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(54) **A method for controlling a laundry drying machine with heat pump system and laundry drying machine controlled by such method**

(57) A laundry drying machine with heat pump system comprises a process air circuit including a rotating drum (10), a blower (12) and a heater (16), a refrigerant circuit including a compressor (22), a condenser (14), an expansion device (23), an evaporator (18), such condenser and evaporator being in heat exchange relationship with the process air circuit, an auxiliary condenser (20) cooled by an air flow driven by a fan (26), and at least two temperature sensors (T1, T2) placed in the process air circuit and/or in the refrigerant circuit. A method for controlling such laundry drying machine comprises inputting a desired behavior of the laundry drying machine selected in the group consisting of optimized use of energy, overall drying time and fabric care, and controlling the components (12, 16, 22, 26) of the machine according to signals from said two temperature sensors (T1, T2) and according to said desired behavior.

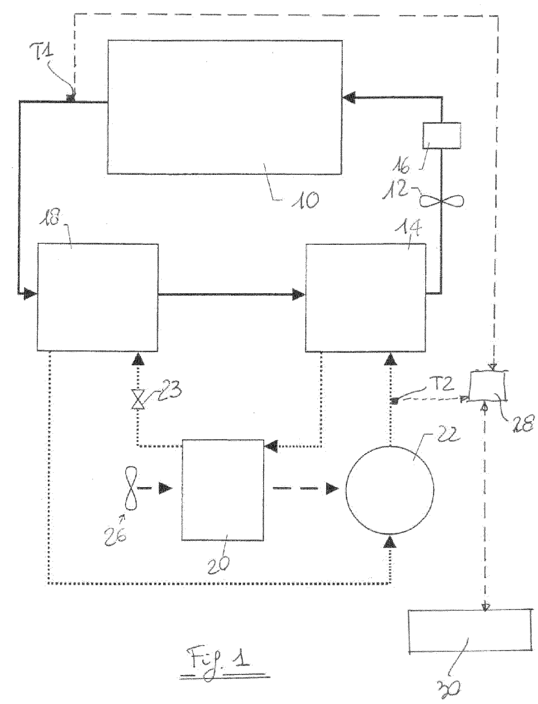

Fig. 1

EP 2 690 212 A1

Description

[0001] The present invention relates to a method for controlling a laundry drying machine with heat pump system comprising a process air circuit including a rotating drum, a blower and a heater, a refrigerant circuit including a compressor, a condenser, an expansion device, an evaporator, such condenser and evaporator being in heat exchange relationship with the process air circuit, and an auxiliary condenser cooled by an air flow driven by a fan, and at least two temperature sensors placed respectively in the process air circuit and in the refrigerant circuit.

[0002] The so called "hybrid" heat pump dryers, in which the process air is heated either by the condenser of the refrigerant circuit and by an auxiliary heater are well known in the art. Moreover, also an hybrid heat pump dryer having an auxiliary condenser with an auxiliary fan (cooled by ambient air) is known from EP 999302.

[0003] Usually such hybrid heat pump dryers, despite being very efficient in term of use of energy, do offer to the user a quite limited range of choices of the drying process, for instance degree of final humidity content of laundry or long or short drying cycle. Such few and simple choices can on one side limit the operational ranges of the machine, and on the other side limit the possible choices of the users which may depend on several factors.

[0004] The purpose of the invention is therefore a goal oriented control method, which increases the possible choices of the user, and which can particularly optimizes a choice on low energy consumption, on cycle overall time or on fabric care of a hybrid heat pump household tumble dryer, with an optimized balance between heating and cooling power.

[0005] Further advantages and features of a method and of a laundry dryer according to the invention will become clear from the following detailed description, with reference to the attached drawings in which:

- Figure 1 is a schematic view of a hybrid heat pump tumble dryer;
- Figure 2 is a block diagram showing a dual loop control architecture according to the invention;
- Figures 3 - 5 are example of control implementations according to different choices of the user based on energy strategy, time strategy and fabric care strategy respectively;
- Figure 6 is a block diagram showing a control loop according to prior art;
- Figure 7 is a diagram showing the temperature and residual moisture content behavior in a prior art dryer using a control system according to figure 6; and
- Figures 8-10 are diagram showing energy optimized cycle temperatures behavior, time optimized cycle temperatures behavior and fabric care optimized cycle temperatures behavior respectively.

[0006] With reference to figure 1, the process air circuit is the one that involves the evaporation of the water retained by the fabric and it is made up of a rotating drum 10 actuated by an electric motor and containing a certain amount of clothes, a process air blower 12that sets the circuit process airflow, a condenser 14 and an heating element 16 that heat the air going inside the drum 10, an evaporator 18 where the moisture contained in the process air can condense, an auxiliary condenser 20 (subcooler), a compressor 22, an expansion tube 23 and a fan 26 for cooling the auxiliary condenser 20 with ambient air.

[0007] The clothes dryer comprises also a NTC temperature sensor T1 placed on the process air exhaust from the drum and a NTC sensor T2 placed in the refrigerant circuit downstream the compressor 22, such temperature sensor being connected to a control process unit 28 which drivers all components of the machine according to a certain process.

[0008] The machine can also include also other components, e.g. an accumulator upstream the compressor 22,which is not shown in figure 1 for sake of clarity.

[0009] An air channel conveys the process air to the evaporator, where the vapor contained in the air thanks to the low temperature condense.

[0010] The heat pump circuit is the one that involves the refrigerant that with its phase variation transfer heat to the air circuit. The temperature sensor T2 that measures the refrigerant temperature may be placed in a position different from compressor outlet, for instance in the capillary tube or other places. The auxiliary fan 26 increases the heat exchange on the auxiliary condenser 20.

[0011] Also temperature sensor T1 may be placed in a different position than the one shown in figure 1, but in any case it is placed in the moist air circuit, by the drum outlet or the blower or the evaporator.

[0012] The second temperature sensor T2, instead of being placed in the refrigerant circuit, may be placed in the moist air circuit in a position different to the first sensor T1, for instance by the heater 16 or the condenser 14 or the auxiliary condenser 20.

[0013] The controllable variables of the system, which may be continuously adjusted or simply ON/OFF, are the compressor speed, the process air blower speed, the heating element power and the auxiliary fan speed.

[0014] Those variables are controlled in order to provide and remove the right quantity of energy respectively by means of the condenser plus the heating element and the evaporator, rising the optimum compromise between evaporation and condensation.

[0015] In the most of the cases, to reduce the cost of the system, the motors of the compressor 22 and the process air blower 12 are constants speed motors, therefore it is not possible to change their speed.

[0016] According to a common practice of controlling the appliance, the compressor 22 is kept on for the entire drying cycle while the heater 16 switches on/off in order to manage the temperature of the tumble dryer by feeding back the drum exhaust temperature measured by sensor T1. Indeed, the drum output temperature is usually a good approximation of the clothes temperature which is therefore kept under control.

[0017] Since it is required the compressor to stay on, due to inefficiency in turning off and on the heat pump system, in order to prevent shifting in the working point of the system that would reflect in less energy removed in the evaporator, thus less condensation and overheating of the compressor, its temperature has to be controlled. Therefore when the temperature of the compressor 22, sensed by sensor T2, reaches a certain value, close to the high limit temperature switch off, the auxiliary fan 26 is turned on.

[0018] The feedback is usually made trough hysteresis control, i.e. the heater 16 and the auxiliary fan 26 are switched on when the feedback temperature is below a predefined threshold and switched off when it is above a second predefined threshold.

[0019] Up to now we have described a dryer which can be controlled either according to prior art or according to the invention. As a matter of fact the main drawback of the known control system is the difficulty in creating a customized appliance behavior aiming to optimize system performances according to the customer choices, who may desire to save energy, to save time or alternately to prefer a more gentle treatment of clothes, for instance by keeping the drying temperatures lower.

[0020] The method according to the invention can control every component of the appliance, and preferably both the auxiliary cooling fan 26 and the heater 16 of a tumble hybrid heat pump dryer, optimizing alternatively energy consumption, drying time or fabric care according to a selection done by the user by means of a user interface 30. This selection can be done through a button, touch display, cycle selection, etc...

[0021] Once the user has done his/her selection, the system temperatures can be controlled by means of several actuators: the auxiliary cooling fan 26, the heater 16, the compressor 22 and the process air blower 12. The way all these actuators are used affects the overall system performances in terms of energy consumption, cycle duration, water extraction efficiency, final moisture retention at the end of the cycle, fabric care (wrinkles, shrinkage, etc...), etc....

[0022] The present invention deals therefore with a method of choosing how to use these actuators in the different parts of a drying cycle.

[0023] The invention is effective even in the case of one or more of the actuators cannot be continuously controlled, e.g. fixed speed compressor, fixed speed fan, etc.

[0024] According to the invention, the drying cycle is conceptually divided in three phases of variable duration: warm up (WU), mid phase (MP) and cool down (CD). In the following the three phases will be identified by means of two temperature measurements and cycle length.

[0025] In particular, naming:

to = 0 the beginning of the cycle,
tend the time at the end of the cycle,
$t_{20} = 0.2^* t_{end}$,
$t_{50} = 0.5^* t_{end}$,
$t_{70} = 0.7^*{}_{tend}$,
$t_{80} = 0.8^* t_{end}$,
T_{1_s}tart the value of temperature T_1 measured at time to,
T_{1_mid} the maximum value of temperature T_1 measured from to to t_{50},
$T_{1\_threshold} = (T_{1\_mid} - T_{1\_start})^*0.8 + T_{1\_start}$, t_{r1} the first time at which the temperature T_1 is greater than $T_{1\_threshold}$,
T_{2_start} the value of temperature T_2 measured at time to,
T_{2_mid} the maximum value of temperature T_2 measured from to to t_{50},
$T_{2\_threshold} = (T_{2\_mid} - T_{2\_start})^*0.8 + T_{2\_start}$,
t_{r2} the first time at which the temperature T_2 is greater than $T_{2\_threshold}$,
t_{WU} = min(t20, tr1, tr2)
t_{MP}_start = max(t_{20}, t_{WU}*1.2)
t_{MP}_end = t_{70}
tCD_start = t_{80}

[0026] The following definitions of the three phases of the cycle are given:

- Warm up (WU): starts at time to and ends at time t_{WU}
- Mid phase (MP): starts at time t_{MP}_start and ends at time t_{MP_end}
- Cool down (CD): starts at time t_{CD_start} and ends at time tend

[0027] Moreover, naming:

P_{WU} the average power absorbed by the heating element during WU phase
P_{MP} the average power absorbed by the heating element during MP phase
P_{CD} the average power absorbed by the heating element during CD phase
S_{F-WU} the average speed of the auxiliary fan during WU phase
S_{F-MP} the average speed of the auxiliary fan during MP phase
S_{F_CD} the average speed of the auxiliary fan during CD phase
Sc_wu the average speed of the compressor during WU phase
S_{C-MP} the average speed of the compressor during MP phase
S_{C-CD} the average speed of the compressor during CD phase
S_{B-WU} the average speed of the process air blower fan during WU phase
S_{B_MP} the average speed of the process air blower fan during MP phase

S_{FB-CD} the average speed of the process air blower fan during CD phase

[0028] In case of a discrete control the averages are computed taking in account 0 as OFF and 1 as ON.

[0029] The proposed controller will be provided with the possibility to choose via UI between at least two of the following cycles, to which the following values of parameters apply:

- Energy Optimized Cycle, characterized by having:

  $P_{MP} < 0.2*P_{WU}$, $P_{CD} < 0.2*P_{W}$
  $S_{f\_WU} < 0.25*S_{F\_MP}$, $S_{f-CD} > S_{F\_WU}$
  $S_{C\_CD} =< S_{C\_MP}$, $S_{C\_CD} =< S_{C\_WU}$
  $S_{B-WU} =< S_{B-MP} =<S_{B-CD}$

- Time Optimized Cycle, characterized by having:

  $0.5*P_{WU} < P_{MP} < 1.2*P_{WU}$, $P_{CD} < 1.2*P_{WU}$
  $S_{f\_WU} < 0.25*S_{F\_MP}$, $S_{f\_CD} > S_{F\_WU}$
  $S_{C\_CD} =< S_{C-MP}$, $S_{C\_CD} =< S_{C\_WU}$
  $S_{B-WU} =< S_{B-MP} =<S_{B\_CD}$

- Fabric Care Optimized Cycle, characterized by having:

  $0.2*P_{WU} < P_{MP} < 0.5*P_{WU}$, $PCD < 0.25*P_{WU}$
  $S_{f\_WU} < 0.25*S_{F\_MP}$, $S_{f\_CD} > S_{F\_WU}$
  $S_{C-CD} =< S_{C\_MP}$, $S_{C\_CD} =< S_{C\_WU}$
  $S_{B\_WU} =< S_{B\_MP} =<S_{B\_CD}$

[0030] Of course the above parameter values are only one example and they can change depending on the actual dryer in which the method according to the invention is implemented.

[0031] A conceptual scheme of which is shown in figure 2, dealing with changing both auxiliary fan motor speed and heating power according to two temperature measurements by sensors T1 and T2, thus controlling the energy delivered to the load inside the drum and the energy removed from the refrigerant giving the possibility to optimize different system performance objective.

[0032] One example of the possible implementations of the control strategy shown in figure 2, considering for sake of simplicity that the process air blower 12 and compressor 22 are maintained at a constant speed during the cycle, respectively for the energy, the time and fabric care strategy are drawn in the Figures 3-5. In these examples, the temperature sensed by sensor T1 is the drum outlet temperature while the temperature sensed by sensor T2 is the capillary temperature of the refrigerant circuit.

[0033] The control strategy according to the invention has been compared with a simple known strategy in which the hysteresis on T1 controls the heater actuation while the hysteresis on T2 controls the fan actuation, as shown in Figure 6, referred to a drying cycle of a 4 kg load.

[0034] With the control system shown in figure 6, the results are shown in figure 7, which shows an energy consumption equal to 1,69 kWh and a drying time around 92 minutes. In the diagrams with reference A it is indicated the temperature of process air entering the drum 10, with B the temperature of air measured at the exhaust of the drum, with C the capillary temperature of the refrigerant circuit and with D the residual moisture content of the fabric inside the drum.

[0035] The energy optimized cycle in Figure8 (corresponding to a control scheme according to figure 3), reveals a lower energy consumption, around 1,54 kWh (9%) and a drying time around 98 minutes (+8 %) compared to the control system of figures 6 and 7.

[0036] The time optimized cycle in Figure 9 has comparable energy consumption 1,72 kWh (+2 %) and a comparable drying time, around 90 minutes (-1%).

[0037] The fabric optimized cycle shown in Figures 5 and 10 keeps very low the fabric temperature avoiding increases by the cycle end therefore the stress for the fabric. In terms of performances, the energy absorbed is slightly below the reference cycle of figures 6 and 7, i.e. 1,6 kWh (-5%) but the drying time is increased lasting 118 minutes (+29%).

Claims

1. A method for controlling a laundry drying machine with heat pump system comprising a process air circuit including a rotating drum (10), a blower (12) and a heater (16), a refrigerant circuit including a compressor (22), a condenser (14), an expansion device (23), an evaporator (18), such condenser and evaporator being in heat exchange relationship with the process air circuit, an auxiliary condenser (20) cooled by an air flow driven by a fan (26), and at least two temperature sensors (T1, T2) placed in the process air circuit and/or in the refrigerant circuit, **characterized in that** the method comprises inputting a desired behavior of the laundry drying machine selected in the group consisting of optimized use of energy, overall drying time and fabric care, and controlling the components (12, 16, 22, 26) of the machine according to signals from said two temperature sensors (T1, T2) and according to said desired behavior.

2. A method according to claim 1, wherein at least two components are controlled.

3. A method according to claim 2, wherein the at least two components to be controlled are selected in the group consisting of blower (12), heater (16), compressor (22) and fan (26).

4. Laundry drying machine with heat pump system comprising a process air circuit including a rotating

drum (10), a blower (12) and a heater (16), a refrigerant circuit including a compressor (22), a condenser (14), an expansion device (23), an evaporator (18), such condenser and evaporator being in heat exchange relationship with the process air circuit, an auxiliary condenser (20) cooled by an air flow driven by a fan (26), and at least two temperature sensors (T1, T2) placed in the process air circuit and/or in the refrigerant circuit, **characterized in that** it comprises a user interface (30) adapted for choosing a desired behavior of the laundry drying machine selected in the group consisting of optimized use of energy, overall drying time and fabric care, and a control unit (28) associated to such user interface (30) and adapted to control the components (12, 16, 22, 26) of the machine according to signals from said two temperature sensors (T1, T2) and according to said desired behavior.

5. Laundry drying machine according to claim 4, wherein at least two components are adapted to be controlled.

6. Laundry machine according to claim 5, wherein the at least two components to be controlled are selected in the group consisting of blower (12), heater (16), compressor (22) and fan (26).

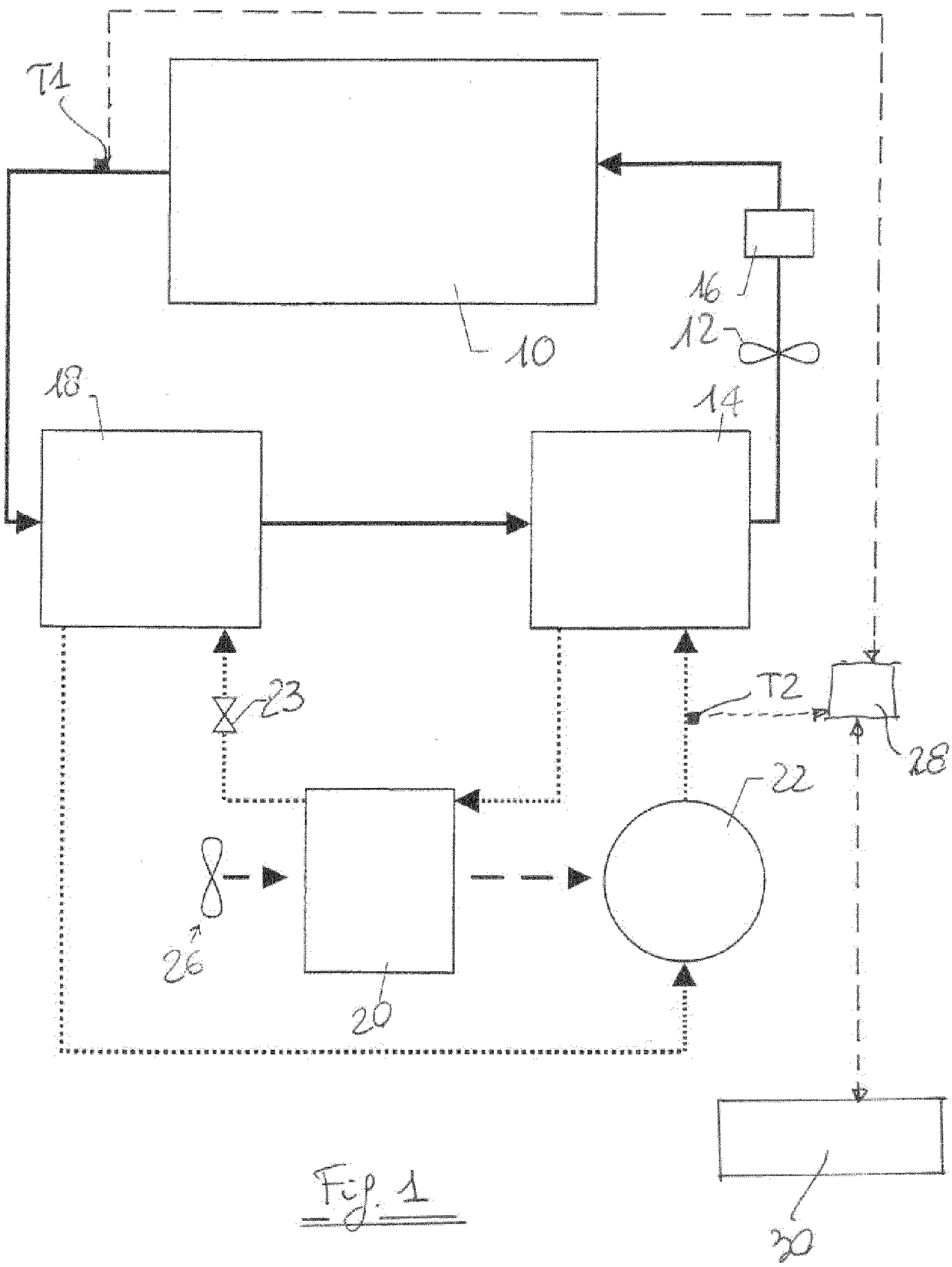

Fig. 1

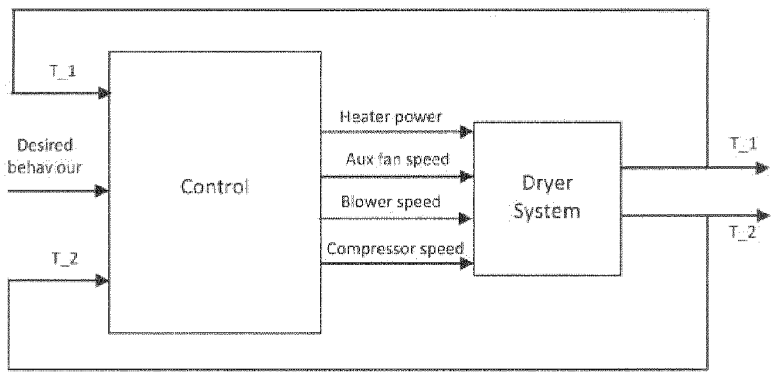

Fig.2

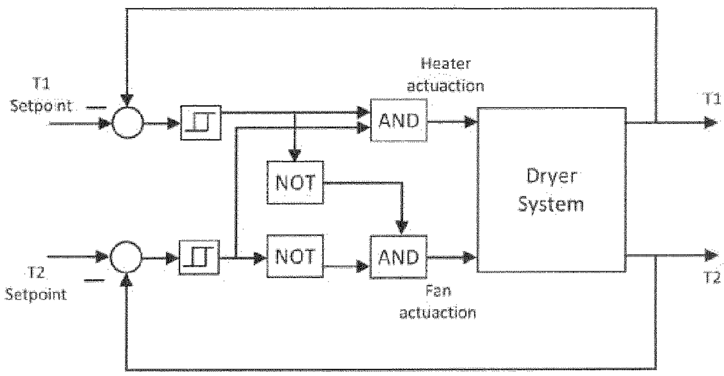

Fig.3

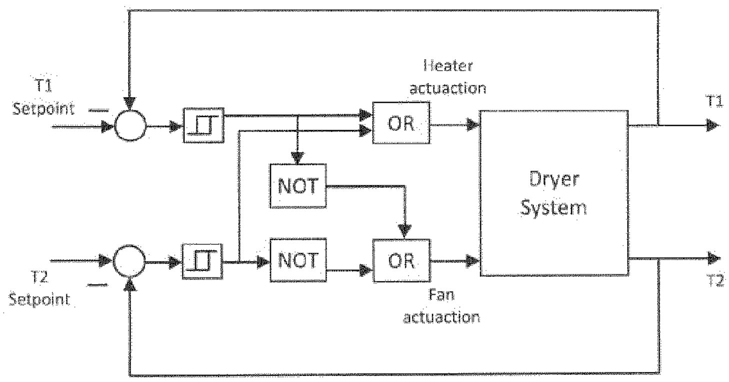

Fig.4

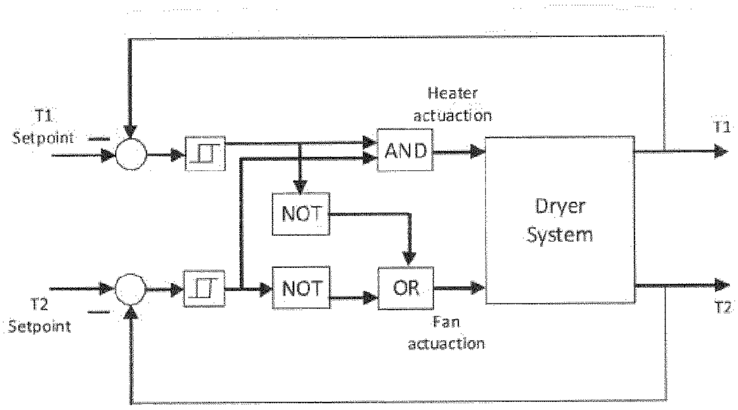

Fig. 5

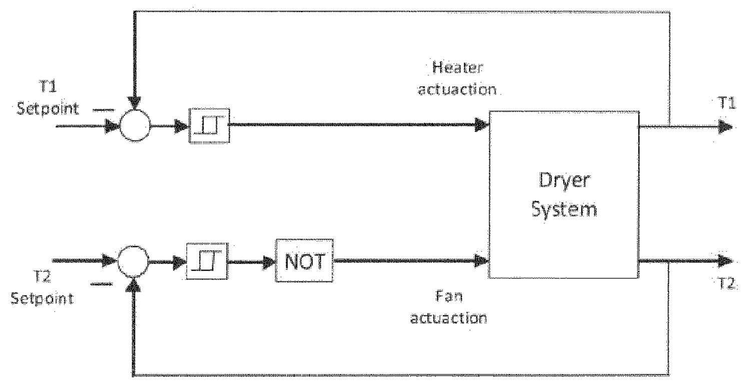

Fig. 6

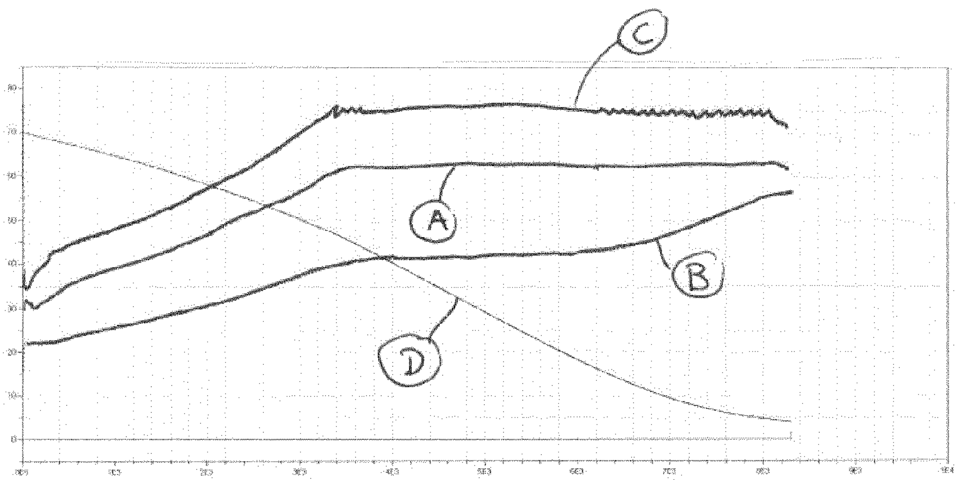

Fig. 7

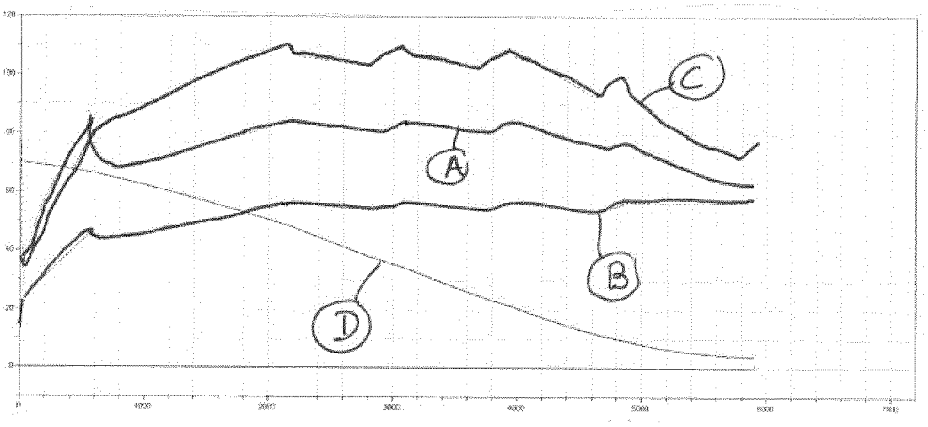

Fig. 8

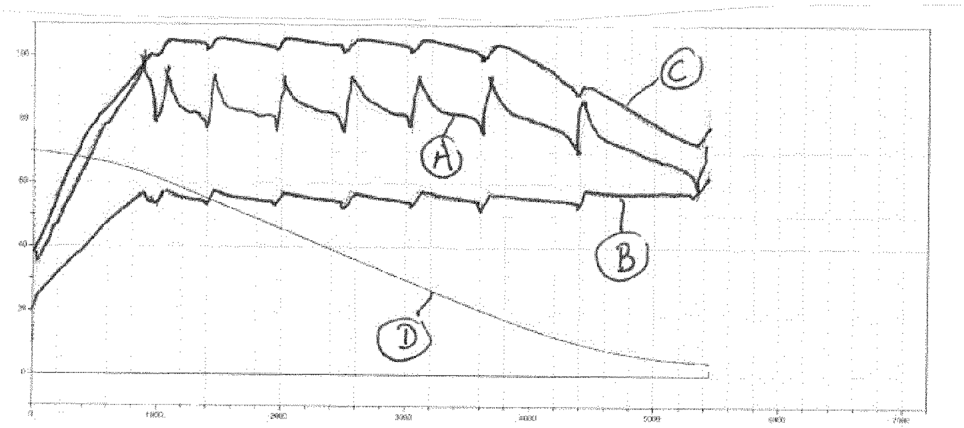

Fig. 9

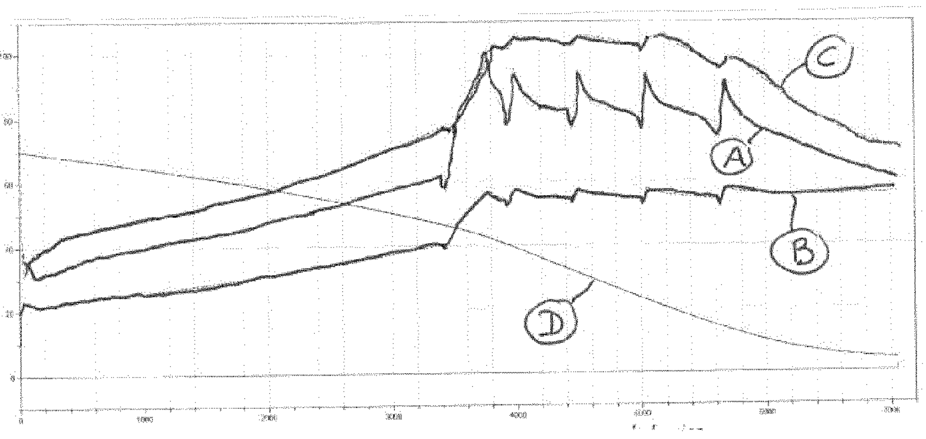

Fig. 10

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EUROPEAN SEARCH REPORT

Application Number
EP 12 17 7506

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
Y	EP 2 034 084 A1 (V ZUG AG [CH]) 11 March 2009 (2009-03-11) * pages 4-5; figures * -----	1-6	INV. D06F58/20
Y	US 2010/077787 A1 (MASUDA TETSUYA [JP] ET AL) 1 April 2010 (2010-04-01) * paragraphs [0038] - [0039]; figures * -----	1-6	

TECHNICAL FIELDS SEARCHED (IPC)

D06F

The present search report has been drawn up for all claims

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Place of search	Date of completion of the search	Examiner
Munich	18 December 2012	Stroppa, Giovanni

CATEGORY OF CITED DOCUMENTS

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18-12-2012

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