying process.

12. Process according to one of claims 10 and11, wherein said superheat is between 8°Cand 16°C.

13. Process according to claim 12, wherein said superheat is about 12°C.

14. Process according to one of claims 10 to 13, which is structured into an initialization phase wherein operating temperatures of the refrigerant upon entering and exiting the heat source (7) and the heat sink (7) vary, and a quasi-stationary phase wherein a majority of the operating temperatures remains without major variation.

15. Process according to one of claims 10 to 14, wherein, at least during a quasi-stationary phase, a temperature of the refrigerant upon exiting the compressor (9) is retained near a predetermined maximum temperature by additional cooling applied to the heat pump (7, 8, 9, 10, 11).

16. Process according to claim 15, wherein the additional cooling is applied by passing cooling air along the heat pump (7, 8, 9, 10, 11).

17. Process according to one of claims 15 and 16, wherein the maximum temperature is between 90 °C and 100 °C.

18. Process according to one of claims 10 to 17, wherein the articles (3) dried are items of laundry (3).

19. Process according to claim 18, wherein the items of laundry (3) are tumbled through the process air.

20. Process according to one of claims 10 to 19, wherein the refrigerant and the process air pass at least one of the heat source (7) and the heat sink (8) in counter flow.

Fig. 1

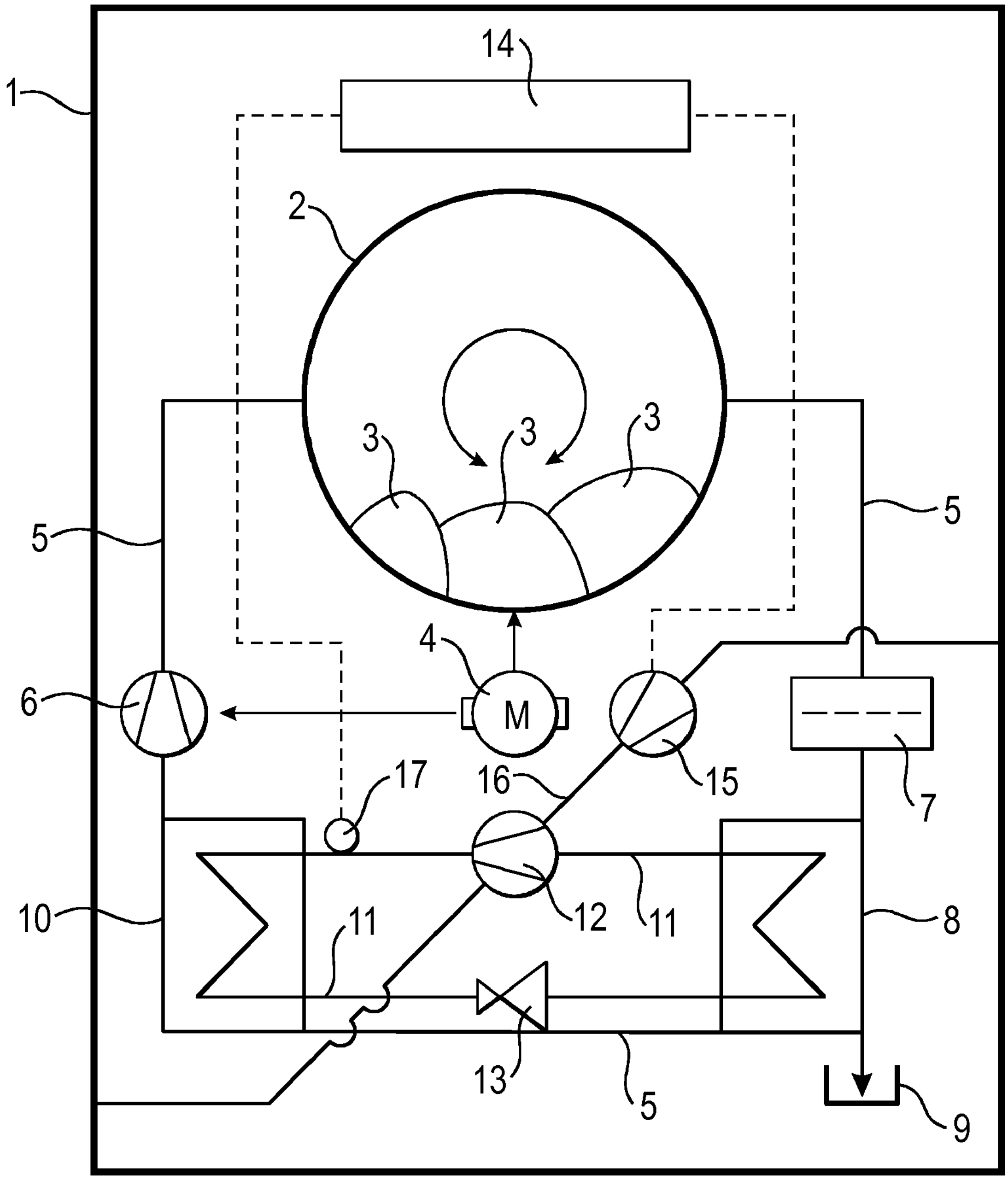


Fig. 2

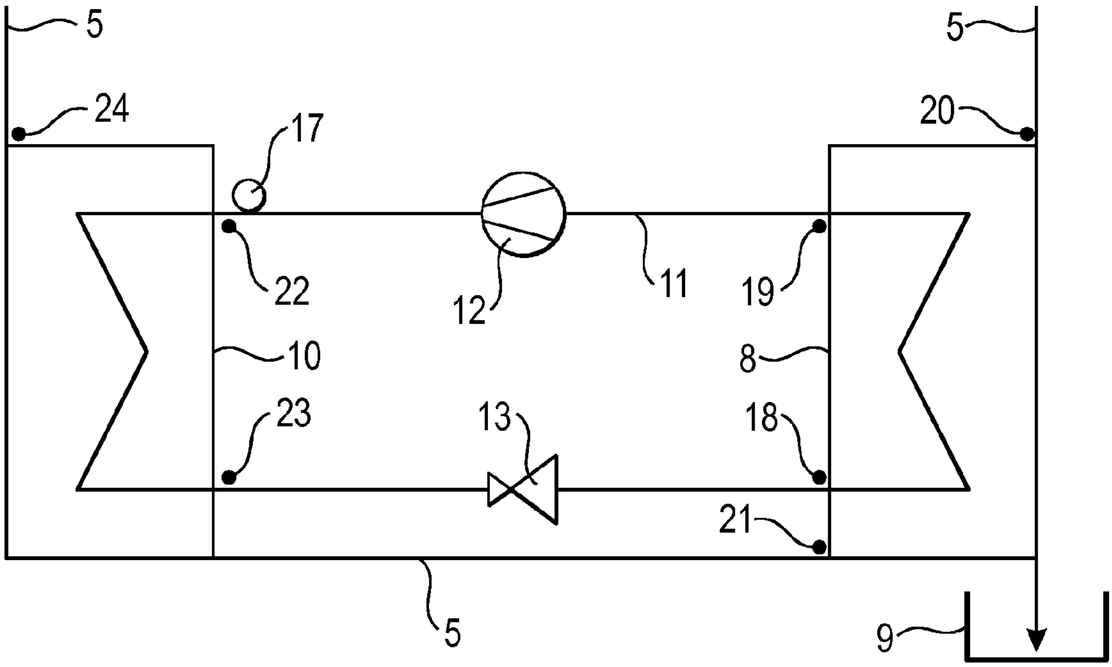


Fig. 3

Superheat 2°C. Results: 25,2 min/kg 0,285 kWh/kg

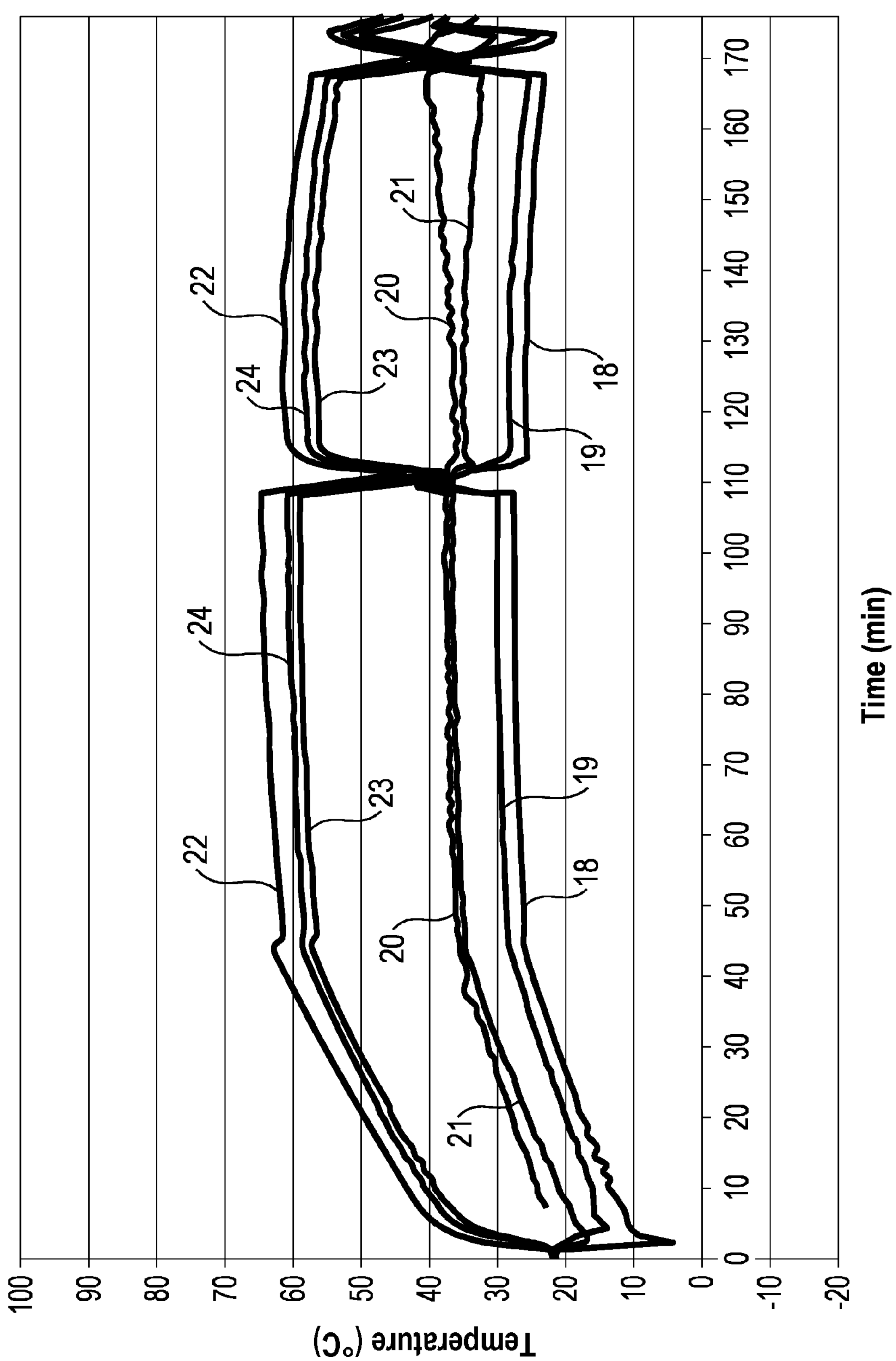


Fig. 4

Superheat 12°C. Results: 20,5 min/kg 0,242 kWh/kg

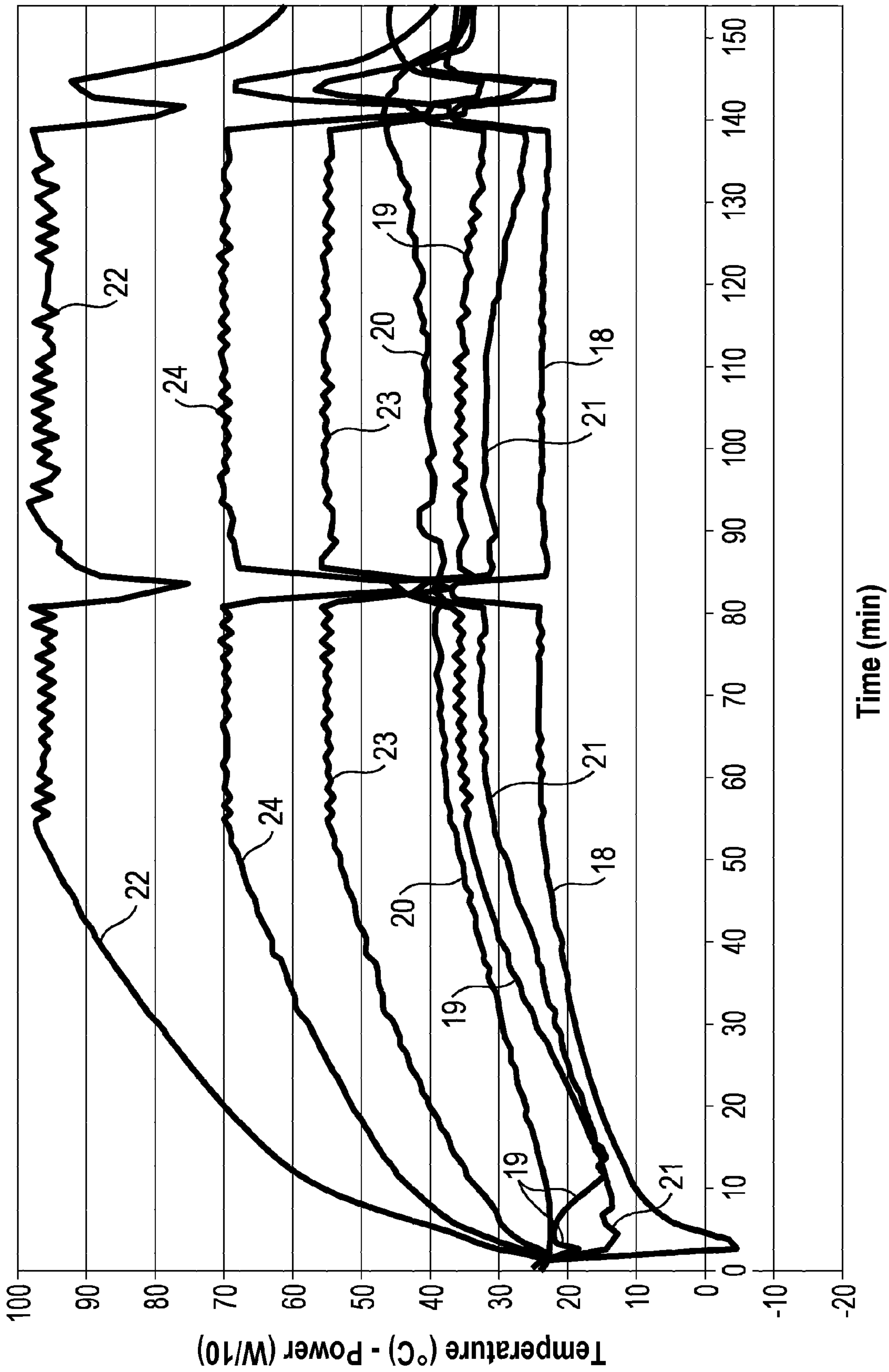
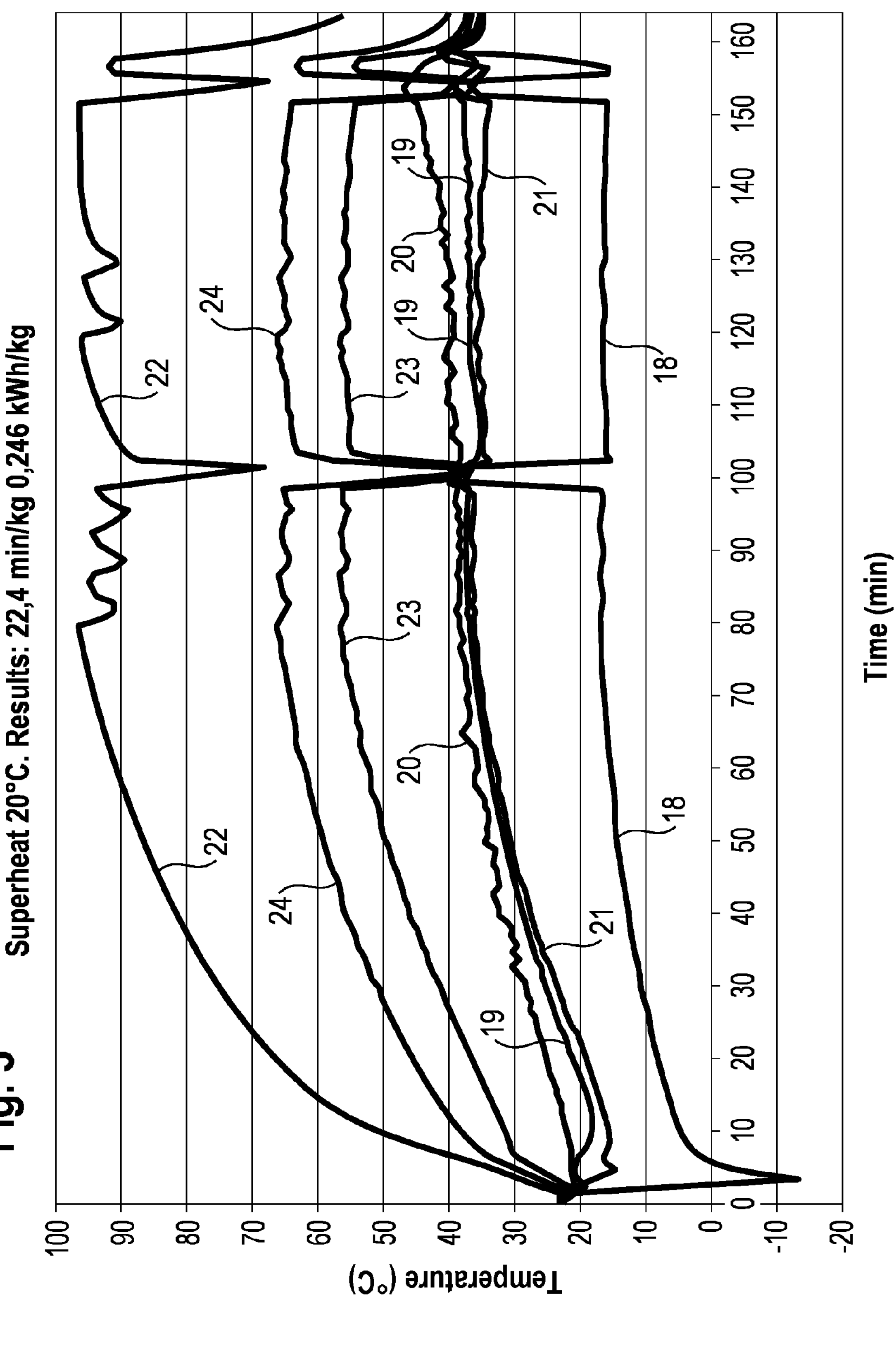


Fig. 5


Superheat 20°C. Results: 22,4 min/kg 0,246 kWh/kg
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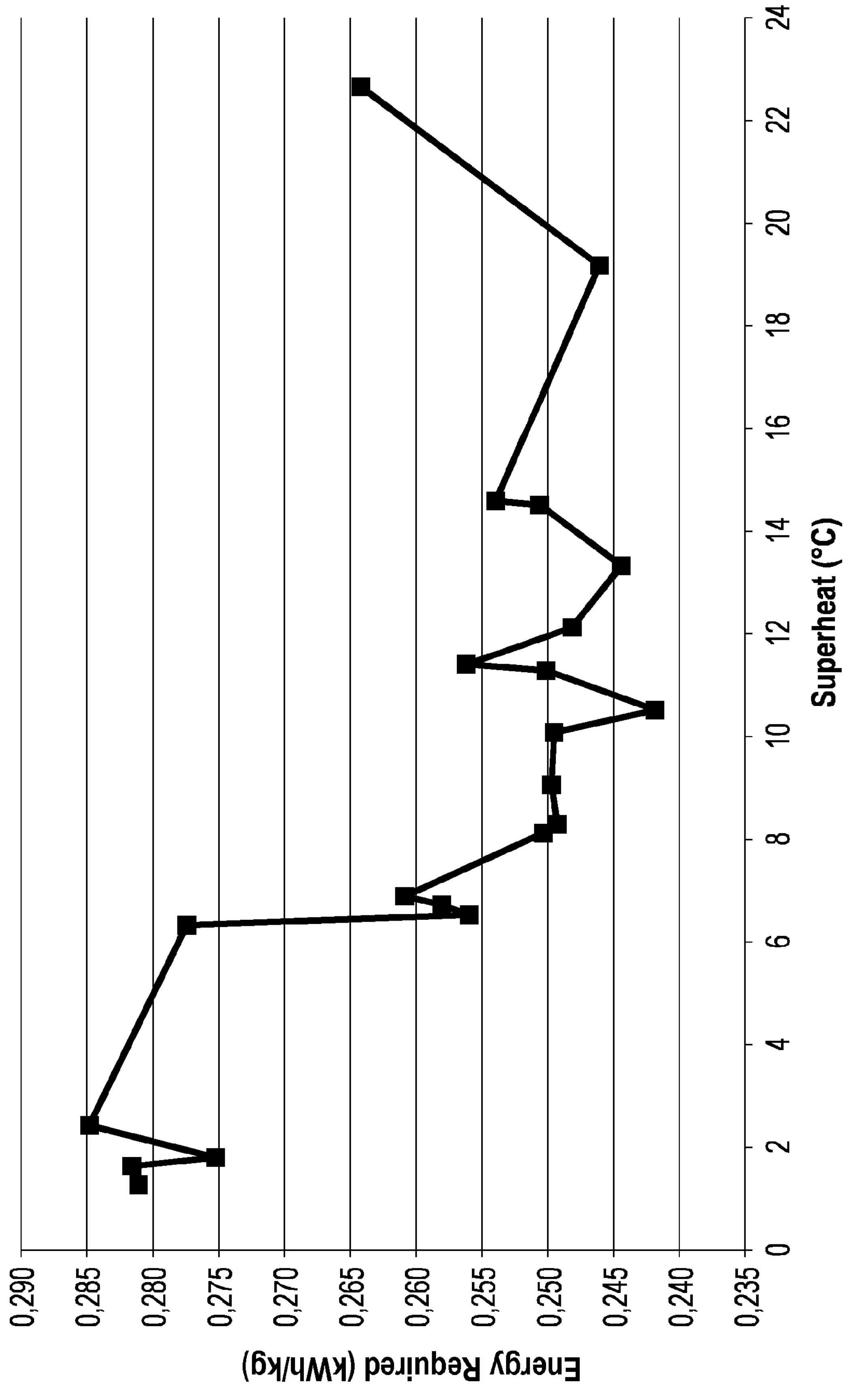
90
80
70
60
50
40
30
20
10
0
-10
-20
Time (min)
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
18
19
20
21
22
23
24

Fig. 6


Energy Required (kWh/kg)
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0,285
0,280
0,275
0,270
0,265
0,260
0,255
0,250
0,245
0,240
0,235
Superheat (°C)
0
2
4
6
8
10
12
14
16
18
20
22
24

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EUROPEAN SEARCH REPORT

Application Number
EP 10 38 2209

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	US 2007/107255 A1 (TAMURA TOMOICHIRO [JP] ET AL) 17 May 2007 (2007-05-17) * paragraph [0082] * * paragraph [0068] - paragraph [0069]; figures 1,5-9 * -----	1-20	INV. D06F58/20
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			D06F

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
Munich	11 January 2011	Hannam, Martin

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1

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