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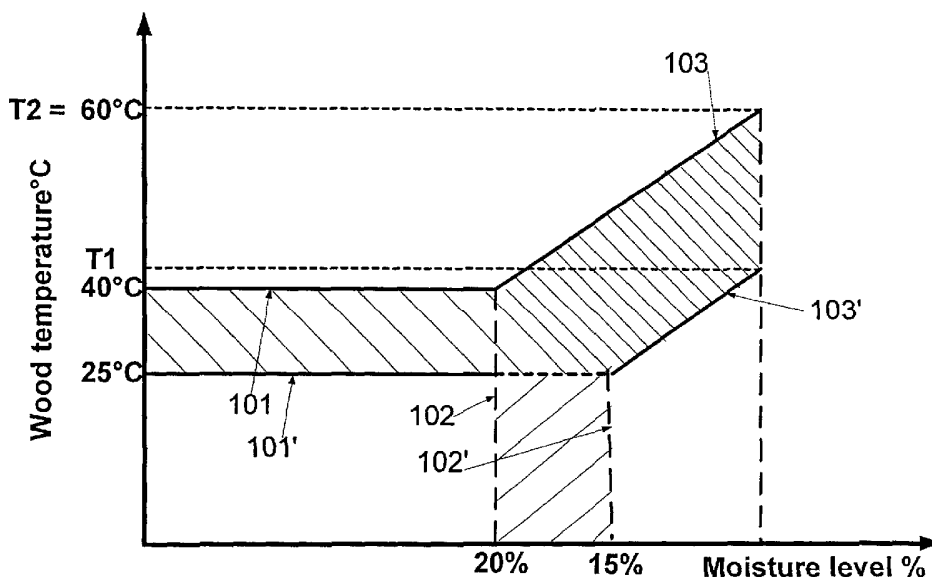
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(54) Title: METHOD AND APPARATUS FOR VACUUM DRYING A MATERIAL



(57) Abstract: Method for vacuum drying a material, particularly timber, where a low temperature is maintained in the material until a predetermined moisture level is achieved, after which the temperature of the material is increased. Material is placed in a drying chamber and produced steam from the drying material is discharged from the drying chamber and compressed by a compression device comprising at least two compression units for raising the heat energy of said steam. This heat energy is transferred from at least part of the compressed steam to the drying chamber through a condenser unit. Steam is added to the compression device, where this additional steam is being heated by external energy before entering the compression unit.



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## Method and apparatus for vacuum drying a material

## FIELD OF THE INVENTION

- 5     The present invention relates to a method and an apparatus for vacuum drying of a material, particularly timber.

## BACKGROUND OF THE INVENTION

- 10     Vacuum drying of materials is generally known and described in prior art, for example in US patent no. 4 753 016 for general purpose, in US patent no. 6 112 426 by Butazzi with a preferred application to leather, and in the following documents for drying of timber, European patent application EP 887 606 by Bernhard, US patent no. 4 467 532 by Drake, and US patent no. 4 893 415 by Moldrup. The material is placed in a drying  
15     chamber, the pressure of which is lowered by vacuum pumps in order to remove air and to make evaporation of water effective at low temperature.

- 20     The drying process can be made more efficient, especially in the beginning of the drying process, by heating up the timber, for example by recirculating steam in the drying chamber, particularly superheated steam. For maintaining a steady condition of the drying process after the preheating stage, steam prevalent in the drying chamber may be superheated by supplying heat to the drying chamber and by discharging steam from the drying chamber, whereby evaporation of water from the timber or the like can be continued. According to prior art, this steam from the drying chamber is com-  
25     pressed into a condenser and a collector outside the drying chamber. The condensed liquid is then removed from the collector, for example by a conventional water ring vacuum pump.

- 30     The drying process can be accelerated, by supplying supplementary energy to the drying chamber from the outside, for example by using heat exchangers placed inside the drying chamber. Normally, the temperature of the heat released by a condenser is lower than the temperature in the drying chamber, why the heat from the condenser can not directly be used in the actual drying process for heating the timber.

As disclosed in US patent no. 4 753 016 by Eichholz and in US patent no. 5 819 436 by Helevirta – the latter related to European patent application EP 769 123 and International patent application WO96/01401 - an improvement of conventional drying processes is achieved by separate compression of the steam extracted from the drying chamber and reuse of this for raising temperature in the drying chamber in order to accelerate evaporation of water from the timber and to reduce energy consumption for the process. The aim of this disclosure is to dry timber energetically favourable. This method in many ways is superior to other known method because the temperature in the drying chamber and the partial pressure difference can be regulated independently, which eases the regulation of the process. The partial pressure difference is the difference between the actual pressure in the drying chamber and the pressure corresponding to the vapour pressure of the timber. However, in this disclosure, no clear advice is given for any temperature or pressure to be used for the drying process.

A well known problem is the start of the evaporation process, where, normally, additional heat has to be added to activate the drying process. Heat may also be added during the drying process for acceleration. In the aforementioned US patent no. 5 819 436, it is proposed to add heat by a heating element in the drying chamber, where the heating element is heated by for example water or steam. In this case, the temperature of the water or steam has to be rather high, typically 70°C - 80°C, in order to work efficiently, which leads to a relatively high energy consumption.

Additional heating means are also disclosed in the aforementioned US patent no. 4 753 016. This preheating or booster heating means may increase the temperature of the circulating steam in the heat exchanger inside the drying chamber above the actual temperature for conventional running of the drying apparatus. The steam temperature may be up to 90°C, which requires substantial energy for the booster heater to raise the temperature of the steam further.

Reduction of the energy consumption in drying processes has a high interest generally and is subject to focus in research and development in this field. But also the quality of the dried timber is of high concern, especially because timber that has been dried by

known processes has a quality which leaves a desire for substantial improvements. The inferior quality of the dried timber is mainly due to the fact that the drying process is accelerated in order to save drying time. Thus, the drying of timber is a compromise between on the one hand a fast drying time with respective high temperature and on the other hand a high quality of the dried timber.

It would be desirable to have an optimised process with small energy consumption, short drying time and still gentle drying of the timber in order to achieve a high quality of the dried wood.

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### SUMMARY OF THE INVENTION

It is the therefore the purpose of the invention to provide an improved drying method and apparatus with a short drying time, where the improvement in particular concerns the quality of timber that has gone through a drying process. However, it is a further purpose of the invention to minimise the energy consumption in a drying process, especially if preheating or additional heating is used. Thus, the more general purpose of the invention is to increase the standard of technology in the field.

20 This purpose is achieved by a method for vacuum drying a material, the method comprising

- placing the material in a drying chamber,
  - producing vacuum in the drying chamber by a vacuum producing unit,
  - regulating the vapour pressure in the drying chamber to below the partial vapour pressure of the liquid in the material for causing vapour to be produced in the drying chamber due to evaporation of liquid from the material,
  - discharging the vapour from the drying chamber, and
  - regulating the temperature in the drying chamber independently of the vapour pressure in the drying chamber
- 30 - regulating the vapour pressure and the temperature in the drying chamber such that a temperature of the material in the drying chamber is achieved between a high, predetermined level and a low, predetermined level, the high, predetermined level being low enough for substantially preventing damage of the material,

- maintaining, until the decreasing liquid content in the material reaches a predetermined moisture level, a continuing regulation of the vapour pressure and the temperature in the drying chamber such that the temperature of the material is kept between the high level and the low level,
- 5 - after having reached the predetermined moisture level regulating the vapour pressure and the temperature in the drying chamber such that a temperature of the material in the drying chamber is raised over the high level.

10 The method according to the invention is particularly useful for timber of different kind, why in the following, the invention will be described with respect to drying of timber. However, it should be emphasised that this does not limit the applicability of the invention for other materials, as skin, for example for leather production, corn, grain, natural fibres, cotton, wool, or cloth. Also, the liquid to evaporate is typically water though other liquids may be evaporated from material by a method and an apparatus according to the invention, for example alcohol or glycol.

15 The speed at which a water permeable material dries under heating conditions is depending on the temperature. The higher the temperature of the material, the easier water is transported from the surface of the material and is evaporated. In case of a material like wood, a higher temperature also results in a lower viscosity with an easier escape of water from the fibres in the wood. The speed for evaporation of water from the material is also dependent on the pressure in the surrounding of the wood. If the pressure is low in the surroundings, liquid evaporates easier from the surface of the material. Thus, a lower drying temperature may to a certain extend be replaced by a lower pressure in order to keep a certain drying speed. In fact, what governs the speed of the evaporation process is the difference between the partial pressure of the liquid in the drying chamber and the partial pressure of the liquid in the wood at the actual temperature of the wood. If the difference is high, water tends to evaporate quickly from the surface of the material. In most drying processes according to prior art, however with the exception of the process as disclosed in the aforementioned US patent no. 5 819 436, the temperature of the material and the partial pressure difference are dependent parameters that cannot be treated as independently. However, it is impor-

tant to regulate the temperature in the drying chamber independently of the vapour pressure in the drying chamber in order to optimise the drying process.

Wood has to be dried gently at moderate temperatures in order to prevent deformations due to tension in the wood, seepage of resin, occurrence of cracks, and discolouring of the wood. Thus, it is an advantage to dry wood at moderate temperatures. However, this implies long drying times. As has turned out surprisingly, high quality of wood can be achieved, if the temperature is kept low, for example between 25°C and 40°C, during the first part of the drying process until a certain amount of liquid content is reached, for example between 15% and 20% of weight dependent on the type and the dimensions of the wood. After that, a faster evaporation can be used with a higher temperature of the wood to accelerate the process. This accelerated procedure does not damage the wood, as has turned out experimentally. A likewise beneficial effect is expected for drying of skin or fibres, where, however, other temperature ranges may be important. For example, the temperature for drying skin is preferably lower, typically 18°C, than for drying wood. Also the amount of remaining liquid left in the material when starting to raise the temperature – the predetermined moisture level - may be different for different materials.

Due to the regulation of temperature and pressure independently, a very low drying temperature may be used in the beginning of the process, for example the high predetermined level may be 40°C, which should not be overshoot in the first part of the drying process. Despite the relatively low temperature of the wood, still a fast drying process may be obtained. Though acting against prejudice by using temperatures below 40°C for drying timber, it has surprisingly turned out, that timber can be dried with a short drying time and with a final quality which is by far superior to the quality of timber dried by other known methods. The explanation for this effect has been found through intense study by the inventor of the drying problem leading to the observations that though the temperature of the timber has to be relatively low, there is no necessary limitation for the difference between the vapour pressure of the water in the wood and the partial vapour pressure in the drying chamber where the timber is placed. The partial pressure difference, however, determines the speed of the drying process.

Furthermore, due to the low temperature, also the energy consumption is significantly reduced.

- 5     The above mentioned low, predetermined level for the temperature may typically be chosen a few degrees under the high predetermined level.

10     Production of vacuum in the drying chamber is achieved by a vacuum producing unit, for example a water ring vacuum pump. Due to the liquid evaporation from the material, for example water evaporation from wood, the material is cooled, which reduces the evaporation speed from the material. In order to maintain a high evaporation speed, the material has to be heated.

15     A regulation of the temperature in the drying chamber can be achieved by any heating mechanism. However, it is preferred that produced vapour, typically steam, from the drying material, typically timber, in the drying chamber is discharged from the drying chamber and compressed by a compression device for raising the heat energy of the vapour. The heat energy of this vapour, or at least part of the energy dependent on the energy needed, is then transferred to the drying chamber through a condenser unit in  
20     thermal contact with the interior of the drying chamber.

25     When material, for example timber, has been placed in the drying chamber, this is closed sealingly against the environment to ensure that desired pressure conditions can be achieved inside the drying chamber. A vacuum pump unit may pump air out of the closed drying chamber and produce vacuum - or more precisely: low pressure - inside the chamber. Vacuum, or low pressure, in this respect means a pressure of considerably less than atmospheric pressure, for example 5 - 100 mbar. At this low pressure, liquid, for example water, starts evaporating from the material by which the temperature is reduced inside the drying chamber resulting in a reduced evaporation speed. To  
30     counteract this decrease in evaporation speed, a compressor unit discharges the vapour, for example water steam, from the drying chamber and compresses it to a higher pressure and temperature such that heat energy from the compressed vapour can be

transferred back to the drying chamber through a condenser which is in thermal contact with the drying chamber.

5 The discharge of the vapour from the drying chamber by the compressor ensures that the partial pressure in the drying chamber is kept below the pressure necessary for liquid evaporation from the timber.

10 This process may be used for timber at temperatures below typical room temperatures. Therefore, for initially cold timber, a preheating stage has to be included to heat the timber in the drying chamber to a temperature, where the drying process can be performed with acceptable speed. This preheating may advantageously be achieved according to the invention by feeding additional vapour, in this case steam, into the compression unit. This steam may be generated in a supply having a heat transfer unit coupled to an external liquid supply. Thus heated steam is produced in a heat exchanger after which the steam enters the compression device. As the temperature of this generated steam is increased further through the compression unit, a relatively low preheat temperature and pressure of the generated steam is sufficient. This opens the possibility for using external heat energy for the heat exchanger directly from waste water, which may have a temperature of below 40° C, typically 30°C. This is in contrast to prior art, as described above, where heating units require much higher source temperatures for achievement of satisfactory results. Being able to use heat energy at these low temperatures, very cheap and environmentally sound technology may be used. Another example for heating the steam is by solar heat collection which then is transferred to the additional generated steam.

25 Though the heating of the additional vapour is primarily intended to be used at the beginning of the drying process, it may also be used during the drying to accelerate the process. This may be particularly relevant, if the drying chamber is losing heat energy through not sufficiently insulated chamber walls, especially if the surrounding temperature is very low. Furthermore, external energy may be supplied in the final stage of the process, where the temperature of the material is raised.

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The arguments concerning reduced energy consumption in connection with preheating and additional heating by feeding heated steam into the compression unit are equally valid for drying methods at temperatures higher than 40°C. Though it is preferred to use this principle of additional heating at temperatures below 40°C and most preferably in a method according to the invention, the principle of this preheating and additional heating would also improve known methods at higher temperatures, for example the method as disclosed in the aforementioned US patent no. 4 753 016.

In order to achieve a gentle and nevertheless fast drying of the material as described before, it is necessary to apply a compressing device which is able to meet the demand of a sufficient high compression rate. In known apparatuses, one single compression unit is foreseen. However, by using only one compression unit, the compression rate of the compression is very low and does not imply a fast drying method as desired by a process according to the invention. The reason for the very low compression rate is that the compression by only one compressor with high compression rate results in a temperature and a pressure of the compressed gas at the outlet of the compressor at a level which causes damage to the compressor. This may be overcome by injecting cooling water into this one compressor, but this in return would result in a low capacity of the compression. Thus, at first sight, the desired fast and nevertheless gentle drying process according to the invention seems in contrast to established knowledge in the field and not possible with known apparatuses.

This apparent contradiction, however, has been overcome by an apparatus for drying a material having

- a drying chamber for the material,
- a vacuum producing device connected to the drying chamber for producing vacuum in the drying chamber,
- a compression device with an inlet connected to the drying chamber for compressing vapour discharged from the drying chamber,
- a condenser unit connected to the outlet of the compression device and in thermal contact with the drying chamber for transferring heat from the compressed vapour to the drying chamber,

wherein the compression device comprises at least two compression units, the outlet of the first of the at least two compressing unit and the inlet of the second of the at least two compressing units being connected through a first heat transfer unit for reducing the energy in the vapour after the first compressing unit and before the  
5 second compressing unit.

By using two or even more compression units and extracting energy from the vapour between the compression units, the temperature of the compressed vapour at the outlets of the compression units can be kept at temperatures and a compression ratio not  
10 damaging the compression units and still having very high drying speed.

Advantageously, the first heat transfer unit is in thermal contact with the drying chamber for transfer of heat from the compressed vapour to the drying chamber. This way, extracted energy can be used most efficiently for the drying process resulting in reduced energy consumption for the drying.  
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The capacities of the compression units have to be regulated in order to adjust the pressure in the drying chamber, and in particular to regulate the evaporation speed of the liquid in the material through the difference between the pressure in the drying  
20 chamber and the partial vapour pressure of the liquid in the material. Also, it is important that the compression units are prevented from overload. Thus, a too high pressure difference between the inlet of a compression unit and the outlet of a compression unit or a too high temperature of the vapour at the outlet should be prevented. Therefore, in a further embodiment of the invention, a first connection and a first regulation valve is  
25 situated between the inlet of the first compressing unit and the inlet of the second compressing unit for transfer of cooled vapour to the inlet of the first compressing unit. And likewise for the second compression unit, the apparatus comprises a second connection and a second regulation valve between the inlet of the second compressing unit and the outlet of the condenser unit for transfer of cooled vapour to the inlet of the  
30 second compressing unit. By these features, the capacity of the compression units is regulated by regulating the valves in accordance with the actual needs and, furthermore, overload may be prevented in an efficient and simple way.

In comparison, the regulation of the capacity of the compression units by frequency control of the compression units – which would be an alternative solution - is more expensive and more difficult. Furthermore, the energy of the process is not transferred to the drying chamber to the same degree, which would require the addition of more energy from external sources.

In order to start the evaporation process and for supply of additional energy during the process, especially if the drying chamber is located in cold environments without being sufficiently isolated, there is a need for an external energy source. Such a supply of energy may be an electrical heater. However, in order to save energy and to find an environmental sound method, the invention foresees a different solution. Therefore in a further embodiment of the invention, the apparatus further comprises a supply unit for supplying additional vapour to the first compression unit and a heating unit for heating the additional vapour before entering the first compression unit. As the temperature of this heated vapour is increased further through the compression unit, a relatively low preheat temperature of this heated vapour is sufficient. This opens the possibility of using external heat energy through heat exchange directly from waste water, which may have a temperature of below 40° C, typically 30°C. Alternatively, liquid heated by solar energy may be used.

In order to regulate the temperature in the drying chamber, the amount of additional preheated steam is regulated by an adjustable valve before the first compressing unit. Once a desired temperature of the drying chamber and the timber has been reached, the transfer of the additional steam may be reduced or even stopped.

Air that may be accumulated in the system and water has to be discharged, why the outlet of the condenser unit is connected to a discharge unit with a pumping device for discharge of liquid, vapour and air. By also discharging vapour, energy is efficiently removed from the system.

A possible regulation of the amount of discharged water, air and/or vapour is achieved through the discharge unit in the following way. While the pumping device is running continuously, for example with constant capacity, air is in parallel entered into the

pumping device, whereby the suction from the condenser is reduced. Therefore, the apparatus according to the invention comprises a regulation valve with an air inlet connected to the inlet of the pumping device for regulating the discharge flow through the pumping device. This regulation valve may be configured to be regulated in dependence of the liquid temperature and the vapour pressure in the discharge unit.

The apparatus and method initially developed for a method according to the invention, where timber is dried at low temperatures, is also inventive for applications at any other temperature, especially at higher temperatures. By the invention, energy consumption is substantially reduced as compared to drying techniques according to prior art.

#### SHORT DESCRIPTION OF THE DRAWINGS

The invention will be explained in more detail in the following with reference to the drawing, where

FIG. 1 illustrates qualitatively the temperature of the wood for the drying process,

FIG. 2 is a diagram of the apparatus according to the invention,

FIG. 3 are enthalpy/entropy diagrams illustrating the compression and cooling of the steam,

FIG. 4 is a schematic of the apparatus according to the invention as seen from the side and from the end.

#### DETAILED DESCRIPTION / PREFERRED EMBODIMENT

The invention is primarily intended for drying of wood and will in the following be explained in this context. However, this does not limit the general character of the invention that may be used for drying of other material. Also, the liquid to be removed from the material need not be water, but may also be other kind of evaporable liquid.

FIG. 1 illustrates the drying process according to the invention. The temperature of the wood has to be kept low during the first part of the drying process, for example between a high, predetermined level 101, 101' of 40°C or 25°C and a low, predeter-

mined level being typically a few degrees below the high level. The high, predetermined level 101 may be dependent on the type of wood and the dimensions of the wood to be dried. Once, however, a certain predetermined moisture level 102, 102' in the wood, for example 20% or 15% by weight, has been achieved by still keeping the temperature low, for example substantially constant with a tiny temperature variation of 1K, the temperature may be increased 103, 103' in order to achieve the desired final content of water. For example, if the start temperature is 25°C and the predetermined moisture content is 20%, the final temperature T1 achieved by increasing 103' the temperature may be lower than the final temperature T2 achieved by increasing 103' the temperature for a start temperature of 40°C and the same predetermined moisture level of 20%. However, the final temperature depends on the predetermined moisture level. As illustrated on the diagram in FIG. 1, the final temperature, is lower than T2, if raising of the temperature starts at a lower predetermined moisture level, for example 15% as shown with the increase of the temperature 103', respectively 103.

15 In FIG. 3, the advantage of using two compression units instead of one is illustrated in enthalpy versus entropy diagrams. The diagram contains isobars 301 with indicated pressure in bars and isotherms 302 with indicated temperature in °C. Furthermore, curves 303 for constant steam ratios, the ratios of which are indicated. The curve 303' for a steam ratio of 1 is the saturation curve for the steam. The full drawn curve in FIG. 3a for one compressor used shows the conditions for the steam during compression 304 and cooling 305 in the condenser. In order to achieve a higher temperature difference, the temperature during compression is raised to 350°C, which may damage the compression unit. In FIG. 3b, a corresponding curve is seen for compression 306 by the first compression unit C1, cooling 307 in the first heat exchanger EX2, compression 305 by the second compression unit C2, and final cooling 308 in the condenser unit. As can be observed, the steam temperature at the outlet of the first and the second compression units is slightly higher than 150 °C, being far below any for the compression units dangerous temperature. This illustrates, how by the invention, a very high drying efficiency can be obtained without the risk for damaging the compression units due to too high steam temperature at the compressor outlet.

The apparatus according to the invention is illustrated in FIG. 2. It comprises a drying chamber 200 into which the material to be dried, preferably wood in the form of timber, is inserted. The chamber 200 is closed sealingly against the environment in order to produce low pressure conditions in the drying chamber 200. For initial evacuation of the drying chamber 200, vacuum pumping units VA1 and VA2 are started, thereby evacuating pipes 209, 208, 207, 206, 205, 204, 203, 202, 201, and finally the interior of the drying chamber 200. Vacuum pumping units VA1 and VA2, preferably, have different capacities, which is convenient if the necessary capacity for evacuation has to be varied, because one pumping unit may be stopped when low capacity is needed.

Once the drying chamber 200 has been evacuated and a sufficient low pressure is achieved in the chamber 200, for example 100 mbar, a compression device 211 including a first compressor unit C1 and a second compressor unit C2 continue evacuating the drying chamber 200 through the pipe 201 causing water to evaporate from the timber. The steam from the drying chamber 200 is transported by pressure difference through piping 201, valve V1, and piping 202 to the compression unit C1, where it is compressed, which results in a higher temperature of the steam. The steam is then led through piping 203 into a first heat transfer unit EX2 for transfer of the heat to the drying chamber 200 for heating of the wood therein. After having been cooled in the first heat transfer unit EX2, the steam is transferred through piping 204 to a second compression unit C2 for further compression. The temperature of the steam increases in this process, and the steam is transferred through piping 205 into a further heat exchanger EX1 in the form of a condenser unit in the drying chamber 200 and the steam is condensed before transfer through piping 206. Heat is transferred to the drying chamber 200 from the condenser unit EX1 in order to regulate the temperature of the drying chamber in which the temperature is measured by temperature gauge T1. Also, the temperature of the material in the drying chamber 200 is measured, which, however, is not shown in the drawing.

Condensed water, eventual air, and, eventually, steam are discharged through a discharge unit 210 comprising a container B2 piping 208, 209 and a vacuum producing device containing vacuum pumping units VA1 and VA2. Final discharge of water, steam and/or air is through piping 212, 213 and a storage tank B3 that may be emptied

through a drain 214. Steam may be discharged through the discharge unit in order to remove energy from the system, as steam contains energy in the form of heat. The latter is applicable for reducing the temperature in the drying chamber. The pumping efficiency from pipe 207 through the pumping units VA1, VA2, is advantageously  
5 adjusted through regulation of a valve V5, entering air into the piping 209 and the pumping units VA1, VA2.

In the container B2 of the discharge unit 210, liquid is accumulated until the liquid level reaches the lower end 221 of tube 222 extending to a position at a prechosen  
10 distance above the bottom of container B2. The reason for gathering liquid in this container is the desire to measure the temperature of the liquid, which is done by temperature gauge T. For a certain liquid temperature, the pressure in the container is known and verified by a pressure gauge P. Inconsistency between the expected and measures pressure on the base of the water temperature indicates that other gases than steam, for  
15 example air, is present in the system, such that an additional amount of gases has to be discharged from the system.

By compressing the steam in the compression device 211, energy is added to the process. However, in the beginning of the drying process, the material in the drying chamber may have a temperature which is lower than desired. Therefore, additional energy  
20 has to be supplied. This may happen through a supply unit B1 for supplying additional vapour through piping 216, regulating valve V2, and piping 202 to said first compression unit C1. Liquid to produce additional vapour may be taken from piping 217 from the storage tank B3 through valve V9. Steam is produced due to the low pressure in  
25 piping 216 and due to the heat exchanger 215. The additional vapour enters the first compression unit C1, whereby energy is added to the process. The heating unit 215 advantageously is a heat transfer unit coupled to water supply 218 for supply of heat from the water. Because the temperature of the vapour from the vapour supply B1 is compressed in the first compression unit C1, the water in the water supply 218 need  
30 not have a high temperature. Therefore, this water may be said waste water at low temperature, for example 40°C or less or, alternatively, solar heated water.

The addition of energy may also be used for increasing the temperature of the wood in the final process, where the temperature of the wood increases beyond the high, predetermined level.

- 5        However, the temperature may be caused to increase in another way. By reducing the capacity of the vacuum pumping units (VA1, VA2), less steam is discharged and, therefore, less energy is taken from the process, which results in an increase of the temperature of the wood due to the surplus of energy because of the energy supply from the compression units and the ventilation.

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- The pressure in the drying chamber 200 may be regulated by adjustment of the capacities of the compression units C1, C2. As this also influences the heat transfer in the first heat transfer unit EX2 and the condenser unit EX1, a capacity adjustment, in fact, regulates the above mentioned partial pressure difference being the difference between
- 15        the actual pressure in the drying chamber and the pressure corresponding to the vapour pressure of the timber. An adjustment of the compressor capacity is advantageously done in the following way. Through piping 220 and regulating valve V3, cooled steam from the first heat exchanger EX2 may be added at the inlet of the first compression unit. Regulation by the valve V3 is especially useful in the beginning of the drying
- 20        process in order to avoid a too high partial pressure difference, which could result in cracks in the wood. In addition, through piping 206, 209 and valve V4, cooled return steam from the condenser unit EX1 may be added to compression unit C2. The addition of cooled return steam from prevents overheating of the compression units. Also, in order to prevent overheating of the compression units C1, C2, optionally, water may
- 25        be injected through valves V7 and V8 into the compression units.

- A typical steam amount to be circulated in order to avoid colouring of the timber in the drying chamber 200 is 12,000 m<sup>3</sup> per m<sup>3</sup> of wood. This ensures efficient removal of moisture from the wood without heating the timber too much. For example, a temperature in the drying chamber 200 of 15K over the temperature of the wood is recommended.
- 30

In order to achieve an even temperature distribution in the drying chamber 200, ventilators may conveniently be installed in the chamber.

5 The described vapour supply B1 for additional heating by waste water or by solar energy through heat exchange in heating unit 215 may, in principle, also be used to improve known methods, for example the method as disclosed in the aforementioned US patent no. 4 753 016. The use of this principle for a general drying apparatus is for illustration described in the following with reference to FIG. 4, where FIG. 4a illustrates the apparatus in a side view and FIG. 4b in a view as seen from the end.

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The apparatus 401 comprises a drying chamber 402, in which the material 403 to be dried, for example timber 403, is placed. A pump unit 404, in this case comprising a water ring vacuum pump with a water supply pipe 405 connected to a water storage tank 406, discharges air from the drying chamber 402 through the valve inlet 407 of a valve 408 and a connecting pipe 409. When the drying chamber 402 has been substantially emptied for air, water will evaporate from the timber 403 which leads to a decrease in temperature in the drying chamber 402 resulting in a reduced evaporation speed. To counteract this reduction of the evaporation speed and to even increase it, a compression unit 410, preferably with variable capacity suck, discharges the water steam from the drying chamber 402 through the valve inlet 407 and compresses this steam to a higher pressure and temperature. The compressed steam at higher temperature is transferred through the connecting pipe 409 into a condenser 411, which is in thermal contact with the drying chamber 402 such that heat energy is transferred back to the drying chamber 402 through the walls of the condenser 411.

20

25 To secure sufficient convection in the drying chamber 402, ventilators 420 may be used to achieve circulation of the steam inside the drying chamber 402.

30

In order to initiate the evaporation process, typically a preheating of the timber 403 in the drying chamber 402 is necessary. Therefore additional preheated steam is supplied to the compression unit 410 through the vapour pipe 412 connected to the valve 408. The preheating of the additional steam is achieved by a heating unit. This heating unit can be of various kind, for example comprising an electric heater, but it is preferred

that this heating unit comprises a heat exchanger 413, whereby heat is transferred to the steam from a liquid, typically water, that enters 422 and exits 421 the heat exchanger 413. As the temperature of this heated steam is increased through the compression unit 410, a relatively low temperature of this heated steam is sufficient.

5 Therefore, waste water or water heated by solar energy, which may have a temperature of below 40° C, may be used in the heat exchanger 413.

The heat exchanger 413 may be located outside the drying chamber 402, but preferably, the heat exchanger 413 is located inside the drying chamber 402. Because the

10 pressure in the drying chamber 402 and in the heat exchanger 413 are comparable, no high pressure resisting wall of the heat exchanger 413 is needed when placed inside the drying chamber 402, which reduces the costs of the apparatus 401.

Typically the additional steam is only supplied in the beginning of the process, as heating by the compression of the steam is sufficient to maintain a satisfactory evaporation speed. In order to prevent overheating of the timber 403 by the heat supply from the compressed steam in the condenser 411, part of the compressed steam may bypass the condenser 411 through the bypass line 414 with a bypass valve 415. The bypass valve 415 is adjustable, whereby the temperature in the drying chamber 402 can be regulated

15 to a desired temperature.

20

Steam that has been removed from the drying chamber 402 is discharged from the system as liquid through a discharge pipe 416 into a liquid tank 406. This liquid tank 406 also serves as a water supply for the water ring vacuum pump in the pump unit

25 404. Also, from the water supply of the tank 406, water is taken through a connection 417 for the additional water for evaporating in heat exchanger 413, where a valve 424 regulates the level of the water in the vessel around the heat exchanger 413.

The liquid level 418 in the tank 406 is kept constant because of liquid discharge 419

30 from the tank 406 out of the apparatus 401.

Generally, the production costs of the apparatus 401 in FIG. 4 according to the invention are lower than of other comparable known systems. For example, in comparison

with the apparatus as disclosed in the aforementioned US patent 5 815 436, no external cooler structure and corresponding valve system involving several valves are needed. The apparatus 401 according to the invention is therefore more simple, cheaper to produce and cheaper to maintain in addition to the fact, that it is suited for environmentally sound technology utilising solar heating or heat recovery from waste water.

If the drying chamber is well isolated, it may occur that the temperature increases in the drying chamber as energy is added to the system through the work of the compressor unit and the ventilators. In order to limit the temperature in the drying chamber 402 in order not to damage the timber 403, an amount of the compressed steam may bypass the condenser unit 411 for preventing heat transfer from this amount of the compressed steam to the drying chamber. A control of the amount of this bypassing compressed steam regulates the temperature in the drying chamber 402. The amount of the bypassing compressed steam may be chosen to be constant, which is a simple but not flexible solution. Preferably, the amount is regulated actively by an adjustable valve.

The invention foresees drying of especially timber, where water should be removed without resulting in deformations of the wood or colouring, the latter may occur due to presence of oxygen during the drying process. Also, ruptures or cracks in the wood due to the drying are prevented. The process is fast, gentle, energetically very effective and practically independent of the climatic surroundings.

## CLAIMS

1. A method for vacuum drying a material, said method comprising
  - placing said material in a drying chamber (200),
  - 5 - producing vacuum in said drying chamber (200),
  - regulating the vapour pressure in said drying chamber (200) to below the partial vapour pressure of the liquid in said material for causing vapour to be produced in said drying chamber due to evaporation of liquid from said material,
  - discharging said vapour from said drying chamber (200), and
  - 10 - regulating the temperature in the drying chamber (200) independently of the vapour pressure in said drying chamber
- characterised in that said method comprises
  - regulating said vapour pressure and said temperature in said drying chamber such that a temperature of said material in said drying chamber is achieved between a
  - 15 high, predetermined level (101, 101') and a low, predetermined level, said high, predetermined level (101, 101') being low enough for substantially preventing damage of said material,
  - maintaining, until the decreasing liquid content in said material reaches a predetermined moisture level (102, 102'), a continuing regulation of said vapour pressure
  - 20 and said temperature in said drying chamber such that the temperature of said material is kept between said high level and said low level,
  - after having reached the predetermined moisture level (102, 102'), regulating said vapour pressure and said temperature in said drying chamber such that a temperature of said material in said drying chamber is raised (103, 103', 103'', 103''')
  - 25 over said high level (101, 101').
2. Method according to claim 1, wherein said material is timber and that said first, high, predetermined level is between 25°C (101) and 40°C (101').
- 30 3. Method according to claim 1 or 2, wherein said method comprises
  - compressing said discharged vapour by a compression device (211) for raising the heat energy of said vapour,

- transferring heat energy from at least part of said compressed vapour to said drying chamber through a condenser unit (EX1) in thermal contact with said drying chamber (200).
- 5      4. Method according to claims 3, wherein said method comprises adding of additional vapour to said compression device, said additional vapour being generated by external energy before entering said compression device (211).
- 10      5. Method according to any of the preceding claims, wherein said external energy is heat from a heat transfer unit coupled to an external liquid supply.
6. Method according to claim 5, wherein said external liquid supply is waste water, preferably with a temperature below 40°C, or solar heated liquid.
- 15      7. Apparatus for drying a material having
- a drying chamber (200) for said material,
  - a vacuum producing device (VA1, VA2) connected to said drying chamber (200) for producing vacuum in said drying chamber (200),
  - a compression device (211) with an inlet connected to said drying chamber (200) for
- 20      compressing vapour discharged from said drying chamber (200),
- a condenser unit (EX1) connected to said outlet of said compression device (211) and in thermal contact with said drying chamber (200) for transferring heat from said compressed vapour to said drying chamber (200),
- c h a r a c t e r i s e d    in that said compression device (211) comprises at least two
- 25      compression units (C1, C2), the outlet of said first (C1) of said at least two compressing unit and the inlet of said second (C2) of said at least two compressing units being connected through a first heat transfer unit (EX2) for reducing the energy in said vapour after the first compressing unit (C1) and before the second compressing unit (C2).
- 30      8. Apparatus according to claim 7, wherein said first heat transfer unit (EX2) is in thermal contact with said drying chamber (200) for transfer of heat from said compressed vapour to said drying chamber.

9. Apparatus according to claim 7 or 8, wherein said apparatus comprises a first connection and a first regulation valve (V3) between said inlet of said first compressing unit (C1) and said inlet of said second compressing unit (C2) for transfer of cooled vapour to said inlet of said first compressing unit (C1).  
5
10. Apparatus according to any one of the claims 7-9, wherein said apparatus comprises a second connection and a second regulation valve (V4) between said inlet of said second compressing unit (C2) and said outlet of said condenser unit (EX) for transfer of cooled vapour to said inlet of said second compressing unit (C2).  
10
11. Apparatus according to any one of the claims 7-10, wherein said apparatus further comprises a supply unit (B1) for supplying additional vapour to said first compression unit (C1) and a heating unit (215) for heating said additional vapour before entering said first compression unit (C1).  
15
12. Apparatus according to claim 11, wherein said heating unit (215) has a heat transfer unit coupled to waste water supply (218) for supply of heat from said waste water, said waste water optionally having a temperature of less than 40°C.  
20
13. Apparatus according to claim 11, wherein said liquid is solar heated liquid.
14. Apparatus according to any one of the claims 7 – 13, wherein said outlet of said condenser unit (EX1) is connected to a discharge unit (210) with a pumping device for discharge of liquid, vapour and air.  
25
15. Apparatus according to claim 14, wherein said discharge unit (210) comprises a regulation valve (V5) with an air inlet connected to said inlet of said pumping device for regulating the discharge flow through the pumping device.  
30
16. Apparatus according to claim 15, wherein said regulation valve (V5) is configured to be regulated in dependence of said liquid temperature and said vapour pressure in said discharge unit (210).

17. Apparatus (401) for drying a material (403) having
- a drying chamber (402) for said material (403),
  - a vacuum producing unit (404) connected to said drying chamber (402) for producing  
5 vacuum in said drying chamber (402),
  - a compression device (410) with an inlet connected to said drying chamber (402) for  
compressing vapour discharged from said drying chamber (402),
  - a condenser unit (411) connected to said outlet of said compression device (410) and  
in thermal contact with said drying chamber (402) for transferring heat from said  
10 compressed vapour to said drying chamber (402),
- c h a r a c t e r i s e d in that said apparatus (402) further comprises a supply unit for  
supplying additional vapour to said compression unit (410) and a heating unit  
(413) for heating said additional vapour before entering said compression unit.
- 15 18. Apparatus according to claim 17, wherein said apparatus (402) further comprises a  
bypass line (414) for bypassing said condenser unit (411) by an amount of said  
compressed vapour in order to prevent heat transfer from said amount of said com-  
pressed vapour to said drying chamber (402).

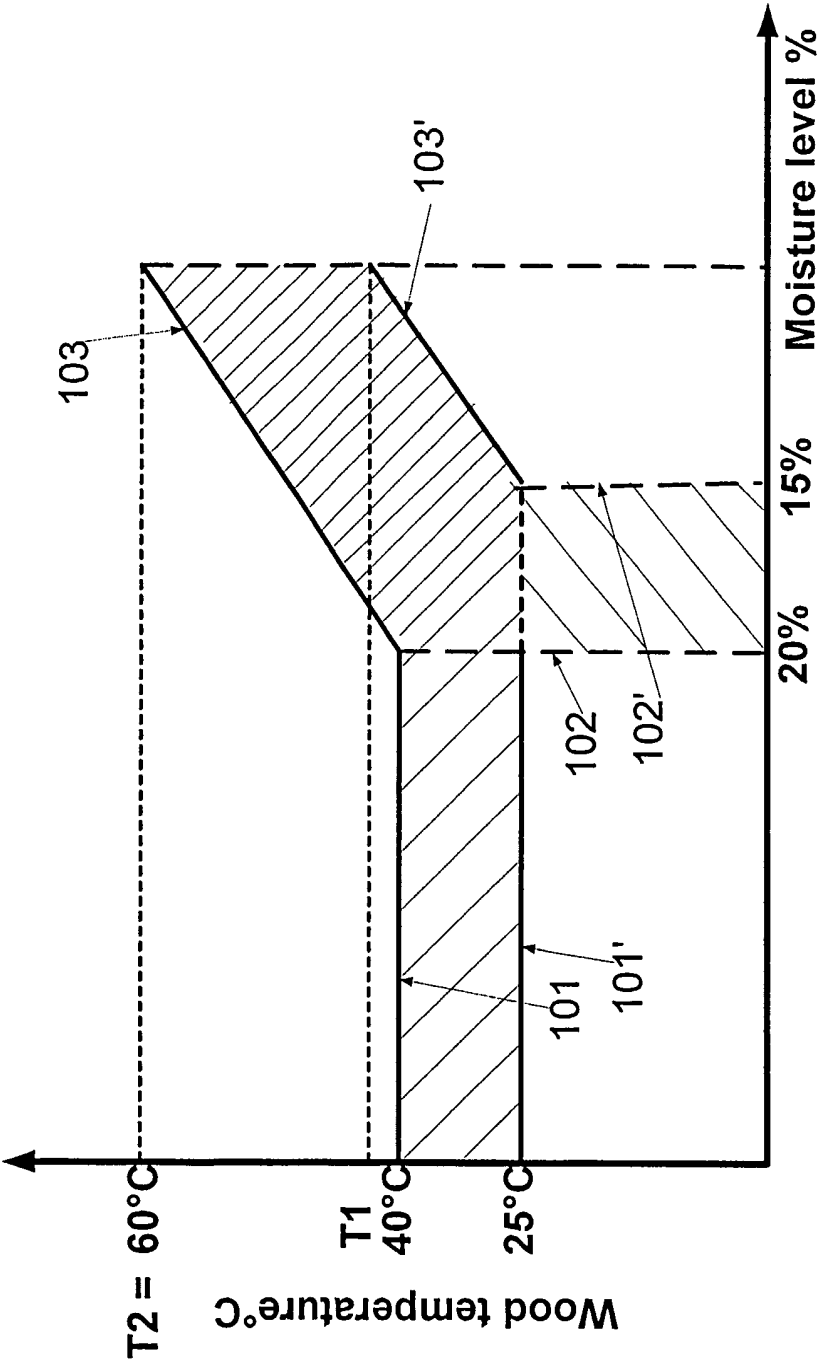


Fig. 1

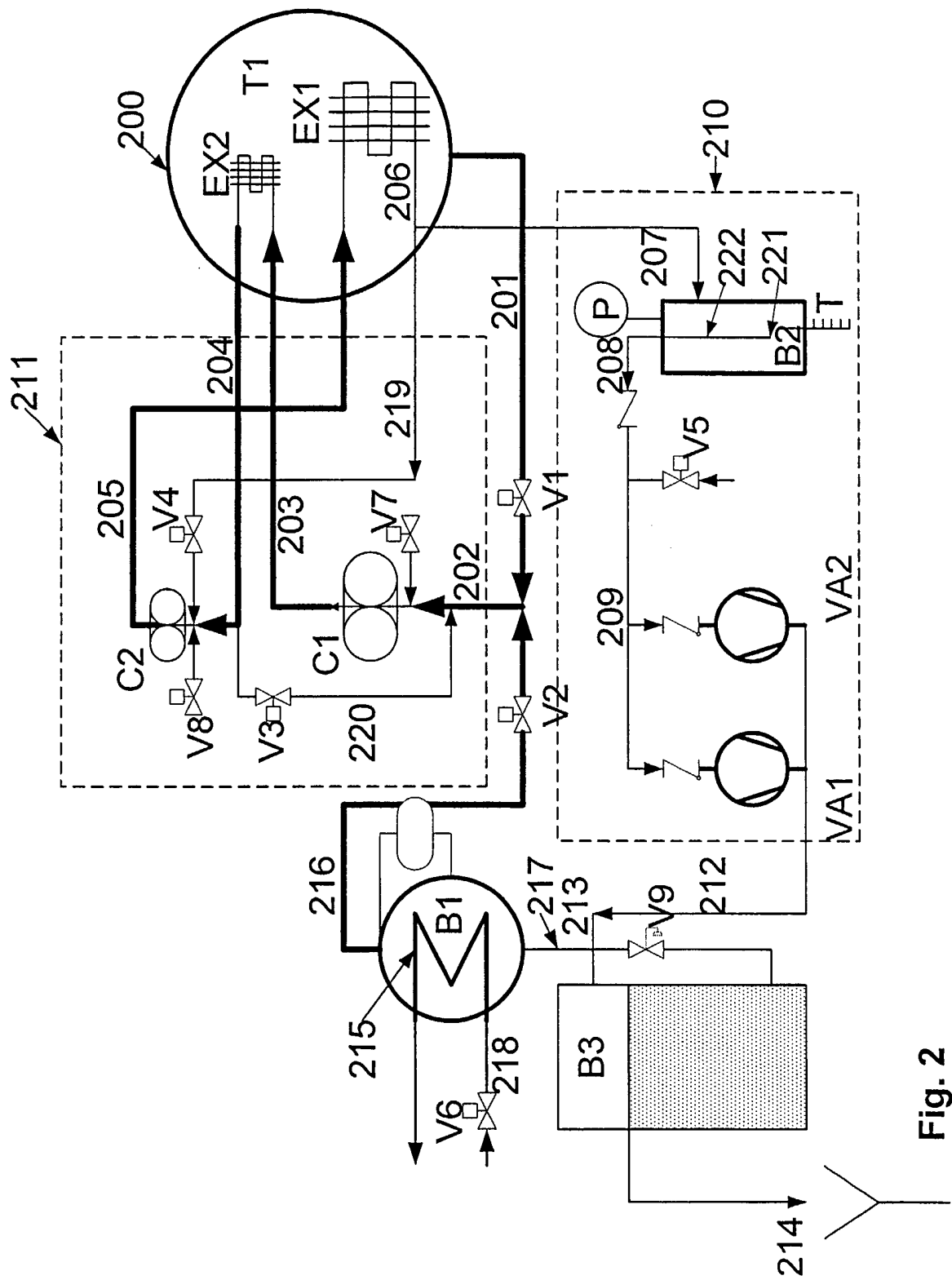


Fig. 2

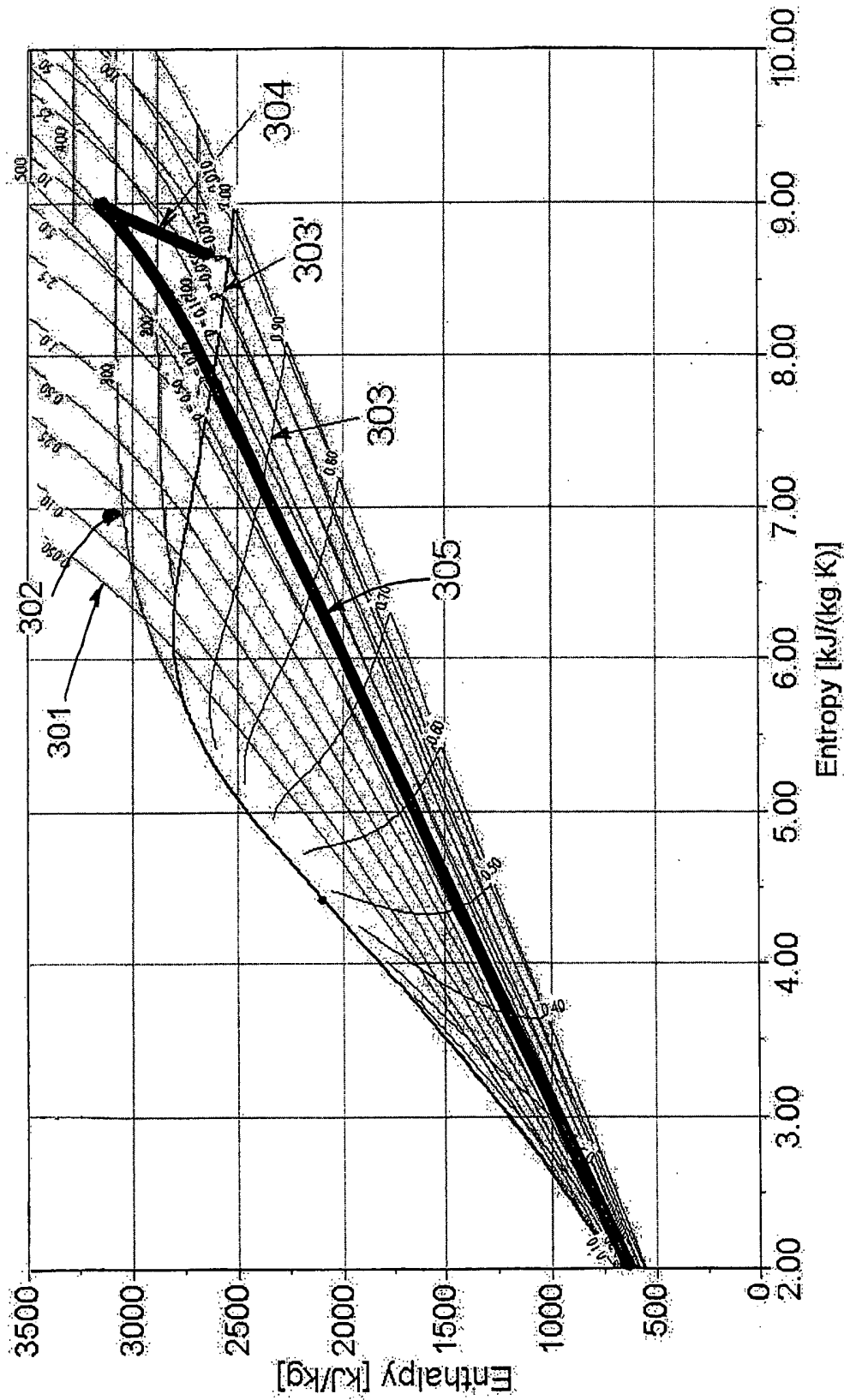


Fig. 3a

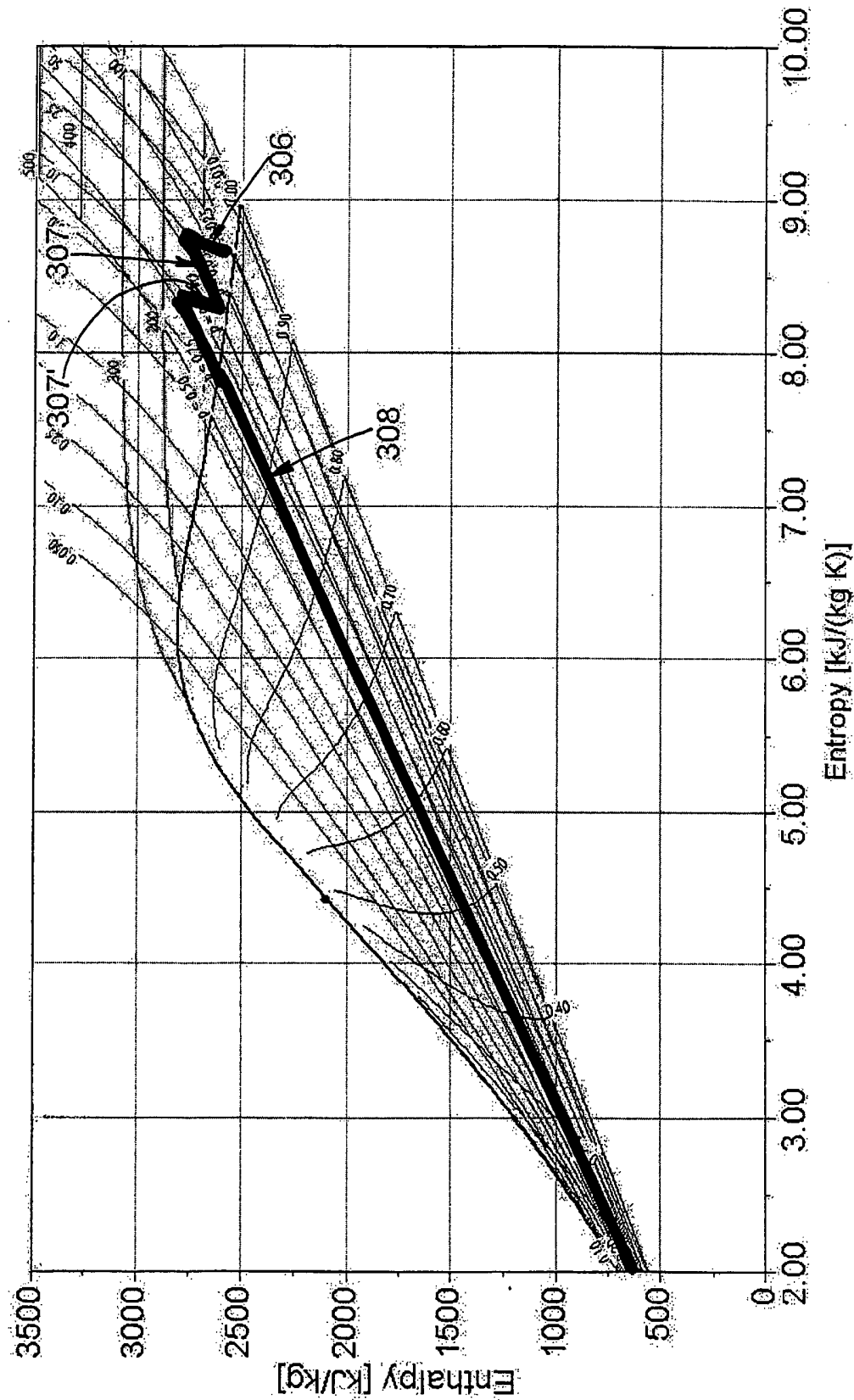


Fig. 3b

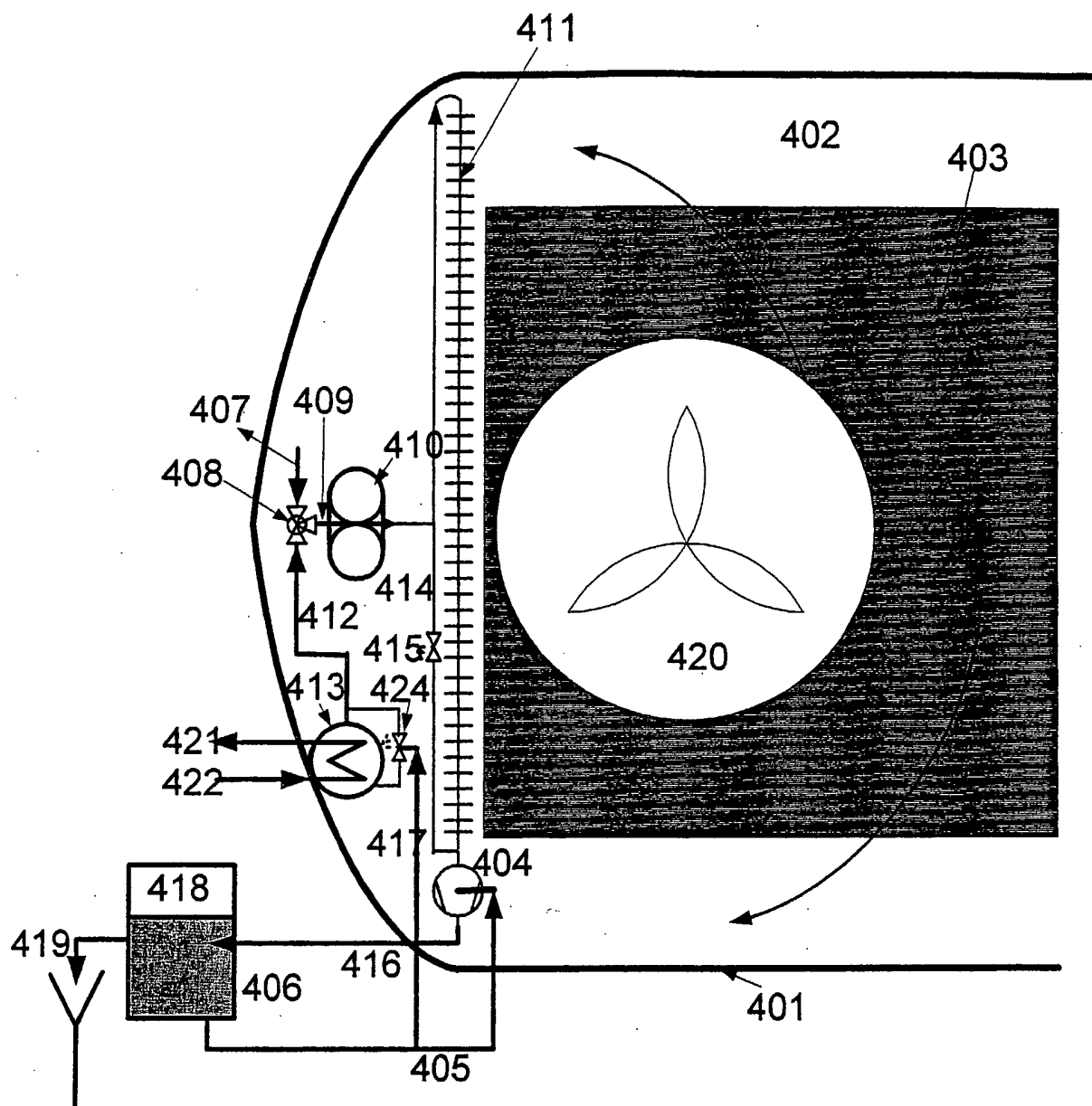


Fig. 4a

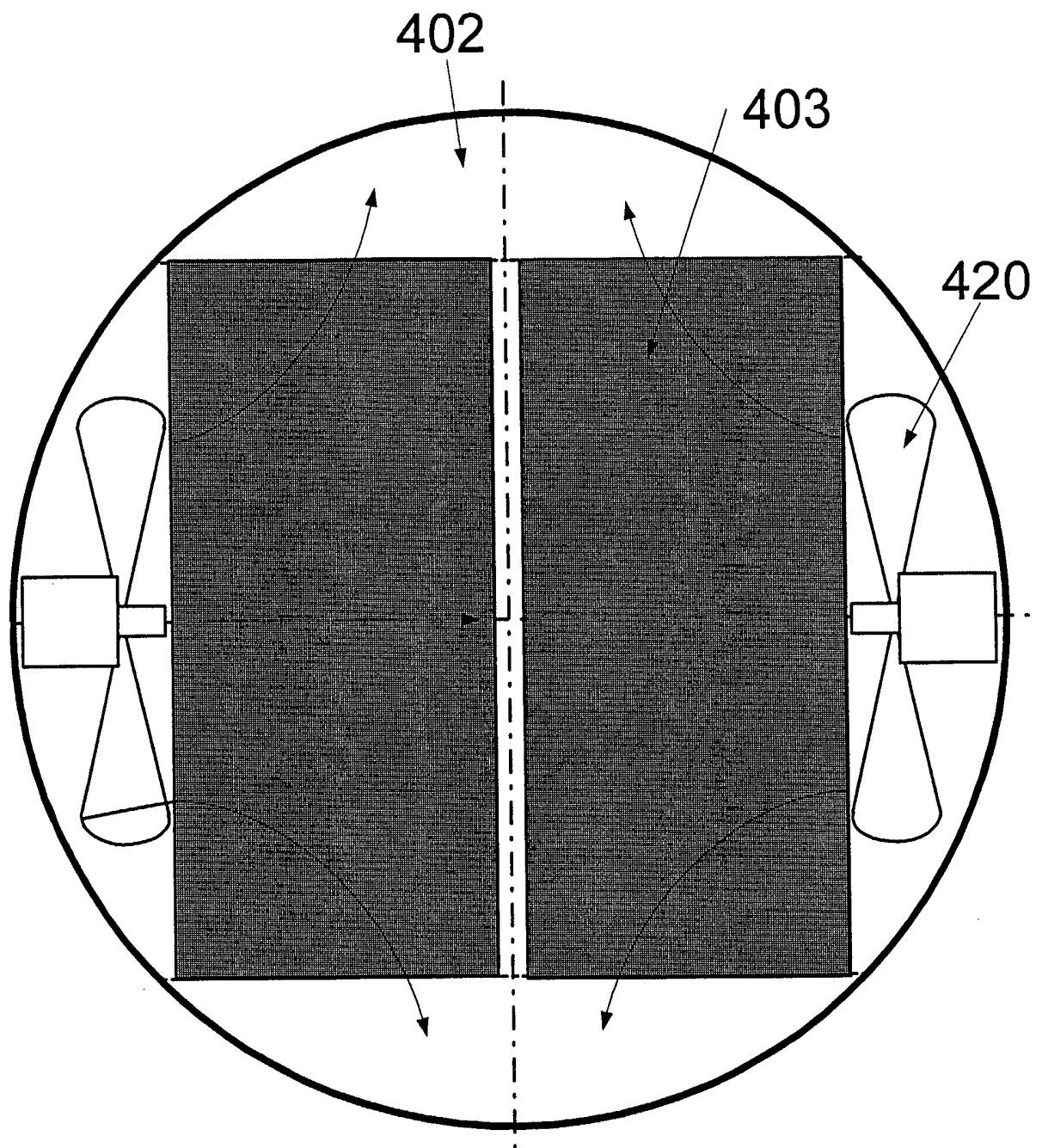


Fig. 4b

## INTERNATIONAL SEARCH REPORT

International application No.

PCT/DK 02/00522

## A. CLASSIFICATION OF SUBJECT MATTER

IPC7: F26B 5/04

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)

IPC7: F26B

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

SE,DK,FI,NO classes as above

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

WPI DATA, EPO-INTERNAL

## C. DOCUMENTS CONSIDERED TO BE RELEVANT

| Category* | Citation of document, with indication, where appropriate, of the relevant passages                                                   | Relevant to claim No. |
|-----------|--------------------------------------------------------------------------------------------------------------------------------------|-----------------------|
| Y         | SE 508070 C2 (RAUTARUUKII OY), 24 August 1998<br>(24.08.98), page 1, line 15 - line 21; page 5,<br>line 15 - line 18, abstract<br>-- | 1-6                   |
| Y         | US 3456356 A (LARS MALMQVIST), 22 July 1969<br>(22.07.69)<br>--                                                                      | 1-6                   |
| Y         | WO 9601401 A1 (HIGH SPEED TECH OY LTD.),<br>18 January 1996 (18.01.96)                                                               | 3-6                   |
| A         | page 4, line 20 - line 25                                                                                                            | 1-2,7-16              |
| Y         | --                                                                                                                                   | 17-18                 |

☒ Further documents are listed in the continuation of Box C.☒ See patent family annex.

\* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance: the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance: the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&amp;" document member of the same patent family

Date of the actual completion of the international search

8 November 2002

Date of mailing of the international search report

13 -11- 2002

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## INTERNATIONAL SEARCH REPORT

International application No.

PCT/DK 02/00522

## C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

| Category* | Citation of document, with indication, where appropriate, of the relevant passages            | Relevant to claim No. |
|-----------|-----------------------------------------------------------------------------------------------|-----------------------|
| Y         | US 3953927 A (HOFFERT), 4 May 1976 (04.05.76),<br>column 4, line 44 - line 48, figure 2       | 4,17-18               |
| A         | --                                                                                            | 11-13                 |
| A         | EP 0798525 A1 (KAJIMA CORPORATION), 1 October 1997<br>(01.10.97), column 7, line 47 - line 55 | 7-16                  |
|           | --<br>-----                                                                                   |                       |

# INTERNATIONAL SEARCH REPORT

International application No.  
**PCT/DK02/00522**

## **Box I** Observations where certain claims were found unsearchable (Continuation of item 1 of first sheet)

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:  
because they relate to subject matter not required to be searched by this Authority, namely:
  
2. ☐ Claims Nos.:  
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:
  
3. ☐ Claims Nos.:  
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

## **Box II** Observations where unity of invention is lacking (Continuation of item 2 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

**see next sheet**

1. ☐ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.
2. ☒ As all searchable claims could be searched without effort justifying an additional fee, this Authority did not invite payment of any additional fee.
3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:
  
4. ☐ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

### **Remark on Protest**

- ☐ The additional search fees were accompanied by the applicant's protest.  
☐ No protest accompanied the payment of additional search fees.

INTERNATIONAL SEARCH REPORT

International application No.  
PCT/DK02/00522

Invention I: Claims 1-6 relates to a method of vacuum drying material and the regulation of the method.

Invention II: Claims 7-16 relates to an apparatus for drying a material comprising at least two compression units.

Invention III: claims 17- 18 relates to an apparatus for drying a material comprising a supply unit for supplying additional energy.

**INTERNATIONAL SEARCH REPORT**  
Information on patent family members

30/09/02

International application No.  
PCT/DK 02/00522

| Patent document<br>cited in search report |         |    | Publication<br>date | Patent family<br>member(s) | Publication<br>date |
|-------------------------------------------|---------|----|---------------------|----------------------------|---------------------|
| SE                                        | 508070  | C2 | 24/08/98            | SE 9402549 A               | 22/01/96            |
| US                                        | 3456356 | A  | 22/07/69            | FI 47815 B                 | 30/11/73            |
|                                           |         |    |                     | FR 1544433 A               | 31/10/68            |
|                                           |         |    |                     | NO 123696 B                | 27/12/71            |
|                                           |         |    |                     | SE 319431 B                | 12/01/70            |
| WO                                        | 9601401 | A1 | 18/01/96            | AU 2794895 A               | 25/01/96            |
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|                                           |         |    |                     | JP 10502444 T              | 03/03/98            |
|                                           |         |    |                     | US 5819436 A               | 13/10/98            |
| US                                        | 3953927 | A  | 04/05/76            | AU 508946 B                | 17/04/80            |
|                                           |         |    |                     | AU 1231476 A               | 29/09/77            |
|                                           |         |    |                     | DE 2606231 A               | 14/10/76            |
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|                                           |         |    |                     | AU 7338596 A               | 22/05/97            |
|                                           |         |    |                     | JP 54031532 A              | 08/03/79            |
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|                                           |         |    |                     | JP 3147142 B               | 19/03/01            |
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|                                           |         |    |                     | JP 10103861 A              | 24/04/98            |
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|                                           |         |    |                     | JP 10103862 A              | 24/04/98            |