(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) **World Intellectual Property Organization**
International Bureau

(43) **International Publication Date**
16 May 2024 (16.05.2024)

WIPO | PCT

(10) **International Publication Number**
WO 2024/099950 A1

(51) **International Patent Classification:**
F26B 15/10 (2006.01) *F26B 21/00* (2006.01)
F26B 15/18 (2006.01)

(21) **International Application Number:**
PCT/EP2023/080817

(22) **International Filing Date:**
06 November 2023 (06.11.2023)

(25) **Filing Language:** English

(26) **Publication Language:** English

(30) **Priority Data:**
22205869.5 07 November 2022 (07.11.2022) EP

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(81) **Designated States** *(unless otherwise indicated, for every kind of national protection available)*: AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CV, CZ, DE, DJ, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IQ, IR, IS, IT, JM, JO, JP, KE, KG, KH, KN, KP, KR, KW, KZ, LA, LC, LK, LR, LS, LU, LY, MA, MD, MG, MK, MN, MU, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA, SC, SD, SE, SG, SK, SL, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, WS, ZA, ZM, ZW.

(84) **Designated States** *(unless otherwise indicated, for every kind of regional protection available)*: ARIPO (BW, CV,

(54) Title: APPARATUS AND METHOD FOR DRYING CONSTRUCTION PANELS

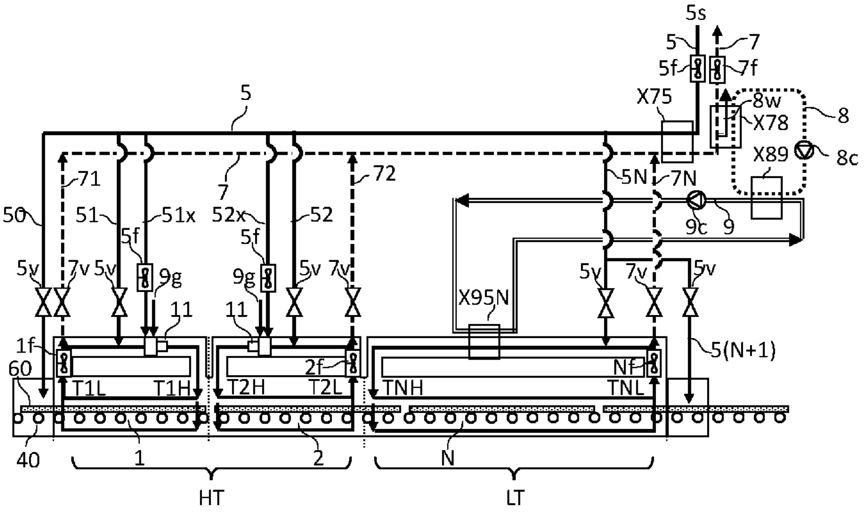

FIG.2

(57) **Abstract:** The present invention concerns an apparatus for drying construction panels comprising, # a conveyor (40) for conveying wet construction panels (60) along a drying path through a number of high temperature chambers (1, 2) (= HT chambers) located upstream along the drying path of a number of low temperature chambers (N) (= LT-chambers), # a distribution system (5) for distributing a fluid into the HT- and LT-chambers for heating the main surfaces of the construction panels and for removing moisture therefrom as they travel through the chambers, # an exhaust system (7) configured for evacuating out of the apparatus exhaust fluid along an exhaust flowing path extending from the N chambers (1, 2, … N) to outside the apparatus, wherein the fluid flowing into the HT-chambers is heated by heating elements (11) and wherein the fluid flowing into the LT-chambers is heated by a heat pump / MVR-system comprising a heat pump (8) transferring heat from the exhaust fluid to an MVR-cycle, which transfers the heat to the fluid in direct communication with the LT-chambers.

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GH, GM, KE, LR, LS, MW, MZ, NA, RW, SC, SD, SL, ST, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, ME, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, KM, ML, MR, NE, SN, TD, TG).

Declarations under Rule 4.17:

— *as to applicant's entitlement to apply for and be granted a patent (Rule 4.17(ii))*

— *of inventorship (Rule 4.17(iv))*

Published:

— *with international search report (Art. 21(3))*

— *in black and white; the international application as filed contained color or greyscale and is available for download from PATENTSCOPE*

APPARATUS AND METHOD FOR DRYING CONSTRUCTION PANELS

TECHNICAL FIELD

[0001] The present invention concerns an apparatus and method for drying construction panels made of gypsum (= plasterboards or gypsum fibreboard) or panels made of cement or calcium silicate during the formation thereof, consuming less energy than state of the art dryers and methods for achieving a same level of drying with lower energy consumption. The construction panels to be dried are typically driven on a conveyor through N chambers of a drying apparatus

BACKGROUND OF THE INVENTION

[0002] Construction panels such as panels made of gypsum (= plasterboards or gypsum fibreboard) or panels made of cement or fibre cement or calcium silicate are formed by mixing and reacting water with a base composition. For example panels made of gypsum ($CaSO_4.2H_2O$) referred to as plasterboards are formed by mixing and reacting plaster of Paris ($CaSO_4.½ H_2O$) with water. The panels thus formed must be heated to accelerate the reaction and eliminate excess water. For example, the apparatus illustrated in Figure 1 comprises a distribution system (5) configured for blowing a heated gas, typically air, over both main surfaces of the panels to raise the temperature thereof and reduce the moisture content, as they pass through N chambers. Before the air reaches the panels in the chambers, it is heated with heating elements (11), which can typically be air-fuel blowers. The N chambers are divided into high temperature (HT-) chambers (1,2) distributed in a HT-drying zone wherein the air is heated at a high temperature, followed by low temperature (LT-) chambers (N) distributed in a LT-drying zone. An exhaust system (7) is provided for evacuating out of the apparatus the cooled gas charged with moisture after it contacted the surfaces of the panels in each chamber.

[0003] Even if efforts are continuously made for reducing the amount of water added to the base composition, drying costs still represent a substantial portion of the total manufacturing costs. In view of the importance of reducing CO_2 emissions and of the rising cost of energy, efforts have been made to increase the efficacy of the drying apparatuses. For example, as illustrated in Figure 1, a heat exchanger (X75) is used to recover some heat from the exhaust air flowing in the exhaust system (7) before being released in the atmosphere and to transfer it to the fresh air flowing in the distribution system (5) prior to reaching the chambers and for feeding with pre-heated air the air-fuel burners used for heating the flowing air.

[0004] GB1562031 describes a drying apparatus wherein the air-fuel burners in the LT-drying zone are replaced by a heat exchanger extracting heat from the exhaust gas from the HT-chambers and transferring the heat to a fresh air supply blown into the LT-chambers. To increase the heat transfer from the exhaust air, the air blown onto the articles in the HT-drying zone has a high temperature and high moisture content. This has the effect of increasing the moisture content in the exhaust air, but it also reduces the amount of water removed from the articles to be dried.

[0005] WO2019105888 describes a dryer and method for drying plasterboards wherein heat from exhaust gas removed from the HT-chambers is extracted by a heat exchanger and transferred to fresh air supplies via heat exchangers arranged in series, each air supply being coupled to a LT-chamber. This method is very efficient, but it is difficult to upgrade an existing dryer of the type illustrated in Figure 1 to a dryer according to WO2019105888 as substantial extra room is required to achieve it.

[0006] . US2010299956 describes a dryer using oil-to-air heat exchangers instead of air-fuel burners for heating the air blown into the chambers. The oil is heated in a furnace, circulated into the various oil-to-air heat exchangers, and returned to the furnace. The dryer is equipped with an organic rankine cycle system (ORC) to use the heat either from the exhaust air from the last LT-chamber or from the furnace to produce electricity.

[0007] CN103708697 describes a mechanical vapour recompression (= MVR-) heat pump sludge drying system comprising a drying machine and a vapour compressor. Wet sludge is dried by the drying machine generating secondary vapour, which is compressed in the vapour compressor to become recompressed vapor. The recompressed vapour flows back into the drying machine. Thus, energy is saved by recovering the latent heat of the secondary vapor. Similarly, CN109282615A describes an MVR band dryer for drying articles.

[0008] It can be seen that various options have been explored in the art, all aiming at reducing energy consumption of the drying process. The present invention proposes an apparatus and method for drying construction boards such as plasterboards and cement boards during production thereof, which is making most use of the calorific energy available in the apparatus to substantially reduce energy consumption. A great advantage of the present invention is that it is easy and economically efficient to upgrade existing drying apparatuses of the type illustrated in Figure 1 to yield a drying apparatus according to the present invention without reducing the capacity of the apparatus.

[0009] These and other advantages of the present invention are described in continuation.

SUMMARY OF THE INVENTION

[0010] The present invention is defined in the appended independent claims. Preferred embodiments are defined in the dependent claims. In particular, the present invention concerns an apparatus for drying construction panels. A conveyor is configured for conveying wet construction panels along a drying path through a drying unit. The drying unit comprises N chambers, a distribution system, heating elements, and an exhaust system.

[0011] The drying unit comprises a number N of chambers distributed in series and in fluid communication with one another along the drying path, comprising a number i of high temperature chambers (= HT chambers) located in a high temperature drying zone (HT) in an upstream portion of the drying path, and a number j of low temperature chambers (= LT-chambers) located in a low temperature drying zone (LT) downstream of the high temperature drying zone (HT) along the drying path, wherein $1 \leq i \leq N-1$, and $j = N - i$.

[0012] The distribution system is in fluid communication at one end with a source of fluid and, at other ends, with the N chambers. It is configured for circulating a flow of the fluid along a fluid flowing path extending from the source of fluid into the N chambers. The heating elements are configured for heating the fluid in the distribution system prior to penetrating into the respective HT-chambers, i.e., the heating elements are located upstream of and adjacent to the access to the chambers at the other ends of the distribution system. The drying unit also comprises the exhaust system which is configured for evacuating out of the apparatus exhaust fluid along an exhaust flowing path extending from the N chambers to outside the apparatus.

[0013] The gist of the apparatus of the present invention includes a heat pump / MVR-system comprising a heat pump, an MVR-cycle, and specific heat exchangers.

[0014] A first heat pump-heat exchanger is configured for transferring heat from the exhaust fluid flowing in the exhaust system to a low boiling point fluid of a heat pump. The heat pump comprises a heat pump compressor configured for compressing and increasing a temperature of the low boiling point fluid, and for driving a flow of the low boiling point fluid from the first heat pump-heat exchanger to a second heat pump-heat exchanger.

[0015] The second heat pump-heat exchanger is configured for transferring the heat thus captured by the low boiling point fluid to a heating fluid, such as water / steam having a boiling temperature higher than the low boiling point fluid of the heat pump. The heating fluid is configured for circulating in a mechanical vapour recompression (MVR-) cycle driven by an MVR-compressor configured for compressing the heating fluid, and thus increasing a temperature of the heating fluid, and for driving a flow of the heating fluid from the second heat pump-heat exchanger to an MVR-heat exchanger.

[0016] The MVR-heat exchanger is configured for transferring heat from the heating fluid of the MVR-cycle to the fluid in the distribution system directly prior to penetrating into the respective LT-chambers, i.e., directly upstream of and adjacent to the access to the chambers at the other ends of the distribution system.

[0017] The coefficient of performance (= COP) of the heat pump / MVR system composed of the heat pump and MVR-cycle is defined as a ratio (Q / W) of a useful heat (Q) supplied by the heat transfer combination to a work (W) required to operate the heat pump compressor and the MVR-compressor. For example, the heat pump / MVR system can be characterized by a COP comprised between 2 and 5, preferably between 2.5 and 4.

[0018] In order to recover as much heat as possible from the exhaust fluid and to preheat the fluid of the distribution system, a pre-heating heat exchanger can be provided, configured for transferring heat from the exhaust fluid in the exhaust system to the fluid in the distribution system to increase the temperature of the fluid flowing in the distribution system. The pre-heating heat exchanger is preferably located in the exhaust system upstream of the first heat pump-heat exchanger wherein upstream is defined relative to a flow direction of the exhaust fluid in the exhaust system. The terms “upstream” and “downstream” are defined herein relative to the flow direction of a fluid in the corresponding fluid system, such as the fluid in the distribution system, the exhaust fluid in the exhaust system, the low boiling point fluid in the heat pump, or the heating fluid in the MVR-cycle.

[0019] In a preferred embodiment, the heating elements are air-fuel burners, and the source of fluid is a source of air. A part of the air flowing in the distribution system is fed to the air-fuel burners to operate them with a fuel. Alternatively, the heating elements can be electrical heaters.

[0020] In yet a preferred embodiment the source of fluid is a source of a gas, preferably air. The distribution system comprises distribution fans configured for driving the flow of gas from the source of gas towards the N chambers, The HT-chambers are equipped with chamber fans configured for driving a gas flow cycle flowing through the heating element and into the corresponding HT-chambers and out of the gas flow cycle into the exhaust system. Similarly, the LT-chambers are equipped with chamber fans configured for driving a gas flow cycle flowing through the MVR-heat exchanger and into the corresponding LT-chambers and out of the gas flow cycle into the exhaust system.

[0021] The temperature in the HT-chambers can vary between 120 and 260°C, preferably between 150 and 250°C, with a maximum temperature in a mid-section of the HT-drying zone. The temperature in the one or more LT-chambers (N) has an average value lower than an average temperature in the HT-chambers and can vary between 90 and 170°C, preferably between 100 and 160°C, with a maximum temperature at an upstream section of the LT-drying zone, wherein upstream is defined relative to the direction of the drying path.

[0022] The temperature of the low boiling point fluid of the heat pump in the second heat pump-heat exchanger can be comprised between 90 and 110°, and is preferably equal to 100°C ± 5°C. The temperature of the fluid of the MVR-cycle in the MVR-heat exchanger can be comprised between 120 and 180°C, preferably between 135 and 170°C, and is preferably equal to 150°C ± 10°C.

[0023] In one embodiment, the heat pump / MVR-cycle system comprises an MVR-distribution system heating loop branching off the MVR-cycle, downstream of the MVR-compressor and joining back the MVR-cycle upstream of the MVR-compressor after passing through a second MVR-heat exchanger configured for transferring heat from the heating fluid in the MVR-cycle to the fluid in the distribution system.

[0024] Several options are available to further increase the heat transfer from the exhaust fluid towards the fluid flowing in the distribution system. For example, a fluid heat exchanger can be configured for transferring heat from the low boiling fluid of the heat pump to the fluid of the distribution system. A second option is to provide the exhaust system with a fluid exhaust duct leading to an LT-heat exchanger configured for transferring heat from the exhaust fluid in the exhaust system to the LT-chambers. The LT-heat exchanger is preferably located upstream of the first heat pump-heat exchanger relative to the flow direction of the exhaust fluid in the exhaust system.

[0025] The present invention also concerns a method for drying construction panels comprising,

- providing an apparatus as discussed supra,
- driving a wet construction panel along the drying path through the chambers of the HT-drying zone followed by through the chambers of LT-drying zone,
- Flowing the fluid through the distribution system into each of the N chambers,
- Heating with the heating elements the fluid to desired temperatures prior to penetrating into the HT-chambers,
- Exhausting the exhaust fluid from each of the N chambers through the fluid exhaust system, wherein
- Heat is exchanged in the first heat pump-heat exchanger from the exhaust fluid in the exhaust system to the low-boiling point fluid in the heat pump and after compression of the low boiling point fluid,
- Heat is exchanged in the second heat pump-heat exchanger from the thus compressed low-boiling point fluid to the heating fluid in the MVR-cycle and after compression of the heating fluid,
- Heat is exchanged in the MVR-heat exchanger from the thus compressed heating fluid to the fluid in the fluid in the distribution system in direct fluid communication with the one or more LT-chambers (N) in the low temperature drying zone (LT).

BRIEF DESCRIPTION OF THE FIGURES

[0026] For a fuller understanding of the nature of the present invention, reference is made to the following detailed description taken in conjunction with the accompanying drawings in which:

Figure 1: shows a typical drying apparatus according to the prior art.

Figure 2 shows an embodiment of drying apparatus according to the present invention.

Figure 3 shows an alternative embodiment of the present invention.

Figure 4 shows yet an alternative embodiment of the present invention.

Figure 5 shows yet an alternative embodiment of the present invention.

Figure 6 shows yet an alternative embodiment of the present invention.

Figure 7 shows an example of heat pump coupled to an MVR-cycle according to the present invention.

DETAILED DESCRIPTION OF THE INVENTION

[0027] The present invention concerns an apparatus for drying construction panels such as made of gypsum (= plasterboards or gypsum fibreboards) or panels made of cement or calcium silicate, during their production. The apparatus comprises a conveyor (40) for conveying the construction panels (60) along a drying path through a number N of chambers (1, 2…N). A distribution system (5) distributes a drying fluid into each chamber, with heating elements (11) provided for heating the fluid in the distribution system before the fluid reaches the chambers. An exhaust system (7) is provided for evacuating the exhaust fluid out of the chambers.

[0028] The present invention is not limited to any specific type of conveyor (40) as long as it allows conveying wet construction panels (60) along the drying path through the chambers exposing both main surfaces of the panels to the drying fluid. For example, the conveyor (40) can comprise rollers or a foraminous sheet configured for supporting and transporting the panels, while exposing both main surfaces of the panels to a flow of hot gas, typically hot air.

[0029] The drying unit comprises a total number N of chambers (1, 2 ... N) distributed in series and in fluid communication with one another along the drying path. The N chambers are composed of a number i of high temperature chambers (1, 2) (= HT chambers) located in a high temperature drying zone (HT) in an upstream portion of the drying path, and of a number j of low temperature chambers (N) (= LT-chambers) located in a low temperature drying zone (LT) downstream of the high temperature drying zone (HT) along the drying path, wherein $1 \leq i \leq N - 1$, and $j = N - i$. Figures 2 to 6 illustrate a total number N = 3 chambers, a number i = 2 HT-chambers (1, 2) and a number j = 1 LT-chamber (N), but it is clear that the numbers N, i, and j of chambers is not limited and can vary depending on the specific applications.

[0030] The distribution system (5) is in fluid communication at one end with a source of fluid (5s), generally air and, at other ends, with the N chambers (1, 2 ... N). It is configured for circulating a flow of the fluid along a fluid flowing path extending from the source of fluid into the N chambers. Heating elements (11) configured for heating the fluid in the distribution system (5) are arranged in the distribution system (5) before the fluid penetrates into the respective HT-chambers (1, 2). The LT-chambers (N) do not need a heating element for the stationary use of the dryer. Usually, shutdown heaters are provided for use only during the shutdown of a panel drying session (cf. shutdown burner (11s) in Figures 3 to 6.

[0031] The exhaust system (7) is configured for evacuating out of the apparatus exhaust fluid along an exhaust flowing path extending from the N chambers (1, 2, … N) to outside the apparatus

[0032] The gist of the present invention is a "*heat pump / MVR system*" used to recover heat from the exhaust fluid flowing in the exhaust system (7) to substantially raise the temperature of the fluid flowing in the distribution system (5). The heat pump / MVR system comprises a heat pump (8) and a mechanical vapour recompression (MVR-) cycle (9), coupled to respective heat exchangers (X78, X89, X95N) for efficiently transferring calorific energy from the exhaust fluid to the fluid of the distribution system (5). In particular, the MVR-heat exchanger (X95N) configured for transferring heat from the heating fluid of the MVR-cycle (9) to the fluid in the distribution system (5) prior to penetrating into the respective LT-chambers (N). The MVR-heat exchanger (X95N) in the LT-chambers (N) has the same function as and replaces the heating elements (11) used in the HT-chambers (1, 2), . This way, during use of the dryer in a stationary mode, no heating element (11) is required to heat the fluid before it flows into the LT-chambers (N), thus reducing the energy consumption accordingly.

[0033] A first heat pump-heat exchanger (X78) is configured for transferring heat from the exhaust fluid in the exhaust system (7) to a low boiling point fluid in the heat pump (8). The heat pump (8) comprises a closed loop duct for circulating the low boiling point fluid and comprises a heat pump compressor (8c) configured for compressing and increasing a temperature of the low boiling point fluid, and for driving a flow of the low boiling point fluid in the closed loop duct from the first heat pump-heat exchanger (X78) to a second heat pump-heat exchanger (X89).

[0034] The second heat pump-heat exchanger (X89) is configured for transferring the heat thus captured by the low boiling point fluid to a heating fluid, preferably steam, having a boiling temperature higher than the low boiling point fluid of the heat pump (8). The heating fluid is configured for circulating in the MVR-cycle (9). The MVR-cycle (9) comprises an MVR-compressor (9c) configured for compressing the heating fluid, and thus increasing a temperature of the heating fluid, and for driving a flow of the heating fluid from the second heat pump-heat exchanger (X89) to an MVR-heat exchanger (X95N).

[0035] The MVR-heat exchanger (X95N) is configured for transferring heat from the heating fluid of the MVR-cycle (9) to the fluid in the distribution system (5) in direct fluid communication with the one or more LT-chambers (N) in the low temperature drying zone (LT). By direct fluid communication, it is herein meant that the fluid in the MVR-heat exchangers (X95N) is not separated from an interior of the LT-chambers (N) by any fluid duct (51, 52) nor by any other device of the apparatus. The heat can be transferred from the fluid to the construction panels at least by forced convection of the fluid. In this embodiment, the fluid is preferably a gas, more preferably air, which flows in contact over the two main surfaces of the construction panels (60) directly after being heated to the corresponding predefined temperatures by the MVR-heat exchanger (X95N) in the LT-chambers and by the heating elements (11) in the HT-chambers (1, 2).

DISTRIBUTION SYSTEM (5) AND CHAMBERS (1, 2 … N)

[0036] The distribution system comprises ducts configured for circulating a flow of the fluid along a fluid flowing path extending from the source of fluid (5s) into the N chambers. The fluid being circulated is preferably a gas, more preferably air which, after heating to desired temperatures is blown over the two main surfaces of the panels as they travel through the successive chambers. Heat is thus transferred from the fluid to the main surfaces of the panels by forced convection.

[0037] The distribution system comprises an upstream end coupled to a source of the fluid (5s). The fluid is preferably a gas. If the fluid is air, the source of air can be atmospheric air at room temperature. A blower or fan (5f) is provided for flowing the gaseous fluid from the source of fluid (5s) into the distribution system (5). As shown in Figures 2 to 6, the distribution system (5) divides into N fluid feeding ducts (51, 52…5N) to flow the fluid in parallel into each of the N chambers (1, 2…N). As a fluid feeding duct reaches the corresponding chamber, it forms a gas flow cycle comprising a chamber fan (1f, 2f…Nf) for driving the gas flow (e.g., air) along the gas flow cycle. The gas flow cycle in the HT-chambers is configured for flowing the gas (e.g., air) through a heating element (11) such as an air-fuel burner, and into the corresponding HT-chamber (1,2) to lick both main surfaces of the panels to increase their temperature and remove moisture therefrom. Analogously, the gas flow cycle in the LT-chambers is configured for flowing the gas (e.g., air) through an MVR-heat exchanger (X95N) (instead of a heating element (11) as is the case in the HT-chambers) and into the corresponding LT-chamber (N) to lick both main surfaces of the panels to remove moisture therefrom. All or a fraction of the gas (e.g., air) can run one or more cycles from the chamber to the heating element (11) or MVR-heat exchanger (X95N), until the moisture content thereof is considered too high, at which point it can be driven out of the gas flow cycle into the exhaust system (7). Valves (5v, 7v) are provided in both distribution system (5) and exhaust system (7) to control the moment and the fraction of gas (e.g., air) to be introduced into and exhausted from the gas flow cycle. Heating elements (11) are used in a stationary use of the dryer in the HT-chambers (1, 2) only. As mentioned supra, the LT-chambers can be equipped with shutdown burners (11s) which are used exclusively during a shutdown operation of the dryer at the end of a drying session after the heating elements (11) in the HT-chambers have been turned off. At the end of a drying operation, as the last panels have run through the HT-chambers, the corresponding heating elements (11) are turned off and the temperature of the exhaust gas in the exhaust system (7) is not sufficient any more to heat to the predefined temperature the fluid flowing into the LT-chambers (N). The shutdown burners (11s) are used exclusively to this end and are not used to heat the LT-chambers during “normal” or stationary use of the apparatus. Alternatively, the shutdown burners (11s) can be used to heat the fluid flowing into the LT-chambers (N) during stationary drying operation at a fraction only of their full heating capacity, such as not more than 25%, preferably not more than 10% of the full heating capacity of the shutdown burners (11s). It is, however, preferred that no heating element be used to heat the LT-chambers in a stationary use of the apparatus. The apparatus may comprise a processing unit configured for controlling that the shutdown burners (11s) remain off or at a fraction only of their full heating capacity during stationary use of the apparatus and the fluid flowing into the LT-chambers is heated exclusively by means of heat exchangers, including the MVR-heat exchanger (X95N). The processing unit can be configured for controlling that the gas (e.g., air) be heated by the heating elements (11) before entering into the HT-chambers (1, 2) and by the MVR-heat exchanger (X95N) before entering into the LT-chambers (N).

[0038] The gas flow cycle in the LT-chambers is similar to the one in the HT-chambers described supra, without the heating element (11). The gas flow cycle in the LT-chambers runs instead through an MVR-heat exchanger (X95N) to increase the temperature of the gas (e.g., air) each time it circulates through the gas flow cycle. A return exhaust duct (7h) can be provided to flow exhaust fluid towards the LT-chambers (N), to circulate through a LT-heat exchanger (X7N) shown in Figure 4. Valves (7v) allow an accurate control of the amount of exhaust fluid introduced from the return exhaust ducts (7h) into the LT-heat exchangers (X7N) to control the temperature transferred to the fluid in the LT-heat exchangers (X7N). Alternatively, as shown in Figures 3 and 6, wherein the source of fluid is a source of gas, the return exhaust ducts (7h) join in fluid communication the distribution system (5), upstream of and adjacent to the MVR-heat exchangers (X95N). and configured for flowing exhaust gas into the LT-chambers (N) admixed with fluid from the distribution system (5), through the MVR-heat exchangers (X95N), and through and out of the LT-chambers (N). The fluid exhaust ducts (7h) are provided with valves (7v) to control a ratio of amount of exhaust fluid to amount of fluid. This is important, since the exhaust gas is loaded with substantial amounts of moisture, and careful balance of the moisture content of the gas blown onto the construction boards travelling through the LT-chambers (N) is required to optimize the drying operation of the boards.

[0039] If the fluid is air, the heating elements (11) are preferably air-fuel burners fed with a fraction of the air flowing through the fluid feeding ducts (51, 52) leading to the HT-chambers. The fuel (generally a gas such as acetylene, natural gas, or propane) is fed to the air-fuel burners via ducts (9g) as shown in Figures 2 to 6. Alternatively, the heating elements (11) can be electrical heaters or heat exchangers receiving a flow of hot fluid, such as a hot oil to increase the temperature of the fluid. In these cases, the fluid can be any gas, although air is readily available and is preferred.

[0040] To increase the temperature of the fluid flowing in the distribution system (5) before it reaches the chambers and air-fuel burners, it is preferably preheated in a pre-heating heat exchanger (X75) configured for transferring heat from the exhaust fluid in the exhaust system (7) to the fluid in the distribution system (5). The pre-heating heat exchanger (X75) is preferably located upstream of at least some, preferably all the fluid feeding ducts (51, 52…5N). The pre-heating heat exchanger (X75) is also preferably located upstream of the first heat pump-heat exchanger (X78) discussed in more detail below. The terms “upstream” and “downstream” are defined herein relative to the flow direction of a fluid in the corresponding fluid system, such as the fluid in the distribution system (5), the exhaust fluid in the exhaust system (7), the low boiling point fluid in the heat pump (8), or the heating fluid in the MVR-cycle (9). In the present instance, upstream is defined relative to a flow direction of the exhaust fluid in the exhaust system (7). Preheating the fluid prior to reaching the chambers and heating elements is advantageous as, on the one hand, less energy is required to heat the fluid to the desired temperatures by the heating elements (11) for the HT-chambers (1,2) and by the MVR-heat exchangers (X95N) for the LT-chambers and, on the other hand, the air-fuel burners are more efficient when fed with warm air.

[0041] The temperature in the chambers (1, 2…N) can be controlled by controlling the fluid flowrates by means of the chamber fans (1f, 2f…Nf) and by controlling the temperature of the fluid. Fluid temperature blown into the HT-chambers (1, 2) can be controlled via the heating elements (11) and into the LT-chambers (N) via the MVR-cycle and MVR-heat exchanger (X95N). For drying plasterboards, the temperature (T1; T2) in the HT-chambers (1, 2) can vary between a low temperature (T1L, T2L) and a hight temperature (T1H, T2H) which can range between 120 and 260°C, preferably between 150 and 250°C, with preferably a maximum temperature in a mid-section of the HT-drying zone. The temperature (TN) in the one or more LT-chambers (N) has an average value lower than an average temperature in the HT-chambers and can vary between a low temperature (TNL) and a hight temperature (TNH) which can range between 90 and 170°C, preferably between 100 and 160°C, with a maximum temperature at an upstream section of the LT-drying zone, wherein upstream is defined relative to the direction of the drying path.

EXHAUST SYSTEM (7) AND HEAT EXCHANGERS (X75, X78, X7N)

[0042] As shown in Figures 2 to 6, the exhaust system (7) comprises fluid exhaust ducts (71, 72…7N) for extracting the fluid from the chambers when the temperature or moisture contents are considered out of predefined boundaries. The fluid exhaust ducts (71, 72…7N) are coupled to the corresponding gas flow cycles at a position between the chamber fan (1f, 2f…Nf) and the heating elements (11) for the HT-chambers (1, 2) and the MVR-heat exchanger (X95N) for the LT-chambers (N).

[0043] The exhaust fluid exiting the chambers through the exhaust system (7) is colder and more humid than the fluid entering the chambers through the distribution system (5) but still retains substantial heat. The aim of the present invention is to recover as much calorific energy as possible from the exhaust fluid by means of different heat exchangers (X75, X78, X7N).

[0044] The fluid at the source of fluid (5s) is generally at room temperature and needs some pre-heating prior to reaching the chambers. If the fluid is air and the heating elements (11) are air-fuel burners, feeding pre-heated air to the air-fuel burners increases the efficacy of the latter. To this effect, and as already mentioned, the apparatus can comprise a pre-heating heat exchanger (X75) configured for transferring heat from exhaust fluid in the exhaust system (7) to the fluid in the distribution system (5) to increase the temperature of the fluid flowing in the distribution system (5) prior to reaching the heating elements (11), such as air-fuel burners. The pre-heating heat exchanger (X75) is preferably located quite upstream of the distribution system (5), upstream of where the fluid feeding ducts (51, 52...5N) branch off towards the respective chambers (1, 2...N). The pre-heating heat exchanger (X75) is preferably located in the exhaust system, upstream of a first heat pump-heat exchanger (X78), (upstream is here defined relative to the flow direction of the exhaust fluid in the exhaust system (7)). The first heat pump-heat exchanger (X78) is configured for transferring heat from the exhaust fluid in the exhaust system (7) to the low boiling point fluid in the heat pump (8).

[0045] As shown in Figures 4 and 5, the exhaust system (7) can also comprise an LT-heat exchanger (X7N) configured for transferring heat from the exhaust fluid in the exhaust system (7) to the LT-chambers (N), which do not rely on a heating element (11) for the stationary use of the apparatus. The LT-heat exchanger (X7N) is preferably located in the exhaust system (7) upstream of the first heat pump-heat exchanger (X78).

HEAT PUMP (8) AND MVR-CYCLE (9)

[0046] The gist of the present invention is the heat pump / MVR system used to recover heat from the exhaust fluid flowing in the exhaust system (7) to substantially raise the temperature of the fluid flowing in the distribution system (5) before the fluid reaches the HT-chambers (1, 2). It comprises the heat pump (8) in heat conductive contact with the MVR-cycle (9) via the second heat pump-heat exchanger (X89), as illustrated in Figure 7.

Heat Pump (8)

[0047] As shown in Figure 7, the heat pump (8) comprises a closed circuit circulating a low-boiling point fluid, driven by a heat pump compressor (8c). The low boiling point fluid can have a boiling temperature of not more than -10°C, preferably not more than -20°C. For example, the low boiling point fluid can be a hydrofluorocabon (HFC) such as tetrafluoroethane, a halogenated fluorocarbon (PFC), a halogenated fluorine olefin (HFO), or a natural gas such as propane. The low-boiling point fluid collects in the first heat pump-heat exchanger (X78) heat from the exhaust fluid flowing in the exhaust system (7). As the thus heated low boiling point fluid passes through the heat pump compressor (8c) the pressure is increased, and the temperature follows the same trend. The heat thus accumulated by the low boiling point fluid is transferred to a heating fluid, preferably steam, flowing in the MVR-cycle (9) through the second heat pump-heat exchanger (X89). The pressure of the thus cooled low boiling point fluid is reduced by an expansion device (8e) to prevent or restrict condensation before flowing back to the first heat pump-heat exchanger (X89) and resuming the foregoing cycle.

[0048] During the transfer of heat in the first heat pump-heat exchanger (X78), the temperature of the moist exhaust fluid drops and condensation water (8w) is formed which has a higher temperature than the fluid at the source of fluid (5s). As shown in Figures 4 and 5, to profit of the heat transported by the condensation water, the apparatus can comprise a condensed heat exchanger (X8w5) configured for transferring heat from the condensation water (8w) to the fluid flowing from the source of fluid (5s) into the distribution system. Since the temperature of the condensation water is not very high, the condensed heat exchanger (X8w5) is preferably positioned upstream of the pre-heating heat exchanger (X75) on the heat distribution system (5). Beside pre-heating the fluid, the use of the condensed heat exchanger (X8w5) has the advantage of also lowering the temperature of the condensate water (8w) which can be used as such for other operations, such as the formation of new construction boards (60), by adding water to the mixer upstream of the production line and well upstream of the drying apparatus. This substantially reduces the water consumption of the board manufacturing process as a whole.

[0049] Downstream of the second heat pump-heat exchanger (X89) and upstream of the expansion device (8e) and of the first heat pump-heat exchanger (X78), the heat still remaining in the low boiling point fluid can be transferred to the fluid flowing in the distribution system (5) by flowing the low boiling point fluid through a fluid heat exchanger (X85) in heat contact with the fluid in the distribution system (5), as illustrated in Figures 4 and 5.

[0050] The temperature of the low boiling point fluid of the heat pump (8) in the second heat pump-heat exchanger (X89) can typically be comprised between 90 and 110°, and is preferably equal to 100°C ± 5°C.

MVR-Cycle (9)

[0051] The heating fluid, preferably water / steam, of the MVR-cycle captures heat from the low boiling point fluid of the heat pump (8) at the second heat pump-heat exchanger (X89).

[0052] The flow of the heating fluid is driven by the MVR-compressor which increases the pressure of the heating fluid, and thus the temperature too. The thus compressed and heated heating fluid flows through the MVR-heat exchanger (X95N), which is configured for transferring heat from the heating fluid of the MVR-cycle (9) to the fluid in the distribution system (5) in direct fluid communication with the one or more LT-chambers (N) in the low temperature drying zone (LT). The MVR-cycle can be an open cycle requiring no expansion device (9e) and producing condensation water which can be recovered. In this case, however, the MVR-cycle must be replenished with heating fluid at regular intervals, which is not readily available from the process. For this reason, the MVR-cycle (9) of the present invention is preferably a closed cycle wherein any condensation liquid (generally water) formed during the transfer of heat from the heating fluid to fluid flowing in the distribution system (5) is vaporized by flowing the heating fluid through an expansion device (9e) as illustrated in Figure 7 (not shown in Figures 2 to 6 for sake of clarity).

[0053] The MVR-heat exchanger (X95N) is located in the distribution system (5) upstream from the entry point of the fluid into the respective LT-chambers (N). In a preferred embodiment, illustrated in Figures 2 to 6, the MVR-heat exchangers (X95N) are located in the distribution system (5) at the level of the gas flow cycles of the corresponding LT-chambers. As the temperature of the heating fluid flowing through the MVR-heat exchanger (X95N) can be comprised between 120 and 180°C, preferably between 135 and 170°C, and is preferably equal to 150°C ± 10°C, it can fulfil in the LT-chambers (N) the same function of the heating elements (11) in the HT-chambers (1, 2) of bringing the fluid to the required temperature of the corresponding LT-chambers (N), which are lower than the temperatures required in the HT-chambers (1, 2). As the MVR-heat exchanger replaces in the LT-chambers (N) the heating elements (11) of the HT-chambers (1, 2), much energy is saved. Indeed, the energy required for operating a heating element (11) of the type of an air-fuel burner or an electrical heater or other heating elements (11) is replaced by the energy required for operating the heat pump / MVR-system, i.e., for operating the heat pump compressor (8c) and the MVR-compressor (9c).

[0054] Since the temperature of the low boiling point fluid at the second heat pump-heat exchanger (X89) can be of the order of 90 to 110°C whilst the temperature required in the LT-chambers can be of the order of 90 to 170°C, the temperature is too low to heat directly the fluid flowing into the LT-chambers to the desired temperature. The heat pump (8) can therefore not be used alone to replace the heating elements (11) in the LT-chambers. Similarly, the MVR-cycle comprise a heating fluid having a higher boiling temperature than the low boiling point fluid of the heat pump (8) and is typically water / steam, the temperature of the exhaust gas flowing in the exhaust system (7) is not sufficiently high to transfer sufficient heat to the heating fluid of the MVR-cycle for it to reach a desired temperature at the level of the MVR-heat exchanger (X95N), after compression of the heating fluid.

[0055] The coefficient of performance (= COP) is defined as a ratio (Q / W) of a heat (Q) supplied by the MVR-heat exchanger (X95N) to a work (W) required to operate the heat pump-MVR-system namely, to operate the heat pump compressor (8c) and the MVR-compressor (9c). It is an excellent indicator of the efficacy of the heat pump / MVR-system. Tests have shown that the COP of the heat pump / MVR-system can be comprised between 2 and 5, preferably between 2.5 and 4 (to be efficient, heat pump / MVR-system must have a COP > 1).

[0056] In an embodiment illustrated in Figure 3, the MVR-loop can comprise an MVR-distribution heating loop (95) branching off the MVR-cycle (9), downstream of the MVR-compressor (9c) and joining back the MVR-cycle (9) upstream of the MVR-compressor (9c). In between, the MVR-distribution heating loop (95) passes through a second MVR-heat exchanger (X95) configured for transferring heat from the heating fluid in the MVR-cycle (9) to the fluid in the distribution system (5) upstream of the fluid feeding ducts (51, 52…5N). Since the heating fluid enters into the MVR-distribution system heating loop (95) downstream of the MVR-compressor (9c) the heating fluid has a high pressure and a rather high temperature. Figure 5 illustrates an alternative embodiment wherein the second MVR-heat exchanger (X95) belongs to the same MVR-cycle as the MVR-heat exchanger (X95N). The temperature of the heating fluid at the level of the second MVR-heat exchanger (X95) is lower than in the embodiment of Figure 3, since the heating fluid has already transferred part of its heat to the gas flow cycle of the LT-chambers (N) through the MVR-heat exchangers (X95N) before reaching the second MVR-heat exchanger (X95).

[0057] The fluid in the distribution system (5) can also collect heat directly from the heat pump (8) via a fluid heat exchanger (X85) as illustrated in Figures 4 and 5.

[0058] The preferred heat exchangers discussed herein can be selected and used in any combination. When positioning several heat exchangers in a same duct, it is important to ensure that the temperature difference between the high temperature fluid and the low temperature fluid is high enough to transfer substantial amounts of heat from the high temperature fluid to the low temperature fluid.

[0059] Upstream of the heating elements (11) and MVR-heat exchanger (X95N), the temperature of the fluid flowing in the distribution system (5) is lowest at the level of the source of fluid (5s) and increases each time it passes through a heat exchanger to be highest when reaching the fluid feeding ducts (51, 52…5N). The heat exchanger whose high temperature fluid has the lowest temperature is therefore preferably positioned most upstream of the distribution system (5). In the present case, as illustrated in Figure 5, the distribution duct can pass through one or more of the condensed heat exchanger (X8w5), the pre-heating heat exchanger (X75), the fluid-heat exchanger (X85), and the second MVR-heat exchanger (X95), before reaching the fluid feeding ducts (51, 52) leading to the HT-chambers (1, 2). They are preferably positioned along the distribution system in the following sequence,

- the condensation water (8w) produced in the first heat pump heat exchanger (X78) flowing into the condensed heat exchanger (X8w5) has the lowest temperature of all high temperature fluids. Consequently, if present, the condensed heat exchanger (X8w5) is preferably positioned most upstream of the distribution system (5).
- The low boiling point fluid flowing through the heat pump (8) has a temperature when passing through the fluid heat exchanger (X85) which is lower than when it passes through the second heat pump-heat exchanger (X89) where the temperature can be comprised between 120 and 180°C. As the low boiling point fluid still carries sufficient heat, if present, the fluid heat exchanger (X85) can therefore safely be positioned downstream of the condensed heat exchanger (X8w5).
- The pre-heating heat exchanger (X75) is generally positioned upstream of the first heat pump-heat exchanger (X78). The temperature of the exhaust fluid flowing through the pre-heating heat exchanger (X75) is therefore higher than the one flowing through the first heat pump-heat exchanger (X78). Depending on whether the temperature of the exhaust fluid in the first heat pump-heat exchanger (X78) is higher or lower than the temperature of the low boiling point fluid flowing through the fluid heat exchanger (X85), the pre-heating heat exchanger (X75) is preferably positioned downstream or upstream of the first heat pump-heat exchanger (X78), respectively. In the example of Figure 5, the fluid heat pump (X85) is positioned downstream of the pre-heating heat pump (X75), suggesting that the temperature of the exhaust gas flowing

through the pre-heating heat exchanger (X75) is lower than the temperature of the low boiling point fluid flowing through the fluid heat exchanger (X85).

- The temperature of the heating fluid in the MVR-distribution heating loop (95) is quite high, of the order of 120 and 260°C and the second MVR-heat exchanger can therefore be positioned most downstream of the distribution system, before reaching the fluid feeding ducts (51, 52…5N).

Heat Transfers

[0060] As discussed supra, the fluid can be pre-heated in the distribution system (5) prior to being distributed to at least the HT-chambers and preferably also prior to reaching the LT-chambers, through the fluid feeding ducts (51, 52…5N) with a number of heat exchangers, which can comprise any one of the pre-heating heat exchanger (X75), the second MVR-heat exchanger (X95), the fluid heat exchanger (X85), the condensed heat exchanger (X8w5), and any combination thereof (cf. e.g., Figure 5). This is advantageous in that, on the one hand, the fluid is already warm when reaching the heating elements (11) in the HT-chambers (1, 2) and the MVR-heat exchanger (X95N) in the LT-chambers and, on the other hand, if air-fuel burners are used, feeding them with warm air is more efficient.

[0061] The fluid reaching the HT-chambers is heated to high temperatures with the heating elements (11) in the corresponding gas flow cycles. The fluid can reach temperatures comprised between 120 and 260°C, preferably between 150 and 250°C, with a maximum temperature in a mid-section of the HT-drying zone. The thus heated fluid is circulated in the gas flow cycles against the main surfaces of the panels (60) to increase the temperature thereof and remove moisture therefrom. At each cycle, a fraction of the thus cooled and moistened fluid can be exhausted and the rest recirculated, mixed with fresh fluid from the source of fluid (5s). Alternatively, the whole fluid is recirculated during various cycles in a closed circuit until it is exhausted to be replaced by a fresh fluid admitted in the gas flow cycle. These operations can be controlled by means of the valves (5v, 7v). In both cases, the exhaust fluid extracted out of the HT-chambers (1, 2) is still quite warm. Like in previous attempts of the prior art, it is mostly the heat stored in the exhaust fluid that is to be recovered, but the apparatus of the present invention takes substantially more profit of it than prior art apparatuses.

[0062] As illustrated in Figures 2 to 6, the apparatus can comprise a pre-heating heat exchanger (X75) for directly transferring part of the heat of the exhaust fluid flowing in the exhaust system (7) to the fluid flowing in the distribution system (5). This is straightforward and is clearly a preferred embodiment. But the pre-heating heat exchanger (X75) alone is not sufficient to make without heating elements (11) in the LT-chambers (N).

[0063] The gist of the present invention is to transfer heat from the exhaust fluid flowing in the exhaust system (7) to the heat pump / MVR-system, which allows increasing the temperature of the heating fluid in the MVR-heat exchanger (X95N) to sufficiently high values to heat the fluid flowing in the fluid feeding ducts (5N) in direct communication with the LT-chambers (N) to predefined temperatures, to replace the heating elements (11) required in the prior art apparatuses (cf. e.g., Figure 1). In particular, the MVR-heat exchangers (X95N) are located in the fluid in the distribution system (5) directly upstream of where the fluid penetrates into the respective LT-chambers (N). If the fluid is a gas (e.g., air) and the fluid feeding ducts (5N) comprise a gas flow cycle, the MVR-heat exchangers (X95N) are positioned in the gas flow cycles directly upstream of the inlets leading into the corresponding LT-chambers (N).This is achieved with addition of an amount of energy (W) required to actuate the heat pump compressor (8c) and the MVR-compressor (9c), which is only a fraction (= 1 / COP) of the heat (Q) thus recovered (note that the COP = Q / W can be of the order 2 to 6).

[0064] As shown in Figure 7, the heat pump / MVR-system requires three heat exchangers:

- The first heat pump-heat exchanger (X78) is configured for transferring heat from the exhaust fluid in the exhaust system (7) to the low boiling point fluid in the heat pump (8),
- The second heat pump-heat exchanger (X89) is configured for transferring the heat of the low boiling point fluid at high temperature and pressure to the heating fluid of the MVR-cycle (9) at low temperature and pressure, and
- The MVR-heat exchanger (X95N) is configured for transferring heat from the heating fluid of the MVR-cycle (9) at high temperature and pressure to the fluid in the distribution system (5) in direct fluid communication with the one or more LT-chambers (N) in the low temperature drying zone (LT). In particular, the MVR-heat exchanger (X95N) can be coupled to the distribution system (5) at the level of the gas flow cycles in the LT-chambers (cf. Figures 2 to 6)

First Heat Pump-Heat Exchanger (X78)

[0065] The low boiling point fluid flowing in the heat pump (8) is in a gaseous state at a low temperature and low pressure when it enters into heat transfer contact with the exhaust fluid in the first heat pump-heat exchanger (X78). As the low boiling point fluid exits the first heat pump-heat exchanger (X78), it has a higher temperature from the heat collected from the exhaust fluid, and maintains the low pressure. Pressure and temperature are increased as it passes through the heat pump compressor (8c) and reaches the second heat pump-heat exchanger (X89) at a higher temperature and higher pressure. When the low boiling point fluid exits the second heat pump-heat exchanger (X89), it is at lower temperature because of the heat released to the heating fluid, and at the high pressure, and part of it may have condensed. The low boiling point fluid is then expanded through the expanding device (8e) shown in Figure 7 (not shown in Figures 2 to 6 for sake of clarity), prior to being reintroduced into the first heat pump-heat exchanger (X78) at the low temperature and low pressure.

Second Heat Pump-Heat Exchanger (X89)

[0066] The heating fluid flowing in the MVR-cycle (9) is at least partly in a gaseous state at a low temperature and low pressure when it enters into heat transfer contact with the low boiling fluid (at high temperature and high pressure) in the second heat pump-heat exchanger (X89). As the heating fluid exits the second heat pump-heat exchanger (X89), it has a higher temperature and maintains the low pressure. Pressure and temperature are increased as it passes through the MVR-compressor (9c) and reaches the MVR-heat exchanger (X95N) at a higher temperature and higher pressure. When the heating fluid exits the MVR-heat exchanger (X95N), it is at the low temperature and at the high pressure, and part of it may have condensed. The condensation liquid (generally water) is vaporized by flowing the heating fluid through an expansion device (9e) as illustrated in Figure 7 (not shown in Figures 2 to 6 for sake of clarity).

MVR-Heat Exchanger (X95N)

[0067] Driven by the MVR-compressor (9c), the gaseous heating fluid reaches the MVR-heat exchanger at a higher temperature and higher pressure to transfer heat to the fluid flowing in the distribution system (5) in direct communication with the LT-chambers (N).

[0068] In the preferred embodiment wherein, the fluid is a gas, preferably air, the MVR-heat exchangers (X95N) are located in the gas flow cycles of the LT-chambers (N), at a corresponding position of the heating elements (11) in the HT-chambers (1, 2), viz., downstream of the corresponding chamber fan (Nf) and upstream of where the fluid is introduced into the LT-chambers (N). The heating fluid in the MVR-heat exchanger (X95N) can have a temperature comprised between 120 and 260°C, which is quite sufficient to ensure a temperature of the fluid in the LT-chambers (N) comprised between 90 and 170°C, without need of an additional heating element (11). As long as the COP of the heat pump / MVR-system is greater than unity (i.e., COP >1), the use of the MVR-heat exchanger (X95N) is advantageous over the use of a heating element (11) such as an air-fuel burner or electrical heater for heating the LT-chambers (N). A COP > 1 is very easy to obtain for a skilled person with heat pumps (8) and MVR-cycles (9) available on the market.

METHOD FOR DRYING CONSTRUCTION PANELS

[0069] The present invention also concerns a method for drying construction panels, using an apparatus as discussed supra. After being formed and cut into panels, the still wet construction panels (60) are driven along the drying path sequentially through the chambers (1, 2) of the HT-drying zone followed by through the chambers (N) of LT-drying zone. As the construction panels travel through the chambers (1, 2…N), the fluid, preferably a gas such as air, flows through the distribution system (5) into each of the N chambers (1, 2 … N), and onto the main surfaces of the construction panels. Before the fluid reaches the main surfaces of the construction panels in the HT-chambers (1, 2), the fluid is heated with the heating elements (11) to desired temperatures. The exhaust fluid is then removed from each of the N chambers through the exhaust system (7).

[0070] At least during a stationary drying operation, the fluid blown into the LT-chambers (N) is heated using exclusively heat recovered from the exhaust fluid. This is achieved by exchanging heat in the first heat pump-heat exchanger (X78) from the exhaust fluid in the exhaust system (7) to the low-boiling point fluid in the heat pump (8). After compression of the low boiling point fluid, exchanging heat in the second heat pump-heat exchanger (X89) from the thus compressed low-boiling point fluid to the heating fluid in the MVR-cycle (9). After compression of the heating fluid, exchanging heat in the MVR-heat exchanger (X95N) from the thus compressed heating fluid to the fluid in the fluid in the distribution system (5) in direct fluid communication with the one or more LT-chambers (N).

[0071] This method yields the same quality of drying as prior art drying apparatuses but consuming considerably less energy. Table 1 compares the performance of a dryer of the prior art according to Figure 1 with the performance of a dryer of the present invention according to Figure 2, with same components and same temperatures in the chambers. In both cases, the fluid is air, and the heating elements (11) are air-fuel burners. The dryer of the invention comprises a heat pump / MVR-system which is not included in the dryer of the prior art. On the other hand, the dryer of the prior art comprises air-fuel burners in the LT-chambers, whilst the dryer of the invention relies solely on the MVR-heat exchanger (X95N) to heat the air flowing into the LT-chambers. The values are nominal values as they were calculated and not measured. With the components selected for the present simulation, the COP of the apparatus of Figure 2, the heat pump / MVR-system had a COP = 4.

***Table 1**: comparison of the performance of a dryer of the prior art according to FIG.1 with a dryer according to the invention (FIG.2) (calculated)*

34 t / h capacity	**P.A. - FIG.1**	**INV - FIG.2**	**Difference (%)**
Natural gas consumption [kWh / kg H2O]	0.8	0.56	-30%
Electrical energy (compressors) [kWh / kg H2O]	0	0.06	N.A.
Total energy [kWh / kg H_2O]	**0.8**	**0.62**	**-23%**
Condensation water [t / yr]	3	12	+300%

[0072] It can be seen that with no air-fuel burners in the LT-chambers (N), the dryer of the present invention drops the consumption of natural gas by 30%! Of course, the heat pump compressor (8c) and MVR-compressor (9c) consume electrical power, but as long as the heat pump / MVR system has a COP > 1, the total power consumption drops. In the present example, with a COP = 4 of the heat pump / MVR system, the dryer of the invention consumes 23% less energy than the prior art dryer. In times of increasing energy costs, this is a spectacular drop.

[0073] With a lower consumption of natural gas by a lower number of air-fuel burners, the CO_2 emissions have dropped by about 30%. With global warming, it was a priority of the inventors to considerably reduce the CO_2 emissions. The amount of condensation water recovered from the various heat exchangers is an indirect indicator of the efficacy of the heat transfer from the exhaust fluid (air) to the fluid (air) in direct communication with the LT-chambers. It can be seen in Table 1, that more than three times higher amounts of condensation water were recovered from the dryer of the present invention compared with the prior art dryer, showing the superior level of heat transfers thus achieved.

[0074] The dryer of the present invention substantially decreases the energy requirements for drying wet construction panels (60). CO_2 emissions are much lower for similar results.

[0075] Constructions panels are cement boards, calcium silicate boards, fiber cements boards and preferably gypsum boards.

REF #	**Feature**
1, 2…N	1st, 2nd, … Nth chamber
1, 2	High temperature (HT-) chambers
N	Low temperature (LT-) chambers
Nf	Fan in the distribution system at LT-drying zone
5	Distribution system
51, 52…5N	Fluid feeding duct
5f	Fan in the distribution system
5s	Source of fluid
5v	Valve of the distribution system
7	Exhaust system
7f	Fan in the exhaust system
7h	Return exhaust duct of the exhaust system leading to LT-drying zone
7v	Valve of the exhaust system
8	Heat pump
8c	Heat pump compressor
8e	Expansion device
8w	Condensation water in first heat pump heat exchanger (X78)
9	MVR-cycle
9c	MVR-compressor
9g	Fuel supply to fuel-air burners
11	Fuel-air burner
11s	Shutdown burner
50	Preheating branch of the distribution system
51, 52… 5N	Fluid feeding ducts leading to the 1st, 2nd… Nth chambers
5(N+1)	Postheating branch of the distribution system
51x, 52x	Branches of the distribution system feeding the burners 11 of the1st, 2nd chambers
60	Construction panel
71,72…7N	Branches of the exhaust system leading out of the 1st, 2nd… Nth chambers
95	MVR-distribution heating loop
HT	High temperature zone, including hT-chambers (1, 2)
LT	Low temperature zone, including LT-chambers (N)
MVR	Mechanical vapour recompression
TiH, i = 1-N	Highest temperature in a chamber
TiL, i = 1-N	Lowest temperature in a chamber
X75	Pre-heating heat exchanger from exhaust system (7) to distribution system (5)
X78	First heat pump-heat exchanger from the exhaust system (7) to the heat pump (8)
X7N	LT-heat exchanger shared from exhaust branch (7h) to the fluid distribution in the LT-drying zone chambers (N)
X85	fluid heat exchanger from heat pump (8) to distribution system (5)

X89	Second heat pump-heat exchanger from heat pump (8) to the MVR-cycle (9)
X8w5	Condensed heat exchanger from condensation water from X78 to distribution system
X95	Second MVR-heat exchanger from the MVR-cycle (9) to the fluid flowing to the distribution system (5)
X95N	MVR-heat exchanger from the MVR-cycle (9) to the fluid flowing to the fluid feeding duct (5N)

CLAIMS

1. An apparatus for drying construction panels comprising,

- a conveyor (40) for conveying wet construction panels (60) along a drying path through a drying unit; the drying unit comprising,
- a number N of chambers (1, 2 ... N) distributed in series and in fluid communication with one another along the drying path, comprising high temperature chambers (1, 2) (= HT chambers) located in a high temperature drying zone (HT) in an upstream portion of the drying path, and one or more low temperature chambers (N) (= LT-chambers) located in a low temperature drying zone (LT) downstream of the high temperature drying zone (HT) along the drying path,
- a distribution system (5) in fluid communication at one end with a source of fluid (5s) and, at other ends, with the N chambers (1, 2 ... N) and configured for circulating a flow of the fluid along a fluid flowing path extending from the source of fluid into the N chambers,
- heating elements (11) configured for heating the fluid in the distribution system (5) prior to penetrating into the respective HT-chambers (1, 2),
- an exhaust system (7) configured for evacuating out of the apparatus exhaust fluid along an exhaust flowing path extending from the N chambers (1, 2, … N) to outside the apparatus,

Characterized in that,

- it comprises a first heat pump-heat exchanger (X78) configured for transferring heat from the exhaust fluid flowing in the exhaust system (7) to a low boiling point fluid of a heat pump (8)
- the heat pump (8) comprises a heat pump compressor (8c) configured for compressing and increasing a temperature of the low boiling point fluid, and for driving a flow of the low boiling point fluid from the first heat pump-heat exchanger (X78) to a second heat pump-heat exchanger (X89) configured for transferring the heat thus captured by the low boiling point fluid to
- a heating fluid having a boiling temperature higher than the low boiling point fluid of the heat pump (8) and configured for circulating in a mechanical vapour recompression (MVR-) cycle (9) comprising an MVR-compressor (9c) configured for compressing the heating fluid, and thus increasing a temperature of the heating fluid, and for driving a flow of the heating fluid from the second heat pump-heat exchanger (X89) to,
- an MVR-heat exchanger (X95N) configured for transferring heat from the heating fluid of the MVR-cycle (9) to the fluid in the distribution system (5) directly prior to penetrating into the respective LT-chambers (N).

2. Apparatus according to claim 1, wherein a heat pump / MVR system composed of the heat pump (8) and MVR-cycle (9) is characterized by a coefficient of performance (= COP) comprised between 2

and 5, preferably between 2.5 and 4, wherein the COP is defined as a ratio (Q / W) of a useful heat (Q) supplied by the heat transfer combination to a work (W) required to operate the heat pump compressor (8c) and the MVR-compressor (9c).

3. Apparatus according to claim 1 or 2, comprising a pre-heating heat exchanger (X75) configured for transferring heat from the exhaust fluid in the exhaust system (7) to the fluid in the distribution system (5) to increase the temperature of the fluid flowing in the distribution system (5), wherein the pre-heating heat exchanger (X75) is preferably located in the exhaust system (7) upstream of the first heat pump-heat exchanger (X78), wherein upstream is defined relative to a flow direction of the exhaust fluid in the exhaust system (7).

4. Apparatus according to any one of the preceding claims, wherein

- the heating elements (11) are air-fuel burners,
- the source of fluid (5s) is a source of air, and a part of the air flowing in the distribution system (5) is fed to the air-fuel burners,

5. Apparatus according to any one of claims 1 to 3, wherein the heating elements (11) are electrical heaters.

6. Apparatus according to any one of the preceding claims, wherein

- the source of fluid is a source of a gas, preferably air,
- the distribution system (5) comprises distribution fans (5f) configured for driving the flow of gas from the source of gas towards the N chambers (1, 2 ... N),
- the HT-chambers are equipped with chamber fans (1f, 2f) configured for driving a gas flow cycle flowing through the heating element (11) and into the corresponding HT-chambers (1, 2) and out of the gas flow cycle into the exhaust system (7), and
- the LT-chambers are equipped with chamber fans (Nf) configured for driving a gas flow cycle flowing through the MVR-heat exchanger (X95N) and into the corresponding LT-chambers (N) and out of the gas flow cycle into the exhaust system (7).

7. Apparatus according to any one of the preceding claims, wherein,

- a temperature (T1, T2) in the HT-chambers (1, 2) varies between 120 and 260°C, preferably between 150 and 250°C, with a maximum temperature in a mid-section of the HT-drying zone and / or
- a temperature (TN) in the one or more LT-chambers (N) has an average value lower than an average temperature in the HT-chambers and varies between 90 and 170°C, preferably between 100 and 160°C, with a maximum temperature at an upstream section of the LT-drying zone, wherein upstream is defined relative to the direction of the drying path.

8. Apparatus according to any one of the preceding claims, wherein a temperature of the low boiling

point fluid of the heat pump (8) in the second heat pump-heat exchanger (X89) is comprised between 90 and 110°, and is preferably equal to 100°C ± 5°C.

9. Apparatus according to the preceding claim, wherein a temperature of the fluid of the MVR-cycle (9) in the MVR-heat exchanger (X95N) is comprised between 120 and 180°C, preferably between 135 and 170°C, and is preferably equal to 150°C ± 10°C.

10. Apparatus according to the anyone of the preceding claims, comprising an MVR-distribution system heating loop (95) branching off the MVR-cycle (9), downstream of the MVR-compressor (9c) and joining back the MVR-cycle (9) upstream of the MVR-compressor (9c) after passing through a second MVR-heat exchanger (X95) configured for transferring heat from the heating fluid in the MVR-cycle (9) to the fluid in the distribution system (5).

11. Apparatus according to any one of the preceding claims, comprising a fluid heat exchanger (X85) configured for transferring heat from the low boiling fluid of the heat pump (8) to the fluid of the distribution system (5).

12. Apparatus according to any one of the preceding claims, wherein the exhaust system (7) comprises return exhaust ducts (7h) leading to corresponding LT-heat exchangers (X7N) configured for transferring heat from the exhaust fluid in the exhaust system (7) to the LT-chambers (N), wherein the LT-heat exchanger (X7N) is preferably located upstream of the first heat pump-heat exchanger (X78) relative to the flow direction of the exhaust fluid in the exhaust system (7).

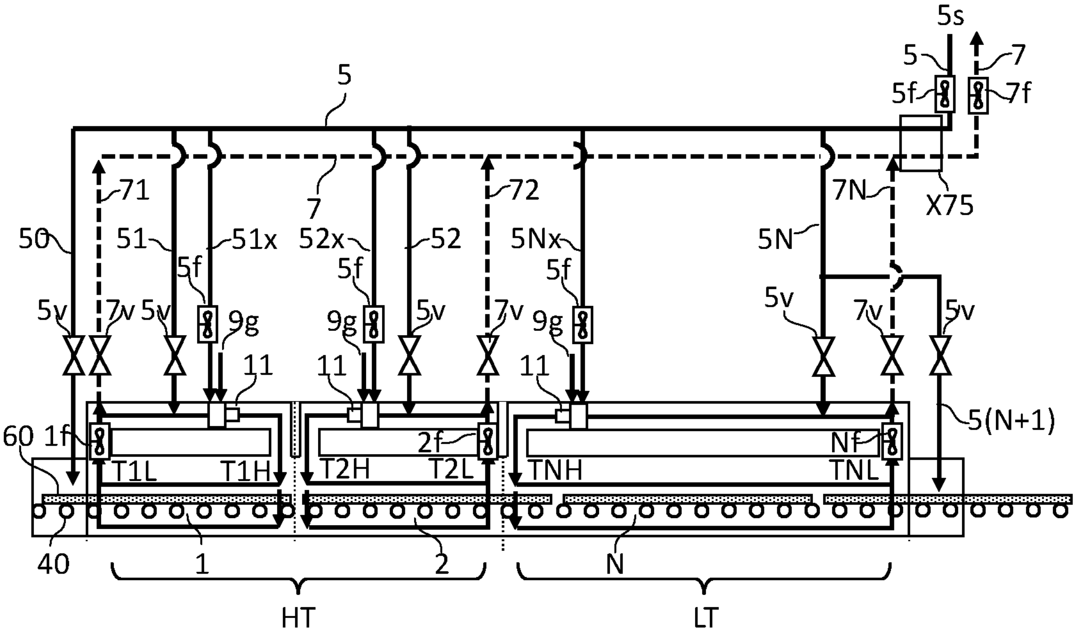
13. Apparatus according to any one of claims 1 to 12, wherein the source of fluid is a source of gas, and wherein the exhaust system (7) comprises return exhaust ducts (7h) joining in fluid communication the distribution system, upstream of and adjacent to the MVR-heat exchangers (X95N), and configured for flowing exhaust gas into the LT-chambers (N) admixed with fluid from the distribution system (5), through the MVR-heat exchangers (X95N), through and out of the LT-chambers (N); wherein the fluid exhaust ducts (7h) are provided with valves (7v) to control a ratio of amount of exhaust fluid to amount of fluid.

14. Method for drying construction panels comprising,

- providing an apparatus according to any one of the preceding claims,
- driving a wet construction panel (60) along the drying path through the chambers (1, 2) of the HT-drying zone followed by through the chambers (N) of LT-drying zone,
- flowing the fluid through the distribution system (5) into each of the N chambers (1, 2 … N),
- heating with the heating elements (11) the fluid to desired temperatures prior to penetrating into the HT-chambers (1, 2),
- exhausting the exhaust fluid from each of the N chambers through the fluid exhaust system (7),

Characterized in that,

- heat is exchanged in the first heat pump-heat exchanger (X78) from the exhaust fluid in the exhaust system (7) to the low-boiling point fluid in the heat pump (8) and after compression of the low boiling point fluid,
- heat is exchanged in the second heat pump-heat exchanger (X89) from the thus compressed low-boiling point fluid to the heating fluid in the MVR-cycle (9) and after compression of the heating fluid,
- heat is exchanged in the MVR-heat exchanger (X95N) from the thus compressed heating fluid to the fluid in the fluid in the distribution system (5) in direct fluid communication with the one or more LT-chambers (N) in the low temperature drying zone (LT).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5
7
5f
7f
5
X75
71
7
72
7N
50
51
51x
52x
52
5Nx
5N
5f
5f
5f
5v
7v
5v
9g
9g
5v
7v
9g
5v
7v
5v
11
11
11
5(N+1)
60
1f
2f
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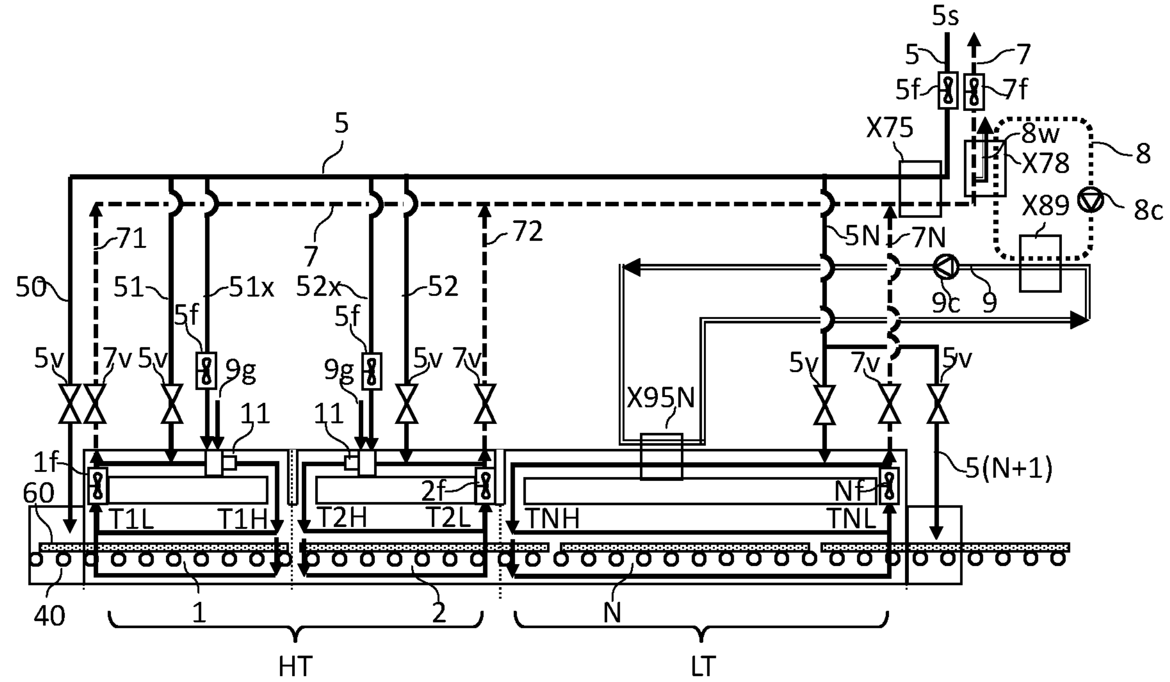
T2H
T2L
TNH
TNL
40
1
2
N
HT
LT

FIG.1 (P.A.)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51
51x
52x
52
9c
9
5f
5f
X95N
5v
7v
5v
9g
9g
5v
7v
5v
7v
5v
11
11
1f
5(N+1)
60
2f
Nf
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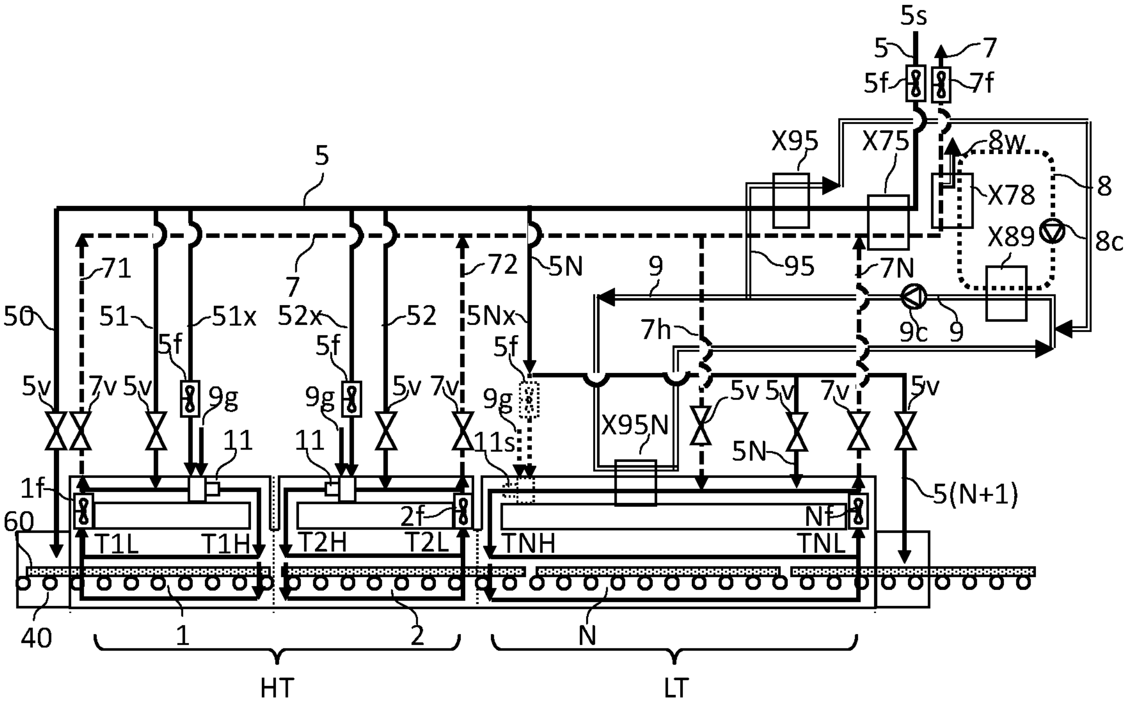
T1H
T2H
T2L
TNH
TNL
40
1
2
N
HT
LT

FIG.2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51
51x
52x
52
5Nx
9c
9
7h
5f
9g
5f
9g
5f
9g
5v
7v
5v
5v
7v
X95N
5v
5v
7v
5v
11
11
11s
5N
5(N+1)
1f
2f
Nf
60
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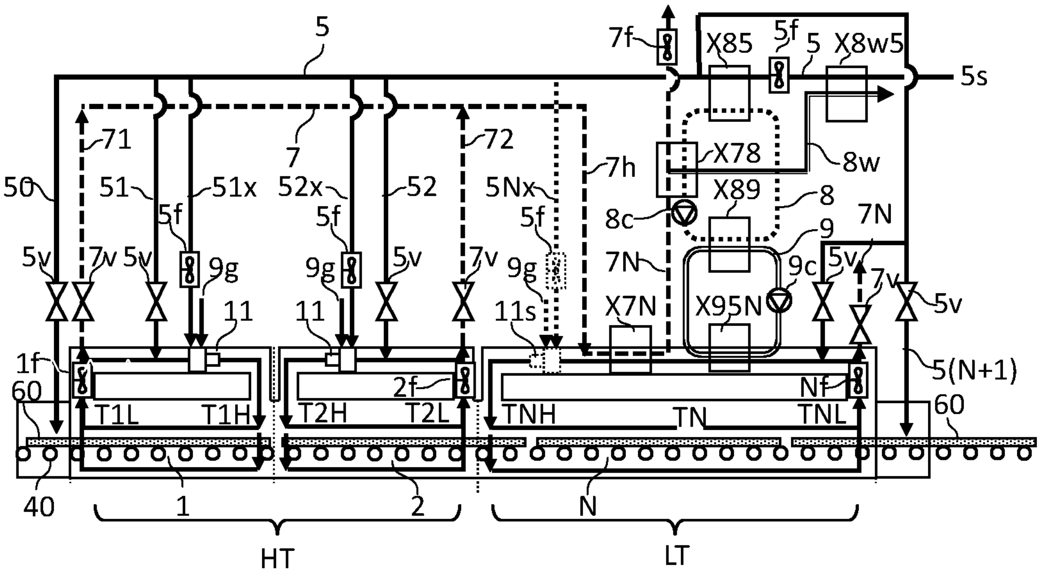
T1H
T2H
T2L
TNH
TNL
40
1
2
N
HT
LT

FIG.3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72
7h
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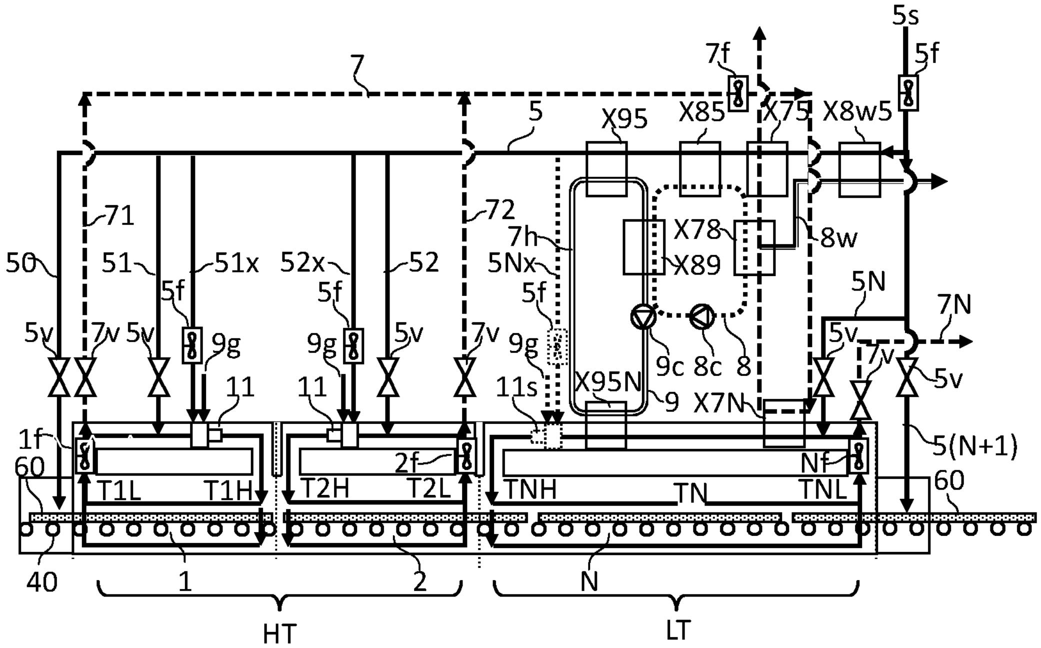
51x
52x
52
5Nx
5f
5f
5f
X89
8
8c
9
7N
7N
9g
9g
9g
5v
7v
5v
5v
7v
9c
5v
7v
5v
11
11
11s
X7N
X95N
1f
60
2f
Nf
5(N+1)
60
T1L
T1H
T2H
T2L
TNH
TN
TNL
40
1
2
N
HT
LT

FIG.4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52x
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5Nx
5N
7N
5f
5f
5f
5v
7v
5v
9g
9g
5v
7v
9g
9c
8c
8
5v
7v
5v
11
11
11s
X95N
9
X7N
1f
60
2f
Nf
5(N+1)
T1L
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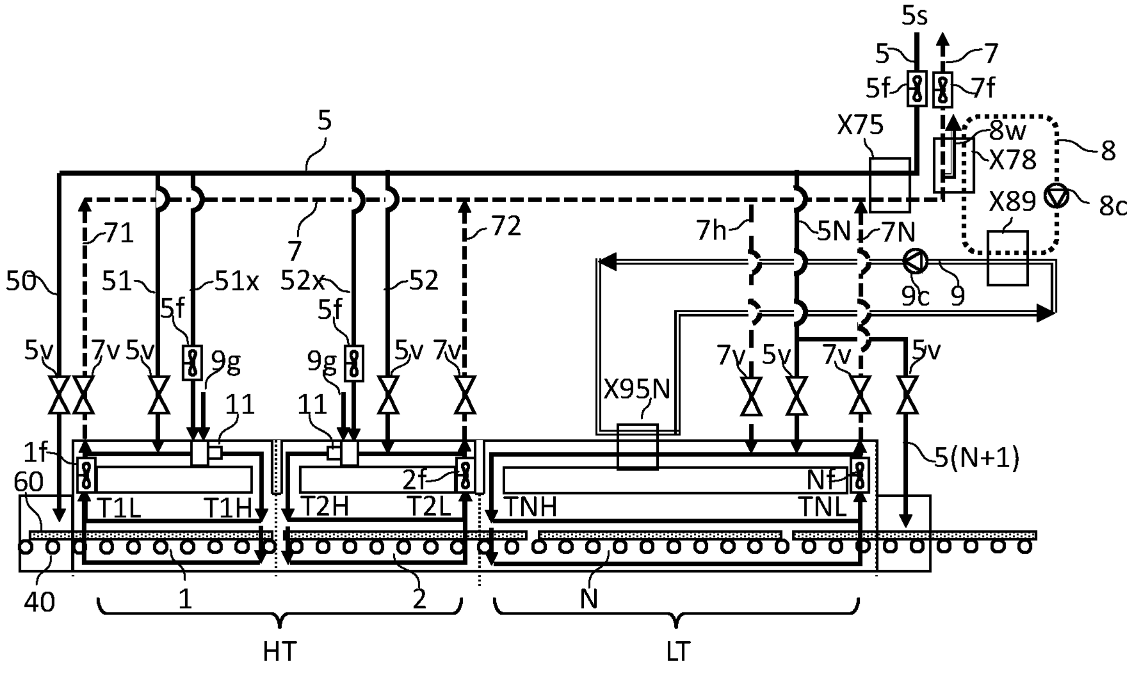
T2H
T2L
TNH
TN
TNL
60
40
1
2
N
HT
LT

FIG.5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9c
9
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51
51x
52x
52
5f
5f
5v
7v
5v
9g
9g
5v
7v
X95N
7v
5v
7v
5v
11
11
1f
60
2f
Nf
5(N+1)
T1L
T1H
T2H
T2L
TNH
TNL
40
1
2
N
HT
LT

FIG.6

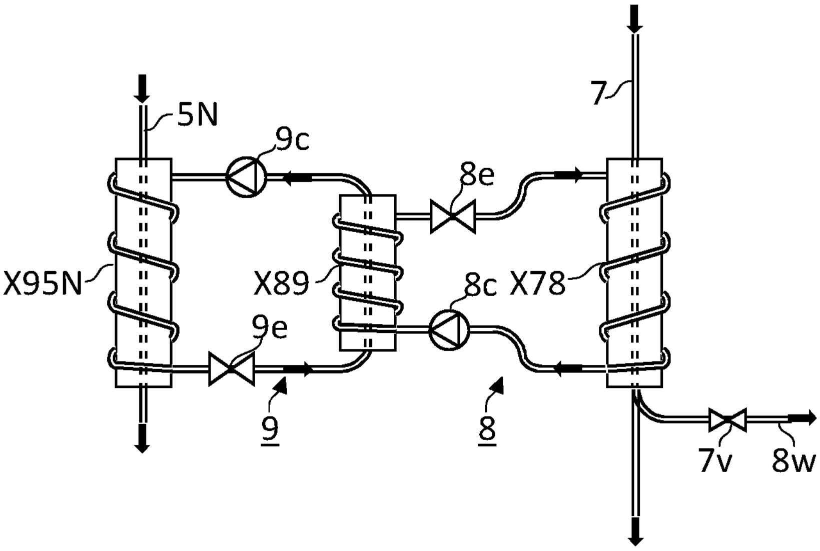

FIG.7

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2023/080817

A. CLASSIFICATION OF SUBJECT MATTER
INV. F26B15/10 F26B15/18 F26B21/00
ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
F26B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EPO-Internal

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
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☒ Further documents are listed in the continuation of Box C.

☒ See patent family annex.

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Date of the actual completion of the international search 30 November 2023	Date of mailing of the international search report 12/12/2023
Name and mailing address of the ISA/ European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Authorized officer Makúch, Milan

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INTERNATIONAL SEARCH REPORT

International application No
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C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
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