



(12) **EUROPEAN PATENT APPLICATION**

(43) Date of publication:
01.11.2017 Bulletin 2017/44

(51) Int Cl.:
D06F 58/20 ^(2006.01) **D06F 58/28** ^(2006.01)

(21) Application number: **16166996.5**

(22) Date of filing: **26.04.2016**

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

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(54) **METHOD FOR OPERATING A LAUNDRY DRYING APPARATUS AND LAUNDRY DRYING APPARATUS**

(57) The invention relates to a method for operating a laundry drying apparatus during a drying program and to a laundry drying apparatus, the laundry drying apparatus (2) comprising: a drum (18) adapted to receive laundry (19) for drying the laundry using drying air, a drying air fan (8) adapted to convey drying air through the drum (18), a motor adapted to drive the drying air fan (8), and a heat-pump system (4) comprising a first heat exchanger (10) adapted to heat the drying air, a second heat exchanger (12) adapted to cool the drying air for humidity condensation, and a compressor (16) adapted to circulate refrigerant through the first and second heat exchangers (10, 12), wherein the compressor (16) is a var-

iable speed and/or variable power compressor; wherein the method comprises: starting a drying program for drying the laundry received in the drum (18), during a first phase of the drying program, operating the compressor (16) at a first compressor performance and operating the drying air fan (8) at a first fan performance, and during a second phase of the drying program, operating the compressor (16) at a second compressor performance and operating the drying air fan (8) at a second fan performance, wherein the second compressor performance is lower than the first compressor performance, and wherein the second fan performance is higher than the first fan performance.

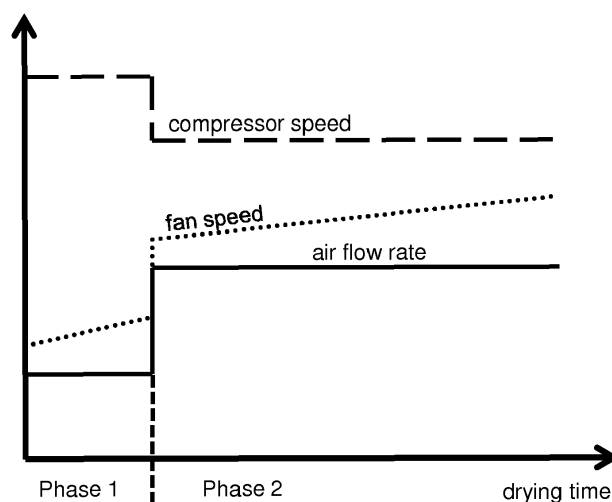


Fig. 6

Description

[0001] The invention relates to a method for operating a laundry drying apparatus comprising a heat pump system during a drying program, and to a laundry drying apparatus, in particular a laundry dryer or a washer-dryer.

[0002] WO 2014/067797 A2 discloses a method for operating a laundry dryer comprising a heat pump system. To prevent an overheating of a compressor of the heat pump system, a process air fan performance is increased in dependency of a temperature of the heat pump system. Thereby the operation of the heat pump system does not have to be adjusted.

[0003] AU 2011/244860 A1 discloses a method for operating a laundry dryer comprising a heat pump system. The air flow of drying air in the laundry dryer is reduced as the drying process proceeds, such that the drying air has enough time to take up a large amount of water from the laundry and it remains possible to efficiently extract water therefrom. Advantageously, the power of a heat pump in the device can be adjusted depending on air flow.

[0004] It is an object of the invention to provide an improved method for operating a laundry drying apparatus and an improved laundry drying apparatus.

[0005] The invention is defined in claims 1 and 17, respectively. Particular embodiments are set out in the dependent claims.

[0006] According to claim 1, a method for operating a laundry drying apparatus during a drying program is provided. The laundry drying apparatus, in particular a laundry dryer or a washer-dryer, comprises a drum adapted to receive laundry for drying the laundry using drying air, a drying air fan adapted to convey the drying air through the drum, a motor adapted to drive the drying air fan and a heat-pump system. The heat pump system comprises a first heat exchanger (e.g. a condenser) adapted to heat the drying air, a second heat exchanger (e.g. an evaporator) adapted to cool the drying air for humidity condensation, and a compressor adapted to circulate refrigerant through the first and second heat exchangers. The compressor is a variable speed compressor and additionally or alternatively a variable power compressor. Preferably the variable speed and/or variable power compressor is a compressor driven by a compressor motor, wherein the compressor motor is a variable speed and/or variable power motor.

[0007] The method for operating the laundry drying apparatus comprises the following steps:

- starting a drying program for drying the laundry received in the drum,
- during a first phase of the drying program, operating the compressor at a first compressor performance and operating the drying air fan at a first fan performance, and
- during a second phase of the drying program, operating the compressor at a second compressor performance and operating the drying air fan at a second fan performance. Therein (i) the second compressor performance is lower than the first compressor performance and (ii) the second fan performance is higher than the first fan performance.

[0008] The term "performance" may be taken as a performance value, wherein the attribute or label "higher/lower" with respect to the first/second compressor performance and first/second fan performance relates to the same type of compressor performance and fan performance, respectively. For example the first and second compressor performance relates to compressor speed and the first and second fan performance relates to fan speed. In this example the (first) compressor speed in the first phase is higher than the (second) compressor speed in the second phase, wherein the (first) fan speed in the first phase is lower than the (second) fan speed in the second phase. Preferably the change of performances of the compressor and the fan is controlled by a control unit of the laundry drying apparatus.

[0009] In particular (and according to current technology also generally) the energy consumption of the compressor is higher than energy consumption of the process air fan. As the compressor performance is reduced and the fan performance is increased during the course of a drying operation, in summary energy is saved. E.g. the total or overall energy necessary for a drying operation or cycle is reduced.

[0010] Further, the flexible control of both, the compressor and the process air fan, increases the flexibility and the adaptability of the drying apparatus, so that the working conditions may be kept close to optimum in every circumstance and throughout the whole cycle. In particular by adapting operational parameters of the process air fan and the compressor during a drying cycle, the overall performance of the laundry drying apparatus may be improved in terms of energy saving, cycle time reduction and enhanced fabric care.

[0011] The first/second fan performance may be a first/second fan speed, such that a first/second process air flow rate is provided. In this example, the second fan speed is higher than the first fan speed and additionally or alternatively the second flow rate is higher than the first flow rate. In particular the fan may be operated at a constant first/second fan speed (first fan speed lower than second fan speed), while the generated air flow rate decreases due to the increasing air resistance of the gradually drying laundry (higher volume expansion of the dryer laundry and/or increase of fluff collection at fluff filter(s)). Additionally or alternatively the first/second fan performance which is controlled by a control unit of the drying apparatus may be the process air flow rate of the drying air fan. For example the fan speed may be adjusted such that a constant or substantially constant air flow rate is provided.

[0012] The first/second compressor performance may be a first/second compressor speed and additionally or alternatively a first/second compressor power. In this example, the second compressor speed is lower than the first compressor speed and additionally or alternatively the second compressor power is lower than the first compressor power. In each case energy consumption of the compressor decreases in the second phase when compared to the first phase.

[0013] The (drying air fan and/or compressor) performance may be an average value over time within the (overall) period of the first phase and/or second phase. For example, when only one motor is provided for driving the drying air fan and for driving (rotating) the drum, the fan rotation and drying air flow rate may be interrupted when the drum rotation is stopped. Additionally or alternatively the fan rotation may be temporally reverted for laundry redistribution and/or slackening of the laundry. For example fan rotation interruptions or stops or reversals are not meant with reduced/increased fan performance, but the average is meant thereby. For example the fan and/or compressor performance is considered for a time average over at least 1, 3, 5, 7 or 10 minutes or an average taken in a period of 1 to 5 min, 3 to 8 min or 7 to 15 min.

[0014] The second phase may directly follow at the end of the first phase, but it does not necessarily follow directly at the end of the first phase. For example an intermediate phase may be provided between the first and second phase. In an intermediate phase at first the compressor performance (e.g. compressor speed and/or power) may be reduced and then the fan performance (e.g. fan speed and/or flow rate) may be increased. Alternatively at first the fan performance may be increased and then the compressor performance may be decreased. According to a further alternative embodiment the compressor performance and the fan performance may be reduced/increased concurrently during an intermediate phase.

[0015] Preferably the compressor performance is one or more of:

- a motor speed of a motor driving the compressor,
- an electrical power supplied to the compressor,
- the frequency of the voltage and/or current applied to the motor of the compressor, and
- the refrigerant conveyance rate of the compressor.

[0016] These performances relate to the above mentioned first and second compressor performance. As mentioned above the first and second performance represent the same type of performance or the same group of performance parameters (as listed immediately before).

[0017] For example the compressor performance may be adjusted by adjusting or controlling the outlet pressure or flow rate of the refrigerant. For this purpose an adjustable capillary or expansion valve may be used downstream the second heat exchanger (condenser).

[0018] Most preferable compressor performance is constant or essentially constant during the first phase and/or the second phase - at least after an initial transition time e.g. for accelerating/decelerating the compressor speed. For example the consumed compressor electrical power increases over time in the first phase, while it decreases over time during the second phase, when the compressor speed is kept constant. Preferably the compressor speed relates to compressor motor speed.

[0019] The compressor performance may be adapted by one or more of the following:

- the second compressor speed is lower than the first compressor speed by at least 10%, 20%, 25%, 30% or 40% and/or the second compressor speed is in the range of 85-95%, 75-90%, or 50-75% of the first compressor speed (the 'and' is valid for those combinations where these values are compatible), and/or
- the second compressor performance is lower than the first compressor performance by at least 10%, 20%, 25%, 30% or 40% and/or the second compressor performance is in the range of 85-95%, 75-90%, or 50-75% of the first compressor performance (the 'and' is valid for those combinations where these values are compatible).

[0020] The drying air fan performance may be one or more of:

- a motor speed of the motor driving the drying air fan, and
- the air conveyance rate or air flow rate of the drying air conveyed by the fan.

[0021] These performances relate to the above mentioned first and second fan performances.

[0022] Preferably fan speed means or relates to a driving motor speed of the fan motor or is proportional thereto. In particular the fan speed is a fan rotation speed which in turn is equal to or is proportional to a fan motor speed. An air flow rate relates to a total or overall flow rate, wherein the flow rate is the flow rate of drying air. As described in more detail below, the fan speed and the fan flow rate are not necessarily proportional to each other as the flow rate depends on the air resistance of the laundry to be dried, e.g. the type, humidity and amount of laundry in the drum.

[0023] Preferably the drying air fan performance is adapted by one or more of the following:

- the second drying air fan speed is higher than the first drying air fan speed by at least 10%, 20%, 25%, 30% or 50% and/or the second drying air fan speed is in the range of 110-140%, 130-160%, or 150-200% of the first drying air fan speed (the 'and' is valid for those combinations where these values are compatible), and/or
- the second drying air flow rate is higher than the first drying air flow rate by at least 10%, 20%, 25%, 30% or 50% or the second drying air flow rate is in the range of 110-140%, 130-160%, or 150-200% of the first drying air flow rate (the 'and' is valid for those combinations where these values are compatible).

[0024] The method may further comprise the following steps:

- during the running drying program, detecting an operational parameter of the heat-pump system,
- evaluating the operational parameter, and
- in dependency of the operational parameter, starting the second phase of the drying program.

[0025] Generally, a drying cycle of a heat pump dryer (both with regard to the refrigerant side and the process-air side) may be split in two main phases. During the first phase temperatures and compressor power consumption increases. Similarly, the condensation and evaporation pressure increases as well. When the process air temperature and refrigerant temperature reach an optimum level that is a good compromise between efficiency and effectiveness of the drying process the heat pump system may be stabilized ("balanced") by cooling the compressor, e.g. by means of a compressor cooling fan. In particular condensation and evaporation rates do not continue to increase when the above mentioned optimum temperature levels of the process air and/or refrigerant are achieved.

[0026] Preferably the change from first to second phase is defined by starting/activating a compressor cooling phase (as begin of second phase). In particular the change to a second phase or the ending of the first phase and starting the second phase may be controlled in dependency of a temperature of the heat-pump system. In particular, the fan performance and/or the compressor performance may be changed from first to second phase in dependency of the refrigerant temperature. The detected operational parameter of the heat pump system may be the refrigerant temperature out from the first heat exchanger (condenser). The temperature may be measured by a NTC (negative temperature coefficient) sensor to split the drying cycle in two parts or phases. For example in the second phase the performance of the compressor may be adapted by reducing the compressor speed. Preferably and as described above, starting the second phase preferably means ending or terminating the first phase.

[0027] According to an embodiment, the performance of the fan is increased in reaction to reducing the compressor speed in the second phase. Alternatively in reaction to increasing the performance of the fan, the performance of the compressor is reduced. According to a further alternative, the performance of the compressor is reduced and the performance of the fan is increased simultaneously in reaction of detecting the refrigerant being at a temperature threshold. Additionally or alternatively, if the operational parameter has reached a predetermined state or level, the change from the first to the second phase is initiated or is initiated after a predetermined delay. The predetermined delay time may be dependent on one or more of the following: a user selection, a laundry load, the laundry humidity. The laundry humidity may relate to a current or actual humidity level and/or to the decrease of laundry humidity over time.

[0028] An operational parameter of the heat-pump system may be one or more of the following:

- a temperature of the heat-pump system,
- a temperature of the compressor,
- a temperature of the refrigerant,
- a temperature of the refrigerant at the compressor outlet,
- a temperature of the refrigerant at the condenser outlet,
- a temperature representative for a temperature of the heat-pump system, and
- a refrigerant pressure of the heat-pump system.

[0029] Most preferably the detected operational parameter of the heat pump system is the temperature of the refrigerant at the compressor outlet or the condenser outlet. For example a detected refrigerant temperature at the condenser outlet being in the range of 45-55°C or 55-65°C could be used as a threshold value or threshold range to initiate or start the second phase of the drying cycle. E.g. the second phase is started or reached when the detected refrigerant temperature remains in the range between 45-55°C or 55-65°C.

[0030] Preferably the motor for driving the drying air fan is a variable speed motor. The motor driving the fan may also drive the drum. In this case the drum speed is also varied when the fan speed or air flow rate is varied or vice versa. Providing only one motor to drive the fan and the drum is a cost-efficient solution.

[0031] Alternatively the drum may be driven by a drum drive motor independent of a motor driving the fan. Thereby the fan performance may be adapted to the specific requirements of the drying operation independently from drum rotation. When additionally using a variable speed motor for the fan, the flexibility and available speed ranges for the

fan are even larger.

[0032] According to a further alternative, the drum and fan are driven by the same motor, wherein a clutch element and additionally or alternatively a gear device is provided between the motor and the drying air fan. The clutch element and/or gear device is adapted to drive the drying air fan at least temporarily at different speeds. The clutch element and/or gear device splits the drum speed and the fan speed, such that they may be individually adapted to the requirements of the drying cycle.

[0033] During the second phase or at least during a time period of the second phase:

- the fan rotation speed may be controlled such that the second drying air flow rate is constant, or
- the fan rotation speed may be controlled according to a predetermined speed profile resulting in the drying air flow rate during the second phase being higher than the drying air flow rate in the first phase.

[0034] During a drying cycle the air flow resistance increases, e.g. due to the dry laundry occupying more volume in the drum and a fluff filter being increasingly clogged. To achieve a constant air flow rate over time during a running drying program it is therefore required to increase the drying air fan rotation speed. For example in the second phase the fan speed may be gradually increased to provide a constant or substantially constant air flow rate, which is higher than the flow rate in the first phase. Preferably the fan rotation speed is constant or essentially constant during the first phase, during the second phase, or during the first and second phase of a drying cycle.

[0035] The drying air fan may be designed such that at same rotation speeds of the fan driving motor in the main rotation direction and in the counter rotation direction the respective flow rate or conveyance rate of the drying air fan is different. Thereby a change of flow rate can be achieved at the same rotation speed of the motor by rotating the fan or fan motor in different directions. For example the main (forward) rotation direction results in a higher flow rate than in the counter (backward) rotation direction. For example an axial fan, a centrifugal fan or a radial blowing fan may be used which have an optimized flow rate for one rotation direction, while the flow rate for other rotation direction is (significantly) lower.

[0036] Preferably one or more of the following drying operation parameters:

- first compressor performance,
- second compressor performance,
- first drying air fan performance,
- second drying air fan performance, and
- heat-pump system operational parameter,

are selected by a control unit of the drying apparatus in dependency of one or more of the following:

- a laundry drying program or a laundry drying option set by a user via an input selector of the drying apparatus,
- the amount or weight of laundry,
- a laundry type as set by a user or as estimated by the drying apparatus,
- the duration of the laundry drying program set by a user or as estimated by the drying apparatus,
- the ambient temperature,
- the starting or current humidity of the laundry,
- the target final humidity of the laundry,
- a parameter of the compressor motor,
- the noise of the conductivity sensor, and
- one or more parameters of a motor driving the drum (like the torque provided by the motor, the power supplied to the motor, the motor current and/or voltage, the magnetic flux or moment, and/or the induction - see also below).

[0037] Preferably the ambient temperature is the temperature corresponding to or indicating the temperature at the outside of a cabinet of the laundry drying apparatus. Preferably the ambient temperature is detected at the start of the drying program, more preferably the ambient temperature detected at the first time of operating the apparatus after an extended period (e.g. apparatus was not used for one or more hours and has cooled down).

[0038] For example a parameter of the compressor motor may be one or more of: the power, the torque, the current, the voltage, and the frequency.

[0039] Preferably the laundry drying apparatus further comprises a laundry load indicating or detecting unit adapted to provide a laundry load parameter. The laundry load indicating or detecting unit may be a control unit of the apparatus (in which the method is implemented) with a memory for storing a user input for laundry load. Alternatively or additionally a laundry load indicating or detecting unit may include a load detector for example as disclosed in EP 1 413 664 B1 and EP 1 988 209 A2. Load signals from the load detector may be subsequently stored in a or the control unit with a memory

for storing load values during a running drying program, wherein the laundry load value corresponds to the laundry load parameter. The laundry load parameter includes at least a laundry load value (or laundry weight value) which indicates the weight of the laundry, wherein the laundry weight value may be a relative value which e.g. is proportional to the actual physical weight of the laundry.

[0040] The noise of the conductivity sensor and/or one or more parameters of the drum motor and/or the condensation rate are parameters which are used for example for estimating the laundry load of the laundry loaded into the drum.

[0041] In an embodiment the laundry load indicating or detecting unit comprises the conductivity sensor for determining the laundry load as follows: The amount of load may be estimated by measuring the electric resistance and/or conductivity of the wet laundry. The amount of load in the laundry drum may be detected by using e.g. two electrodes associated to the laundry drum as the conductivity sensor. The electrodes are advantageously parts of the laundry load indicating or detecting unit which may be provided for detecting both the dryness degree of the laundry inside the drum and for estimating the amount of load in the laundry drum. For this purpose a level of electrical noise and/or fluctuation during the first minutes of a drying cycle is used. The wet load can connect electrically the first electrode to the second electrode, when a part of the wet load touches simultaneously the first electrode and the second electrode. If the wet load in the laundry drum does not touch simultaneously the first electrode and the second electrode, then a peak is detected by the conductivity sensor. It has been found that there is a correlation between the number or frequency of peaks of the electric signal and the amount of load in the laundry drum. The smaller the load inside the laundry drum, the higher the number or frequency of the detected peaks, and the higher is an electrical noise measured by the laundry load indicating or detecting unit. Further, it has been found that the area subtended by peaks of an electric signal corresponding to the detected electric resistance and/or conductivity increases with a decreasing amount of load in said laundry drum and similarly the value of peaks of an electric signal corresponding to the detected electric resistance and/or conductivity increases with a decreasing amount of load in said laundry drum.

[0042] In another embodiment, the laundry load indicating or detecting unit determines or estimates the amount of load by measuring and evaluating the electrical and/or magnetic parameters of the electric drum motor, like the torque, the electric current, the voltage, the power supplied to the motor, the motor current and/or voltage, the magnetic flux or moment, and/or the induction. The electrical current through the electric drum motor is at least approximately proportional to the torque of the electric drum motor. For example, the electric current measured gives a measure of the torque of the electric drum motor and from the torque the amount of load is determined. The torque in turn depends on the drum dimension and the weight of the laundry placed in the drum. The electrical and/or parameter by which the load is estimated/determined includes phases of drum acceleration and/or deceleration and/or of constant drum rotation.

[0043] The condensation rate during a drying cycle may be determined by monitoring one or more of the following:

- (i) the frequency of activation of a condensate pump (e.g. a pump adapted to pump generated condensate to a condensate collection tank or to discharge condensate from the apparatus), and
- (ii) the water level in a condensate collection tank (e.g. a drawer), and (iii) the weight of the water/condensate in the condensate collection tank.

[0044] In an embodiment during the second phase or by starting a third phase following the second phase one or more of the following is applied: reducing the compressor performance from the second compressor performance to a third compressor performance, where the third compressor performance is lower than the second compressor performance; and/or repeatedly, in one or more steps, gradually and/or continuously reducing the compressor performance; and/or increasing the drying air fan performance from the second fan performance to a third fan performance, where the third fan performance is lower than the second fan performance; and/or repeatedly, in one or more steps, gradually and/or continuously increasing the fan performance. For the 'compressor performance' and the 'fan performance' reference is made to the full context of the above and below. The third phase is a phase following the second phase. The second phase however is not a short transition phase, but a 'main drying phase' that is executed when e.g. the heat pump system has achieved its 'operation' temperature (see above) after a warmup during the first phase. The third phase may for example be a cooling-down phase after having dried the laundry essentially to the intended final humidity and/or may be started before an estimated total drying duration is finished.

[0045] A laundry drying apparatus, in particular a laundry dryer or a washer-dryer, as described above is provided, wherein the apparatus comprises a control unit for controlling the execution of a drying program. The control unit is adapted to execute the drying program by:

- starting the drying program for drying the laundry received in the drum,
- during a first phase of the drying program, operating the compressor at a first compressor performance and operating the drying air fan at a first fan performance, and
- during a second phase of the drying program, operating the compressor at a second compressor performance and operating the drying air fan at a second fan performance, wherein the second compressor performance is lower

than the first compressor performance, and the second fan performance is higher than the first fan performance.

[0046] For the embodiments of the method for operating the drying apparatus as well as for the drying apparatus each isolated feature of the claims or description can be added or any arbitrary combination of isolated or individual features can be added to or provided in the claims.

[0047] Reference is made in detail to preferred embodiments of the invention, examples of which are illustrated in the accompanying figures, which show:

Fig. 1 a schematic view of a laundry dryer having a heat pump system,

Fig. 2 a block diagram illustrating the control of some components of the laundry dryer of Fig. 1,

Fig. 3 an exemplary diagram of condenser outlet temperature over time during a drying cycle,

Fig. 4 an exemplary diagram of compressor power consumption and condensation rate over time during a drying cycle,

Fig. 5 an exemplary diagram of evaporation rate over time for two different process air flow rates during a drying cycle,

Fig. 6 a schematic diagram illustrating a method for operating a heat pump laundry dryer as shown in Fig. 1 according to a first embodiment,

Fig. 7 a schematic diagram illustrating a method for operating a heat pump laundry dryer as shown in Fig. 1 according to a second embodiment,

Fig. 8 a schematic diagram illustrating a method for operating a heat pump laundry dryer as shown in Fig. 1 according to a third embodiment with delayed fan activation,

Fig. 9 a schematic diagram illustrating a method for operating a heat pump laundry dryer as shown in Fig. 1 according to a fourth embodiment with delayed compressor speed reduction, and

Fig. 10 a schematic diagram illustrating a method for operating a heat pump laundry dryer as shown in Fig. 1 according to a fifth embodiment with a moderate fan speed increase in the second phase as compared to Fig. 7.

[0048] Fig. 1 shows a schematically depicted laundry dryer 2, which is not drawn to scale and is provided for illustrative purposes. The dryer 2 comprises a control unit 44 (Fig. 2) for controlling and monitoring the overall operation of the dryer 2 and its components. Fig. 2 shows a block diagram to illustrate the control of some components of the laundry dryer 2 of Fig. 1 as described in detail below.

[0049] A heat pump system 4 is arranged in a housing 3 or cabinet of the dryer 2. The heat pump system 4 includes a closed refrigerant loop 6 which comprises in the following order of refrigerant flow B: a first heat exchanger 10 acting as condenser for cooling the refrigerant and heating the process air, an expansion device 14, a second heat exchanger 12, acting as evaporator for evaporating the refrigerant and cooling process air, and a compressor 16 from where the refrigerant is returned to the first heat exchanger 10. The compressor 16 is a variable speed and additionally or alternatively a variable power compressor. Together with the refrigerant pipes connecting the components of the heat pump system 4 in series, the heat pump system 4 forms the refrigerant loop 6 through which the refrigerant is circulated by the compressor 16 as indicated by arrow B.

[0050] The process air flow A within the dryer 2 is guided through a laundry storing compartment 17 of the dryer 2, i. e. through a compartment for receiving articles to be treated, e.g. a drum 18. The drum 18 may be driven by drum drive motor 50 (Fig. 2) controlled by the control unit 44. The articles to be treated are textiles, laundry 19, clothes, shoes or the like.

[0051] The process air flow is indicated by arrows A in Fig. 1 and is driven by a process air blower or drying air fan 8. A motor 46 (Fig. 2) for driving the drying air fan 8 may be a variable speed motor 46 controlled by the control unit 44, such that fan speed may be easily adjusted. The motor 46 driving the fan 8 may also drive the drum 18 (as indicated with dashed arrow in Fig. 2), wherein in this case the drum motor 50 could be omitted. When a single motor 46 is used to drive the fan 8 as well as the drum 18, a clutch element or a gear device (not depicted) may be provided to split and separate the drive of the drum and the fan. By means of the clutch element or gear device the control unit is adapted to drive the drying air fan 8 at least temporarily at different speeds such that fan speed and air flow rate may be varied.

[0052] The process air channel 20 guides the process air flow A outside the drum 18 and includes different sections,

including the section forming the battery channel 20a in which the first and second heat exchangers 10, 12 are arranged. The (heated) process air exiting the first heat exchanger 10 flows into a rear channel 20b in which the drying air fan 8 is arranged. The air conveyed by fan 8 is guided upward in a rising channel 20c to the backside of the drum 18. The air exiting the drum 18 through the drum outlet may be filtered by a fluff filter 22 arranged close to the drum outlet in or at the channel 20. The optional fluff filter 22 is arranged in a front channel 20d forming another section of channel 20 which is arranged behind and adjacent the front cover of the dryer 2.

[0053] Condensate formed at the second heat exchanger 12 is collected and guided to the condensate collector 30. The condensate collector 30 may be connected via a drain conduit 36, a drain pump 32 and a drawer pipe 38 to an extractable condensate drawer 34. I.e. the collected condensate can be pumped from the collector 30 to the drawer 36 which may be arranged at an upper portion of the dryer 2 from where it can be comfortably withdrawn and emptied by a user.

[0054] An input panel 48 is provided preferably at the front upper section of the housing 3. The input panel 48 allows a user to input/select a program and program option selections and also indicates program status information and/or program and option selection choices and parameters.

[0055] As shown in Fig. 2, the control unit controls components of the exemplary dryer 2 (or washer-dryer) by one or more of the following:

- The control unit is connected to the input panel to receive user inputs and to output display information to the panel to be indicated for the user.
- The control unit 44 receives the temperature values from temperature sensors 42a and 42b.
- The control unit is connected to the controller of the heat pump system 4 to control the operation of the heat pump system 4 (e.g. via the compressor performance) and to receive operation status information therefrom.
- The control unit controls the motor 46 of the process air fan 8 and/or the motor of the cooling fan 40 and/or the motor of the compressor 16 (e.g. via the heat pump system controller) and/or the motor 50 for driving the drum 18 (if independent of the process air fan motor 46).

[0056] Preferably the process air fan motor 46 and/or the compressor motor and/or the drum motor 50 are variable speed motors. For one or more of these motors inverters controlled by the control unit 44 are provided which provide power to the motors to set the target speed and/or power.

[0057] In the following, Figs. 2 to 4 show exemplary diagrams of operational parameters of the laundry dryer 2 during a drying operation to illustrate the background or basis for the preferred embodiments for operating the laundry dryer 2 as shown in Fig. 6 and Fig. 7.

[0058] Fig. 3 shows an exemplary diagram illustrating the progress of the refrigerant temperature at the outlet of the condenser 10 over time during a drying cycle. The temperature may be detected by means of a temperature sensor 42a at the condenser outlet, e.g. by means of a NTC sensor. Alternatively or additionally to sensor 42a at the condenser outlet, a temperature sensor 42b at the compressor outlet for detecting the refrigerant temperature at the compressor outlet may be provided.

[0059] A thermodynamic cycle or drying cycle in a heat pump dryer, both with regard to the refrigerant side and the process-air side can be split in two main phases (Phase 1 / Phase 2). As shown in Fig. 3, in the first phase the condensation and evaporation temperatures of the refrigerant at the outlet of the condenser 10 increase. Similarly, the condensation and evaporation rates increase as well. When the process air temperature and refrigerant temperature reach an optimum temperature level that is a good compromise between efficiency and effectiveness of the drying process, the system is artificially stabilized ("balanced") by the use of a cooling fan 40 that is acting on the shell of the compressor 16 with an on/off control strategy. Cooling fan 40 conveys cooling air taken from the outside of the housing or cabinet 3 over the compressor thereby cooling it and removing heat from the heat pump system. Other ways of removing heat from the heat pump system may be implemented (e.g. by using an auxiliary condenser that radiates heat to ambient air). By stabilizing the heat pump system at the optimum temperature level also energy consumption of the compressor 16 is stabilized. Examples for above optimum temperature levels are: an air temperature at drum inlet between 55°C and 65°C and/or a refrigerant temperature at condenser 10 outlet between 45°C and 55°C.

[0060] When the heat pump system reaches an optimum temperature level, the first phase ends and the second phase begins. In other words, the second phase is the phase during which the heat pump system 4 is stabilized or balanced as described above.

[0061] As described above the transition between the first and second phase of the drying cycle may be determined by detecting a temperature of the refrigerant (e.g. at the outlet of the condenser 10 or at the compressor outlet). Alternatively or additionally the start of the second phase or the end of the first phase may be determined by other operational parameters of the heat-pump system 4, like a temperature of the compressor 16, a temperature representative for a temperature of the heat-pump system 4 and/or a refrigerant pressure of the heat-pump system 4. As an example the condition for starting the second phase is detection of a temperature exceeding a predetermined temperature level (e.

g. the optimum temperature level). The temperature may be detected using an NTC temperature sensor as mentioned above and/or may be detected using sensor 42b or preferably 42a at the outlet of the condenser 10 (which may be an NTC temperature sensor). For the purposes herein it is to be noted that in an embodiment the second phase is started when the predetermined temperature level is exceeded, independent whether the compressor cooling fan 40 is operating or activated or not before, at and/or after the transition from the first to the second phase. E.g. when the predetermined temperature level is exceeded, the second phase is started and the (average) speed of the process air fan 8 is increased and/or its conveyance rate is increased while with the transition to the second phase the compressor cooling fan 40 must not be activated as part of the second phase. In an embodiment, the compressor cooling fan 40 is activated (for example the first time) when starting the second phase. The 'first time' activating the compressor cooling fan means the first time when it is activated for actually cooling the heated compressor. E.g. operating the compressor cooling fan during an initialization or start-up phase does mean operating the fan the first time for cooling the compressor. Also during the second phase the compressor cooling fan 40 may be repeatedly being switched on and off (e.g. for keeping the compressor temperature below a predetermined compressor threshold temperature). Preferably the compressor cooling fan 40 is started the first time when the temperature threshold for reducing the compressor performance and increasing the drying air fan performance is initiated. E.g. all three parameters (first time activation of compressor cooling fan, reduction of compressor performance and increase of drying fan performance) are triggered by the same condition.

[0062] Fig. 4 shows an exemplary diagram illustrating the temporal course of the compressor power consumption and the condensation rate during a drying cycle having a first and second phase as described above. The transition between first and second phase is indicated by a vertical line.

[0063] The dotted line illustrates the compressor power consumption and the continuous line illustrates the condensation rate during the first and second phase. As shown in Fig. 4, the condensation rate does not continue to increase when the optimum temperature is achieved and the heat pump system is stabilized during the second phase. Different thereto, the condensation rate decreases during the second phase of the drying cycle.

[0064] Fig. 5 shows an exemplary diagram of evaporation rate over time for two different process air flow rates (generated by fan 8) during a drying cycle. The dotted line shows the evaporation rate for a first air flow rate (a) and the continuous line shows the evaporation rate for a second air flow rate (b), which is higher than the first air flow rate (a). As shown in Fig. 5, a high evaporation rate is achieved in the first phase by means of the first (lower) air flow rate (a) and in the second phase by means of the second (higher) air flow rate (b). This shows that for each of the two phases of the drying cycle a different optimal air flow rate may be applied to achieve a maximum evaporation rate, i.e. to optimize the drying process with respect to energy and time.

[0065] Fig. 6 and Fig. 7 show schematic diagrams to illustrate methods for operating a heat pump laundry dryer 2 of Fig. 1 according to preferred embodiments.

[0066] In both embodiments, the compressor performance is reduced in the second phase of the drying cycle, wherein the compressor performance may be one or more of a motor speed of a motor driving the compressor 16, an electrical power supplied to the compressor 16, the frequency of the voltage and/or current applied to the motor of the compressor 16, and the refrigerant conveyance rate of the compressor 16. In the example as depicted in Figs. 6 and 7 the compressor speed is reduced in the second phase. For example a second compressor speed (during the second phase) is lower than a first compressor speed (during the first phase) by at least 10%, 20%, 25%, 30% or 40% and/or the second compressor speed is in the range of 85-95%, 75-90%, or 50-75% of the first compressor speed.

[0067] Fig. 6 shows a schematic diagram illustrating a method for operating a heat pump laundry dryer as shown in Fig. 1 according to a first embodiment. As described above with respect to Fig. 5, two optimal air flow rate values can be identified for each phase of the drying cycle. Consequently the fan speed is controlled by the control unit 44 in order to maintain these two air flow rate values during each of the two phases, i.e. a lower air flow rate is applied during the first phase and a higher air flow rate is applied during the second phase. For example the second drying air flow rate (during the second phase) may be higher than the first drying air flow rate (during the first phase) by at least 10%, 20%, 25%, 30% or 50% and/or the second drying air flow rate may be in the range of 110-140%, 130-160%, or 150-200% of the first drying air flow rate.

[0068] Since at constant fan speed the air flow rate decreases while the time goes on (e.g. due to increased air resistance of dried laundry, increasingly clogged fluff filter), it is necessary to increase the fan speed accordingly and as qualitatively depicted in Fig. 6.

[0069] Fig. 7 shows a schematic diagram illustrating a method for operating a heat pump laundry dryer as shown in Fig. 1 according to a second embodiment. Unless otherwise mentioned, the same features and steps of the method according to the first embodiment shown in Fig. 6 are applied in the second embodiment illustrated in Fig. 7.

[0070] In contrast to the first embodiment, in the second embodiment the fan speed is controlled by the control unit 44 to maintain a constant or substantially constant fan speed level during the first phase (low fan speed level) and the second phase (high fan speed level). As described above, the air flow rate decreases over time due to an increased air resistance of the laundry/filter. The fan speed levels are selected such that despite this increased air resistance the resulting air flow rate during the second phase is higher than the resulting air flow rate during the first phase. Thereby

it is provided that the air flow rates in the first/second phase are in the range of the desired optimal air flow rates as illustrated in Fig. 5.

[0071] By means of the above described methods the evaporation rate is optimized for each phase of a drying cycle of the laundry dryer 2. Furthermore, as the energy consumption of the compressor 16 is higher than the energy consumption of the fan 8, the total energy consumption during a drying cycle or drying operation is reduced due to the reduced compressor performance and increased fan performance.

[0072] Figs. 8 and 9 show modification of the control sequences shown in Figs. 6 and 7. Fig. 8 exemplifies a modification of Fig. 6 in that the increase in the speed or air flow rate of the cooling fan 40 is applied with a predetermined delay d1 with respect to the reduction of the compressor speed. The compressor speed is for example reduced when a temperature threshold for the temperature of the refrigerant in the heat pump system 4 is exceeded. Preferably when the refrigerant temperature at the outlet of the condenser 10 exceeds a predefined threshold. As depicted in Fig. 8, the second phase starts (the first phase ends) when the fan speed is increased. Alternatively (not shown) it can be considered that the second phase starts when the compressor speed is reduced, while the delayed fan speed increase is part of the initial period of the second phase. In a further alternative consideration it can be considered that there is a transition period of duration d1 between the end of the first phase and the start of the second phase.

[0073] Fig. 9 depicts a modification of Fig. 7 in which the reduction of the compressor speed is delayed by a predetermined delay time or period d2 with respect to the increase of the fan rotation speed or air flow rate. The second phase starts with the reduction of the compressor speed. However and similar to the previous section, it can also be considered that the second phase starts when fan speed or flow rate is increased or a transition period of duration d2 is interleaved between the end of the first period and the start of the second period. Preferably the cooling air fan speed is increased when a temperature threshold for the temperature of the refrigerant in the heat pump system 4 is exceeded.

[0074] Fig. 10 exemplifies another embodiment similar to the one of Fig. 7, where however the fan speed of the process air fan 8 has a more moderate increase from the first to the second phase. As can be seen the speed was increased from the first to the second phase. While at the transition from the first to the second phase the conveyance or air flow rate also increases, due to the above mentioned clogging of the fluff filter 22, the air flow rate (further) decreases over time and during the second phase it may even fall below the highest value of the air flow rate at the beginning of the first phase. Again in this case the average of the air flow rate before the transition from the first to the second phase is lower than the average of the air flow rate after the transition.

Reference Numeral List

2	laundry dryer	20c	rising channel
3	housing	20d	front channel
4	heat pump system	22	fluff filter element
5	base section	30	condensate collector
6	refrigerant loop	32	drain pump
8	process air fan	34	condensate drawer
10	first heat exchanger (condenser)	36	drain conduit
12	second heat exchanger (evaporator)	38	drawer pipe
14	expansion device	40	cooling fan
16	compressor	42a-b	temperature sensor
17	laundry storing compartment	44	control unit
18	drum	46	fan motor
19	laundry	48	input panel
20	process air channel	50	drum motor
20a	battery channel	A	process air flow
20b	rear channel	B	refrigerant flow
		d1, d2	activation delay

Claims

1. Method for operating a laundry drying apparatus, in particular a laundry dryer or a washer-dryer, during a drying program,
the laundry drying apparatus (2) comprising:

a drum (18) adapted to receive laundry (19) for drying the laundry using drying air,
a drying air fan (8) adapted to convey drying air (A) through the drum (18),
a motor (46) adapted to drive the drying air fan (8), and
a heat-pump system (4) comprising a first heat exchanger (10) adapted to heat the drying air, a second heat
exchanger (12) adapted to cool the drying air for humidity condensation, and a compressor (16) adapted to
circulate refrigerant through the first and second heat exchangers (10, 12),
wherein the compressor (16) is a variable speed and/or variable power compressor;

wherein the method comprises:

starting a drying program for drying the laundry received in the drum (18),
during a first phase of the drying program, operating the compressor (16) at a first compressor performance
and operating the drying air fan (8) at a first fan performance, and
during a second phase of the drying program, operating the compressor (16) at a second compressor perform-
ance and operating the drying air fan (8) at a second fan performance,
wherein the second compressor performance is lower than the first compressor performance, and
wherein the second fan performance is higher than the first fan performance.

2. Method according to claim 1, wherein the compressor performance is one or more of:

a motor speed of a motor driving the compressor (16),
an electrical power supplied to the compressor (16),
the frequency of the voltage and/or current applied to the motor of the compressor (16), and
the refrigerant conveyance rate of the compressor (16).

3. Method according to claim 1 or 2, wherein the compressor performance is adapted by one or more of:

the second compressor speed is lower than the first compressor speed by at least 10%, 20%, 25%, 30% or 40%,
the second compressor speed is in the range of 85-95%, 75-90%, or 50-75% of the first compressor speed,
the second compressor performance is lower than the first compressor performance by at least 10%, 20%,
25%, 30% or 40%, and
the second compressor performance is in the range of 85-95%, 75-90%, or 50-75% of the first compressor
performance.

4. Method according to claim 1, 2 or 3, wherein the drying air fan performance is one or more of:

a motor speed of the motor (46) driving the drying air fan (8), and
the air conveyance rate of the drying air conveyed by the fan (8).

5. Method according to any of the previous claims, wherein the drying air fan performance is adapted by one or more of:

the second drying air fan speed is higher than the first drying air fan speed by at least 10%, 20%, 25%, 30% or 50%,
the second drying air fan speed is in the range of 110-140%, 130-160%, or 150-200% of the first drying air fan
speed,
the second drying air flow rate is higher than the first drying air flow rate by at least 10%, 20%, 25%, 30% or
50%, and
the second drying air flow rate is in the range of 110-140%, 130-160%, or 150-200% of the first drying air flow rate.

6. Method according to any of the previous claims, further comprising:

during the running drying program, detecting an operational parameter of the heat-pump system (4),
evaluating the operational parameter, and
in dependency of the operational parameter, starting the second phase of the drying program.

7. Method according to claim 6, wherein the change from the first phase to the second phase, the triggering event for
changing from the first to the second phase, or the ending of the first phase and the starting of the second phase
is controlled in dependency of a or the temperature of the heat-pump system.

8. Method according to claim 6 or 7, wherein an operational parameter or the temperature of the heat-pump system (4) is one or more of:

a temperature of the heat-pump system (4),
a temperature of the compressor (16),
a temperature of the refrigerant,
a temperature of the refrigerant at the compressor outlet,
a temperature of the refrigerant at the condenser outlet,
a temperature representative for a temperature of the heat-pump system (4), and
a refrigerant pressure of the heat-pump system (4).

9. Method according to any of the previous claims, wherein one or more of the following applies:

the change from first to second phase, the triggering event for changing from the first to the second phase, or the ending of the first phase and the starting of the second phase is controlled or is defined by a compressor cooling phase where for the first time a compressor cooling fan (40) is started or activated the first time for cooling the compressor (16),
at the start of the second phase a compressor cooling fan (40) is activated for cooling the compressor (16), and during the second phase a compressor cooling fan (40) is at least repeatedly operated or activated for cooling the compressor (16).

10. Method according to any of the previous claims, wherein the motor (46) for driving the drying air fan (8) is a variable speed motor.

11. Method according to any of the previous claims,
wherein the motor (46) driving the fan (8) is also driving the drum (18), or wherein the drum (18) is driven by a drum drive motor (50) independent of a motor (46) driving the fan (8), or
wherein the drum (18) and fan (8) are driven by the same motor and a clutch element or a gear device is provided between the motor and the drying air fan (8), wherein the clutch element or gear device is adapted to drive the drying air fan (8) and the drum (18) at least temporally at different speeds or speed ratios.

12. Method according to any of the previous claims, wherein during the second phase or at least during a time period of the second phase:

- the fan rotation speed is controlled such that the second drying air flow rate is constant, or
- the fan rotation speed is controlled according to a predetermined speed profile resulting in the drying air flow rate during the second phase being higher than the drying air flow rate in the first phase by increasing the fan rotation speed.

13. Method according to any of the previous claims,
wherein the fan rotation speed during the first phase is constant,
wherein the fan rotation speed during the second phase is constant, or
wherein the fan rotation speed during the first and second phase is constant.

14. Method according to any of the previous claims, wherein the drying air fan (8) is designed such that at same rotation speeds of the fan driving motor (46) in the main rotation direction and in the counter rotation direction the respective flow rate of the drying air fan (8) is different.

15. Method according to any of the previous claims, wherein one or more of the following drying operation parameters:

- first compressor performance,
- second compressor performance,
- first drying air fan performance,
- second drying air fan performance, and
- heat-pump system operational parameter,

are selected by a control unit (44) of the drying apparatus (2) in dependency of one or more of the following:

- a laundry drying program or a laundry drying option set by a user via an input selector (48) of the drying apparatus;
- a laundry type as set by a user or as estimated by the drying apparatus,
- the duration of the laundry drying program set by a user or as estimated by the drying apparatus,
- the ambient temperature,
- starting or current humidity of the laundry,
- the target final humidity of the laundry,
- the amount or weight of laundry,
- a parameter of the compressor motor,
- the noise of the conductivity sensor, and
- the condensation rate.

16. Method according to any of the previous claims, wherein during the second phase or by starting a third phase following the second phase one or more of the following is applied:

reducing the compressor performance from the second compressor performance to a third compressor performance, where the third compressor performance is lower than the second compressor performance; repeatedly, in one or more steps, gradually and/or continuously reducing the compressor performance; increasing the drying air fan performance from the second fan performance to a third fan performance, where the third fan performance is lower than the second fan performance; and repeatedly, in one or more steps, gradually and/or continuously increasing the drying air fan performance.

17. Laundry drying apparatus, in particular a laundry dryer or a washer-dryer, the laundry drying apparatus (2) comprising:

a drum (18) adapted to receive laundry (19) for drying the laundry using drying air;
a drying air fan (8) adapted to convey drying air through the drum (18);
a motor (46) adapted to drive the drying air fan (8);
a heat-pump system (4) comprising a first heat exchanger (10) adapted to heat the drying air, a second heat exchanger (12) adapted to cool the drying air for humidity condensation, and a compressor (16) adapted to circulate refrigerant through the first and second heat exchangers (10, 12), wherein the compressor (16) is a variable speed and/or variable power compressor; and
a control unit (44) controlling the execution of a drying program, wherein the control unit (44) is adapted to execute the drying program by:

starting the drying program for drying the laundry received in the drum (18),
during a first phase of the drying program, operating the compressor (16) at a first compressor performance and operating the drying air fan (8) at a first fan performance, and
during a second phase of the drying program, operating the compressor (16) at a second compressor performance and operating the drying air fan (8) at a second fan performance,
wherein the second compressor performance is lower than the first compressor performance, and
wherein the second fan performance is higher than the first fan performance.

18. Laundry drying apparatus according to claim 17, wherein the control unit (44) is adapted to control the drying program according to any of the previous claims 2 to 16.

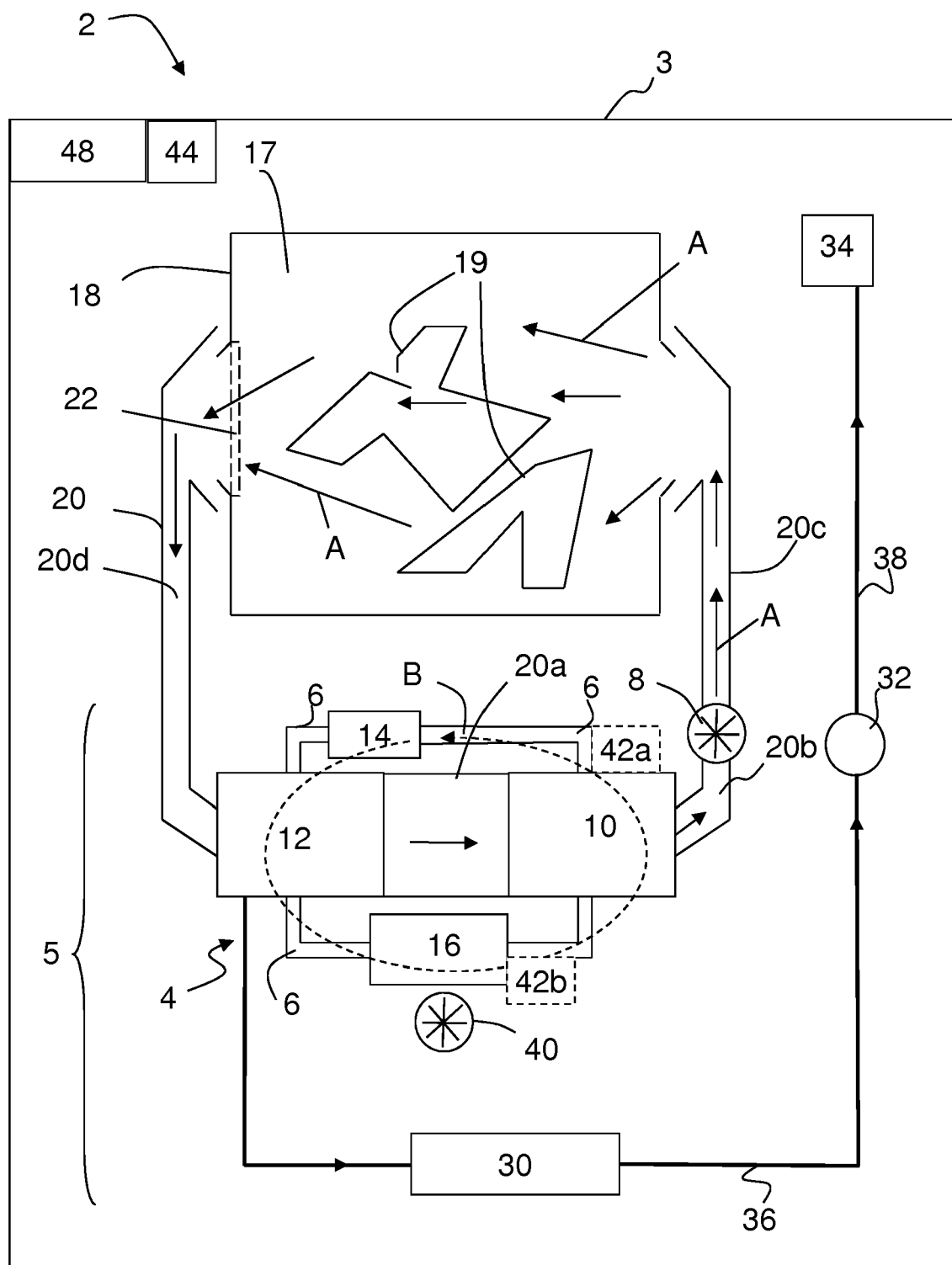


Fig. 1

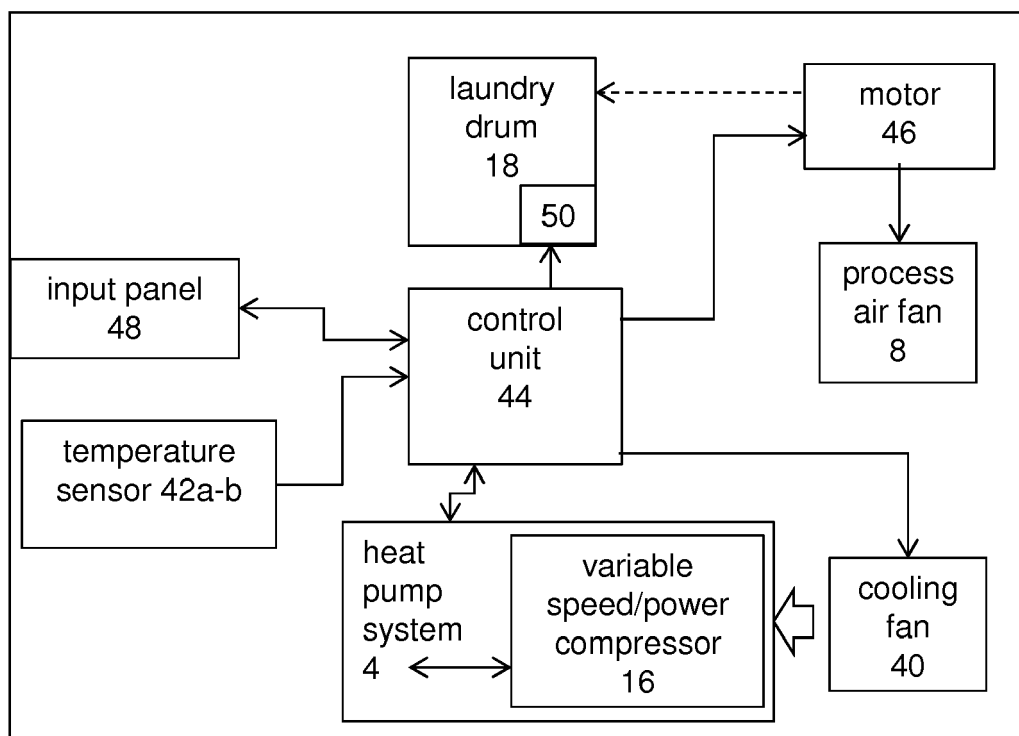


Fig. 2

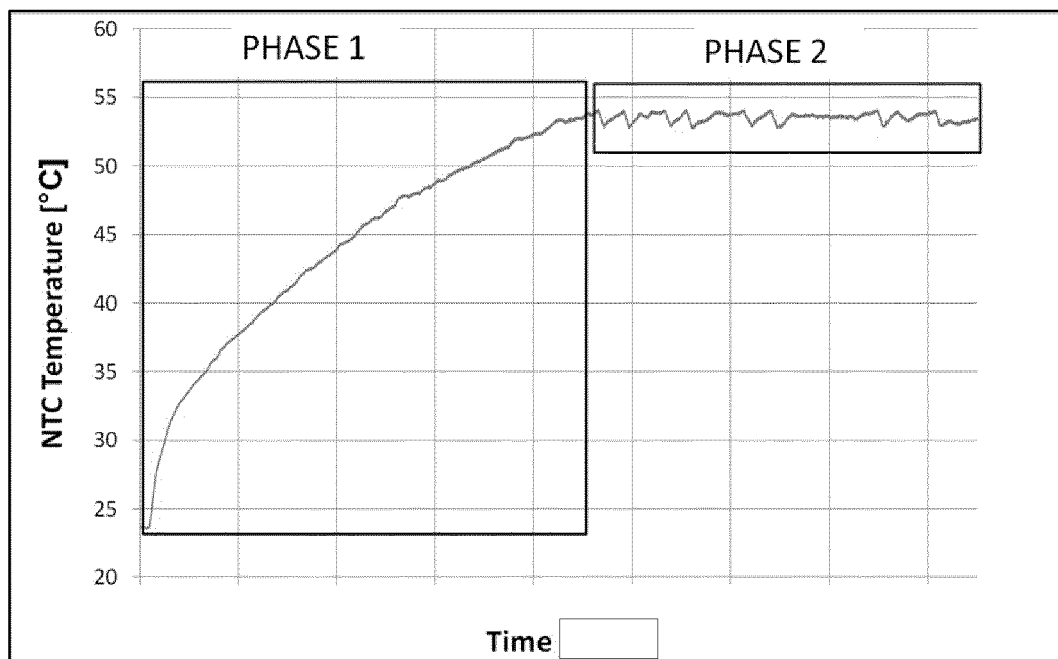


Fig. 3

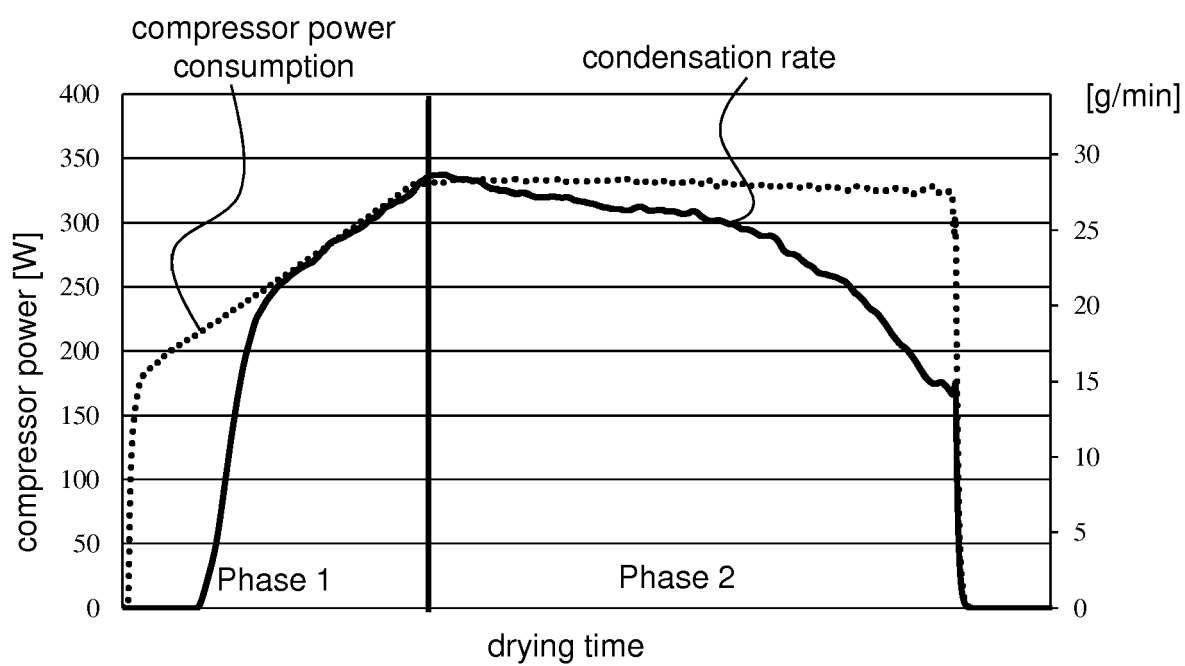


Fig. 4

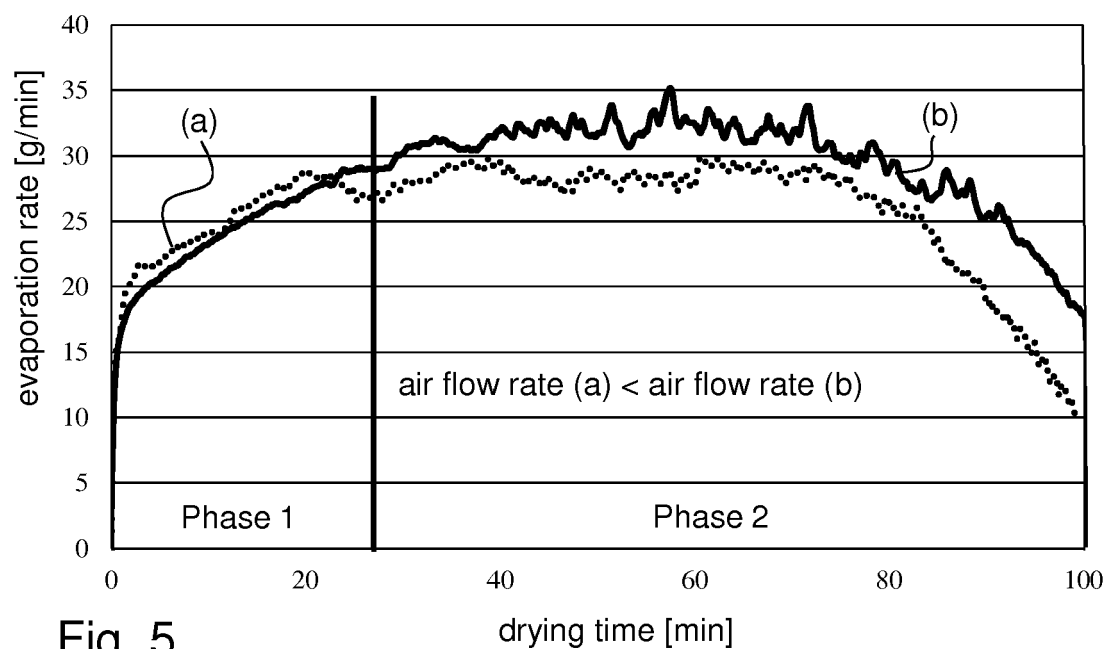


Fig. 5

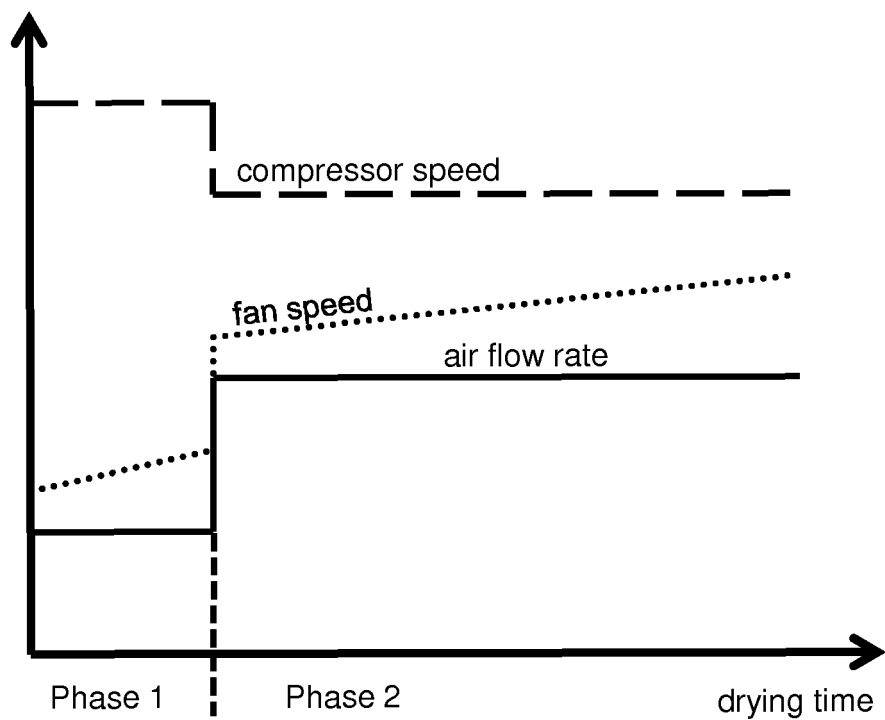


Fig. 6

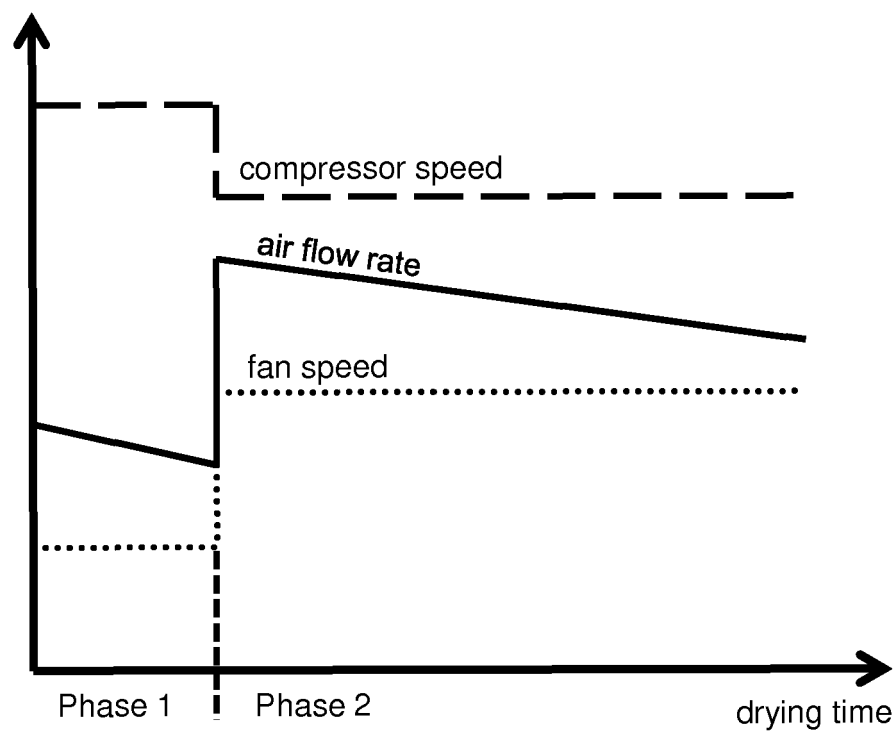


Fig. 7

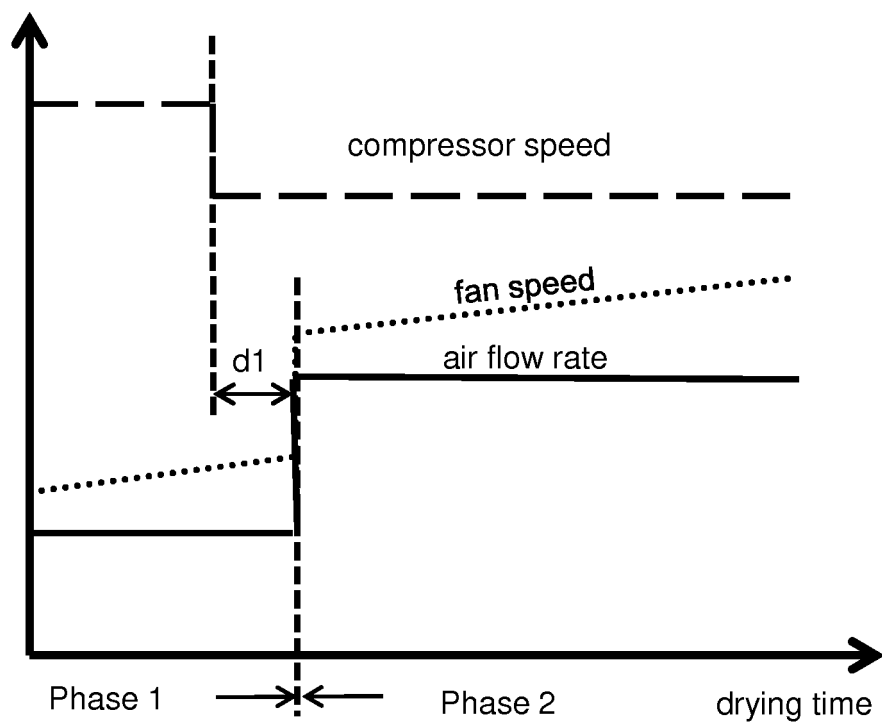


Fig. 8

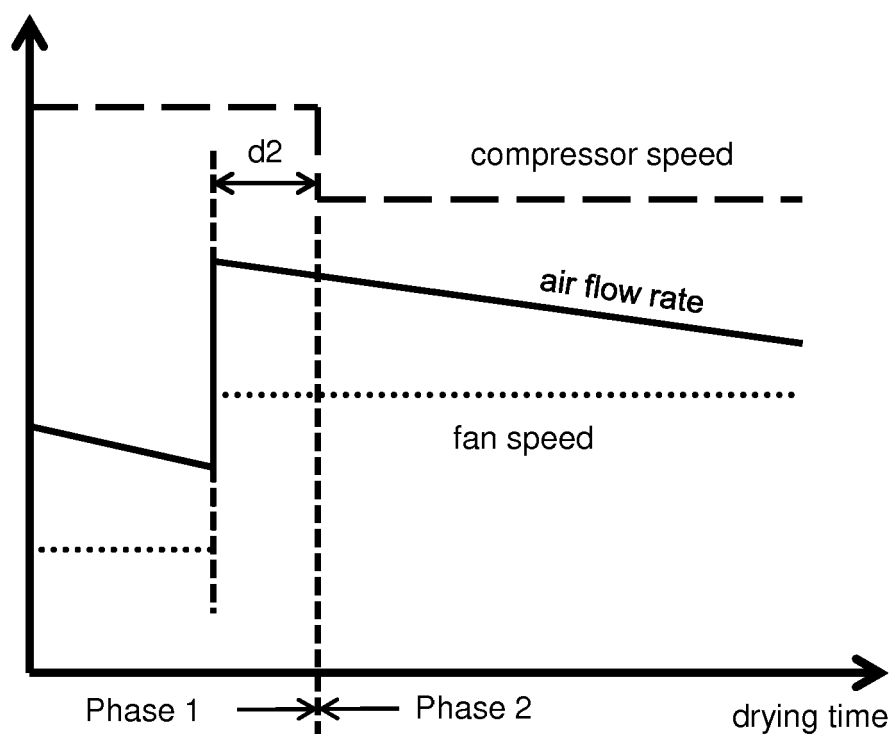


Fig. 9

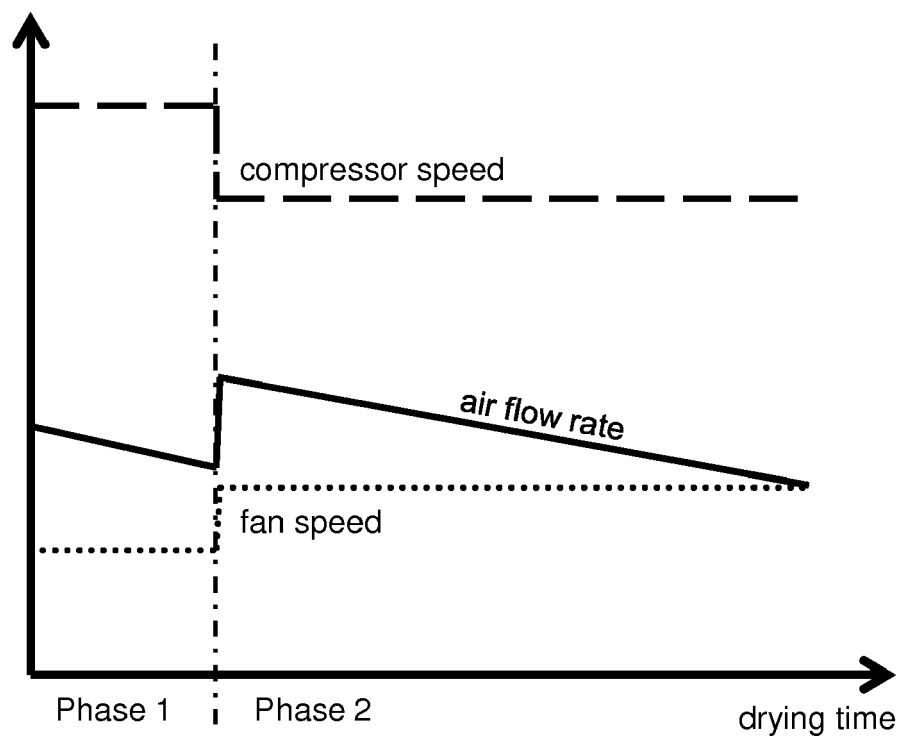


Fig. 10



EUROPEAN SEARCH REPORT

Application Number
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