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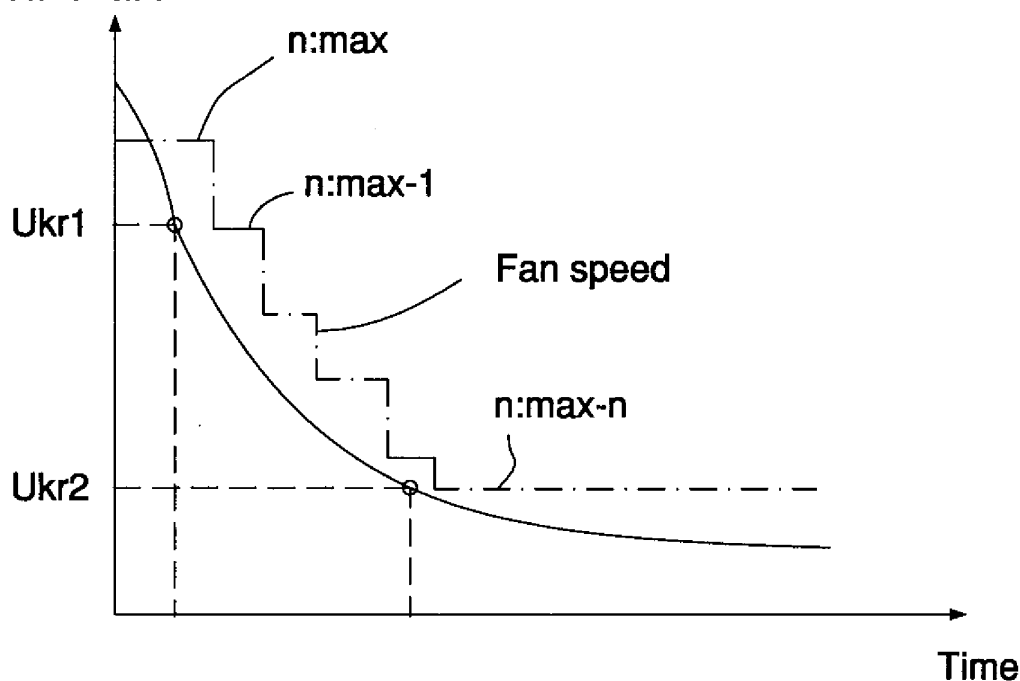
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(54) **A method for adapting the requirement of drying air in wood driers**

(57) The invention concerns a method for adapting the requirement for drying air in a wood dryer, whereby wood in the form of a package is placed into a drying chamber that is closed to the surrounding atmosphere and in which is maintained a water-containing atmosphere with a wet temperature, a dry temperature and the psychrometric difference that is associated with this by means of forced drying air that is caused to pass through

the wood. In order to optimise the consumption of electricity during the drying process, the air speed of the forced drying air is regulated depending on the current water content of the wood or by a recorded reduction in the release of water from the wood, whereby monitoring of the current water content or the appearance of a reduced release of water takes place by measurements that are carried out during the drying process.

Moisture ratio**EP 1 950 516 A2**

Description

[0001] The present invention concerns a method for adapting the requirement of drying air in a wood dryer according to the introduction of claim 1.

[0002] Air is used as heat-transfer and moisture-transport drying medium, which air is circulated through the wood package at a certain determined temperature, humidity and speed of flow with the aid of fans arranged in the drying chamber. The drying process is normally controlled by a pre-determined drying protocol that regulates the temperature, humidity and speed of flow during the process stages that follow each other during the drying process. The drying air is heated with the aid of an air-heating arrangement that includes a heat battery. The drying air is caused to pass through the wood package such that moisture and water in the wood evaporate from the surface and are absorbed by the air. The amount of drying air that is released into the chamber is regulated by the pre-determined drying protocol. The drying protocol is based on the climate in the dryer being continually measured and regulated on the basis of recorded values. In order for the air that circulates in the drying chamber, which air gradually becomes saturated with moisture, to be able to absorb more water from the wood, it must be dehumidified. This takes place through ventilation whereby the air is diluted with cold and relatively dry external air.

[0003] The speed of air flow is the speed that the air is given with the aid of the fans that are components of the air circulation arrangement. The speed of air flow is determined and set in known drying arrangements based on a number of previously determined parameters. These parameters include, among other properties, the technical specifications of the particular dryer arrangement, its actual behaviour, the design and geometry of the drying chamber, the promotion capacity of the fans, and the air resistance of the heat battery. The air that is to be used during the drying is also of interest, since cold air is more viscous than hot air, and requires for this reason greater work from the fans. The climate in the drying chamber, and in particular the relative humidity, is controlled and monitored by, among other actions, measuring the dry temperature and the wet temperature of the drying air. The fans often have relatively large dimensions, and are responsible for a significant part of the consumption of electricity by the drying arrangement.

[0004] In order for the wood to be dried, it is necessary that the water that is bound to and around the cells be transported out from the wood. The speed of this process depends on the temperature, the psychrometric difference, the moisture ratio of the wood, the properties of the wood, and the speed of air flow. The free water is dried relatively rapidly, as the water is evaporated from the surface of the wood, while it takes a longer time to remove the bound water.

[0005] The free water is stored in the cavities between the cells in the wood. Since the wood attempts to reach an even moisture ratio throughout the complete piece at

the same time as water is evaporating from its surface, transport of water will occur from the core to the surface. The transport of free water is controlled by capillary forces that "draw the water out towards the surface". The capillary forces are relatively strong and contribute to the drying process proceeding relatively rapidly as long as free water is available.

[0006] When any part of the wood reaches the fibre saturation point, continued drying takes place through diffusion within the said part, and the establishment of a humidity gradient through the wood, with equalisation of moisture and evaporation from the surface.

[0007] In order to dry the wood in as efficient a manner as possible without having a negative influence on its quality, insight is required into the factors that affect the drying time. This insight is then the basis on which the drying protocol is to be drawn up. A number of factors that affect the drying time arise from the properties and design of the wood and of the wood dryer, and these are different from one time to the next. The drying protocol determines then how the climate is to be inside the dryer throughout the complete drying period. The climate is described by the temperature, the psychrometric difference, relative humidity, and speed of air flow.

[0008] There are two temperatures that are particularly important, as mentioned above: the dry temperature and the wet temperature. The wet temperature is the temperature that a wet object achieves in the air stream. This temperature is always equal to or less than the dry temperature, depending on the content of moisture within the surrounding air stream. When water from the wet object (the wood) evaporates, heat energy is required, and the temperature falls. This continues until equilibrium is reached between the heat energy that is absorbed from the surroundings and the heat energy consumed for the evaporation of the water. The difference between the dry temperature and the wet temperature is known as the "psychrometric difference" and it is a measure of the relative humidity. The wood, which is a wet object at the start of the drying process, achieves the wet temperature. As the drying process continues, the wood achieves a temperature ever closer to the dry temperature. It can be seen that if a constant equilibrium moisture ratio is maintained throughout the drying process, then an increase in temperature increases also the speed of drying, up to an upper limit. The increase depends on the speed of diffusion increasing with increasing temperature. The upper limit is reached in that resin blocks the pathway of water through the wood.

[0009] The speed of drying increases with an increased psychrometric difference. This is a result of a large psychrometric difference being equivalent to a low relative air humidity. It is then easier for the air to absorb water vapour, and the drying process becomes more efficient. An increased psychrometric difference, however, at low temperatures does not give as great an increase as it does at high temperatures.

[0010] In order for it to be possible for water in the wood

to evaporate efficiently, it is required that heat energy continually be supplied from the surroundings. The speed of air flow can be increased in order to increase the supply of heat to the wood. This also contributes to a more efficient removal of the water vapour that is released from the wood. Thus, an increase in speed of air flow contributes to an increase in the speed of drying. The increase in the speed of drying, however, decreases with increased speed of air flow, up to an upper limit. The speed of drying is affected only slightly after this limit. The fans that create the air flow consume eight times more power for a doubling of the speed of air flow, and this means that it is not economically rewarding to have a speed of air flow that is too high. It is known from experience that a minimum in the cost of electrical energy relative to quality and time of drying of the wood is achieved at speeds of around 2-5 m/s. An increase in the speed of air flow decreases the time required for drying as long as the wood has a humidity ratio that is greater than the fibre saturation point. At lower humidity ratios, the air, given the same speed of flow, can transport more water vapour than the amount that is available at the surface of the wood, and the drying time in this case will depend more on the climate.

[0011] One problem with all protocol-controlled drying is that no consideration is given during the drying process to the fact that the moisture-releasing properties of the wood are not ideal, nor are they fully predictable. The drying protocol does not consider, for example, that the evaporation changes during the drying process. This change takes place principally during that phase of the drying during which the wood reaches fibre saturation point, the evaporation of freely bound water stops and the drying process becomes that in which the wood starts to release the firmly bound water. Another description of this is that the wood releases the water that is bound within the fibres of the wood. A further problem in this context is that there is no clear boundary at the transition between the said phases since the transition takes place gradually. An erroneous control during, in particular, the region that is time-consuming during the drying between the critical moisture ratios in the wood at which the combined transport of free and bound water takes place, means that the energy consumption of the drying arrangement is not optimal: the plant has a greater energy consumption than necessary. Erroneous control entails also problems with the quality of the dried wood.

[0012] The aim of the present invention, therefore, is to achieve a method for adapting the requirement of drying air in wood dryers that makes it possible to improve the efficiency of the energy use and in this way reduce it.

[0013] This aim is achieved with a method that demonstrates the technical qualities and characteristics specified in claim 1.

[0014] The insight that forms the basis of the invention is that large savings in energy can be achieved if the speed of the fans, and thus the flow of drying air through the wood package, is large solely on those occasions

during the drying process at which the physical ability of the wood to release water is particularly large. This means in practice that the speed of flow of the drying air needs to be large, or maximally exploited, only as long as the wood contains much water, or is located above the fibre saturation point. The energy consumption of the drying process can be made more efficient by determining the water content of the wood, or its instantaneous release of water, in real time and using this information in feedback in order to adapt and adjust the control systems of the dryer. A number of technologies for measuring the moisture ratio and the water content of wood are already known and will not be described in detail. The moisture ratio is normally measured directly in the wood by means of a resistance meter and with the aid of sensors placed into the wood. Also the fibre saturation point of the wood, i.e. the point during the drying process at which the wood ceases to release by evaporation freely bound water and passes over to releasing fixed bound water, can be measured as a stage in this process. Once this point has been passed, the speed of the circulating air in the drying chamber can be significantly reduced, and thus also the electricity consumption.

[0015] The invention will be described in more detail below with reference to the attached drawing that shows a graph of the development of the moisture ratio as a function of drying time in a drying chamber during the maintenance of a constant climate. A graph is shown also in the drawing of the requirement for air speed as a function of the moisture ratio where the rate of revolution of the fans, which depends on the current moisture ratio, is denoted by "n".

[0016] When carrying out a method according to the invention a conventional drying arrangement for drying wood of the type defined below is used. The drying arrangement comprises a drying chamber that is closed against the surrounding atmosphere. The drying arrangement has an air-circulatory arrangement comprising a fan arranged in the chamber for the circulation of the drying air in the chamber. The fan is driven by electric motors whose rate of revolution can be controlled, for example, alternating current motors whose rate of revolution is controlled by frequency control, with the aid of static frequency changers. Such a motor makes it possible to adapt continually over time the rate of revolution of the fan and thus its power. The drying arrangement comprises also an air-heating arrangement, comprising a heating battery, for heating the circulating drying air. The heating battery is heated with the aid of, for example, hot water.

[0017] In order for it to be possible to evaporate the water in the wood efficiently, it is required that heat energy is continuously supplied to the wood from its surroundings, from the hot air. In order to achieve an increased supply of heat to the wood, it is normal that the speed of the air is increased, such that more hot air per unit of time passes the wood, which, of course, contributes to also a more efficient removal of water, water vapour, from the

wood. The drying arrangement comprises a steam pre-treatment arrangement for the supply of water to the drying air such that the drying is not to take place in an environment that is too dry, which can result in a drying process that is far too rapid and that causes damage. There is present also a ventilation system that makes it possible to ventilate out the air that has passed the wood and that is more or less saturated with moisture. Sensor arrangements and recording arrangements that sense and record various measurable properties are present in the drying chamber. One important sensor arrangement is a psychrometer comprising a set of thermometers mounted on each side of the batch of wood in order to measure the dry temperature and the wet temperature. The difference between these two values is known as the "psychrometric difference" and is used as a measure of the relative air humidity in the drying chamber, which is an important parameter for the process of controlling the drying. The psychrometric difference, the temperature fall, and thus the moisture ratio must not be too great, since this is a sign that much heat energy has been used during the drying, which may suggest that the drying process in this manner risks becoming too rapid, resulting in damage to the wood.

[0018] A method according to the invention is started with the wood that is to be dried being brought into or through the drying chamber. The wood has been stacked in layers with crosspieces laid between the layers of wood such that the wood forms what is known as a "wood package" with air gaps between the layers of wood. Drying air is circulated through and around the wood package by means of the air-circulatory arrangement. Various process parameters in the drying chamber are controlled and regulated with the aid of a control and regulation arrangement that comprises a computer or a PLC, and signals are generated for the air-circulatory arrangement, the fan motors, depending on the psychrometric difference, and thus the air humidity in the chamber, that has been measured.

[0019] The drawing shows a graph of the development of moisture ratio in the wood as a function of process time in a drying chamber. The drying process is controlled by a pre-determined drying protocol that is divided into a number of drying phases that follow after each other, during which the wood demonstrates different properties that must be considered in order to achieve a satisfactory drying result. The climate in the drying chamber follows a drying protocol that is drawn up in advance or that is created in real time, this drying protocol being adapted to at least one of specific or current conditions, including the quality of the dried wood that it is desired to achieve, and the type and dimensions of the wood. The possibilities to control the speed of air and thus its flow through the chamber varies as a result of the different operating conditions during the said drying phases.

[0020] Once the heating phase, i.e. the phase under which no drying takes place, and in which the initially relatively cold wood is only warmed such that it obtains

a homogenous temperature, has been carried out, the first drying phase begins. It is normal to consider the heating phase to be complete when the wet temperature, i.e. in principle the temperature of the wood, has reached the final temperature, for example 58°C, at which it is intended, according to the control protocol, that the drying process is to start. The fans of the air-circulatory arrangement are controlled during the heating phase normally approaching their maximal speed.

[0021] Not only is the selected drying climate and its specified psychrometric difference directly critical for the speed of drying during the said first drying phase above the temperature of the wood, but also the effect of the speed of the air, while the water that is removed during this phase can be said in principle to be directly proportional to the speed of the air. The air-circulatory arrangement is normally controlled during the said first drying phase approaching its maximal speed n_{max} , and the requirement for ventilation is very great. The ventilation baffle of the drying arrangement thus is normally located in an essentially fully open position for this reason. Free water is caused to evaporate from the heated wood during the first drying phase. The moisture ratio of the circulating drying air is reduced by ventilation and by the mixing in of dry atmospheric air with the drying air in order to achieve this. The amount of dry air that is admitted to the chamber through the baffle of the ventilation arrangement is regulated indirectly by the drying protocol. While water can evaporate solely from the surface of the wood it is important that the surface is maintained moist such that the movement of water from the core outwards is not interrupted. It is thus important during this second phase that the psychrometric difference (the difference between the wet temperature and the dry temperature) is maintained at a low value, and that the climate defined in the drying protocol is followed. The speed of the air and thus the flow of air through the wood package are for this reason controlled towards, or at a level that lies only somewhat under, the maximum speed n_{max} .

[0022] During an actual drying process, the various transport processes of moisture for the evaporation of free water and the evaporation of bound water take place to a certain extent at the same time, which results in the drying process taking place rapidly at the beginning and becoming slower as time passes. This behaviour in principle is illustrated in the drawing that shows the behaviour of the drying speed and where the various principles of moisture transport are active, depending on the current moisture ratio of the wood or on its water content. As is made clear by the drawing, only transport of free water takes place up to a certain critical moisture ratio U_{kr1} , while combined transport of both free water and bound water takes place between the two critical moisture ratios U_{kr1} and U_{kr2} . Only bound water is transported out from the wood after U_{kr2} . The steeply downwards gradient of the curve above the critical moisture ratio U_{kr1} makes it clear that the drying process is very rapid at the start, during the phase in which only free water evaporates.

[0023] The drying time increases significantly during the time period that lies between the two critical moisture ratios U_{kr1} and U_{kr2} , as is illustrated by the graph shown in the drawing. The drying process during this period of combined transport of both free and bound water is not so sensitive to variations in the air speed, which means that the air speed can subsequently be reduced. According to the invention, the release of water is measured and recorded repeatedly during the drying process and the air speed is hereby reduced from $n:\max$ to $n:\max-1$ and further reduced to $n:\max-n$ when the first critical moisture ratio U_{kr1} is reached and further reduced to the critical point U_{kr2} and $n:\max-n$, depending on the relationship between free and firmly bound water in the wood. It is appropriate that control of the speed of the fans takes place at each repeated recorded reduction in the release of water during a certain time period. The time point at which the critical moisture ratio U_{kr1} and downwards, and control of the air speed, are to be commenced is difficult to determine exactly, but it is determined according to the invention in a number of different ways that all have in common the fact that they provide an indication that the freely bound water of the wood is starting to come to an end, or is at least significantly reduced, relative to the original amount of firmly bound water.

[0024] According to the invention the entrance to the said transition area or drying zone between the two critical drying ratios U_{kr1} and U_{kr2} is determined firstly by measurement of the fall in temperature ΔT through the package of wood. Since the fall in temperature is severely reduced at the transition from evaporation of free water to that of firmly bound water, or the combination of both free water and firmly bound water in the region between U_{kr1} and U_{kr2} , the air speed at this position can be reduced, as is illustrated with the graph that has the form of a step in the drawing, depending on the recorded relative fall in temperature ΔT .

[0025] The second way in which the entry to the said transition area between U_{kr1} and U_{kr2} can be determined is by measurement of the ventilation requirement. Since a significantly reduced ventilation requirement $\Delta \Theta$ means that the ventilation baffles will be positioned in an essentially closed position, it should be realised that a transition from evaporation of free water to that of firmly bound water in the wood, or to a combination of free water and firmly bound water such as takes place in the region between U_{kr1} and U_{kr2} , can be simply indicated by monitoring major changes in the ventilation requirement. In this condition, the air speed is reduced, as is shown in the drawing, depending of the reduction in ventilation requirement $\Delta \Theta$.

[0026] The third way in which the entry to the said transition area between U_{kr1} and U_{kr2} can be determined is by recording a reducing requirement for heating power ΔP . Since a significantly reduced requirement for heating power ΔP or a rapidly increasing temperature in the drying chamber indicates a lower release of water and thus a transition from evaporation of free water to that of firmly

bound water in the wood, or to a combination of free water and firmly bound water such as takes place in the region between U_{kr1} and U_{kr2} in the wood, the air speed can be reduced, as is shown in the drawing, depending on the reduction in requirement for heating power ΔP across the heating battery.

[0027] The fourth way in which the entry to the said transition area between U_{kr1} and U_{kr2} can be determined is by measuring the fall in temperature ΔT_B across the battery of the air-heating arrangement. Since a significantly reduced fall in temperature ΔT_B across the heating battery indicates a transition from evaporation of free water to that of firmly bound water in the wood, or to a combination of free water and firmly bound water such as takes place in the region between U_{kr1} and U_{kr2} in the wood, the air speed can be reduced, as is shown in the drawing, depending of the reduction in the fall in temperature ΔT_B across the heating battery.

[0028] The fifth way in which the entry to the said transition area between U_{kr1} and U_{kr2} can be determined is by an immediate measurement of the moisture ratio of the wood, measured in percent. Since an essentially constant, or only slowly falling, moisture ratio of the wood indicates a transition from the evaporation of free water to that of firmly bound water in the wood, the air speed can be reduced, as is shown in the drawing, depending on the essentially constant moisture ratio. The start of the entry to the transitional area between U_{kr1} and U_{kr2} is determined, for example, by measuring the moisture ratio of individual pieces of wood by means of the capacitance method or with the aid of other known methods, for example, by weighing and determining the current weight percentage of the current batch of wood relative to its dry weight. Since an essentially constant, or only slowly falling, moisture ratio indicates a transition from the evaporation of free water to that of firmly bound water in the wood, the air speed can be reduced, as is shown in the drawing, depending on the essentially constant moisture ratio.

[0029] During the second drying phase, which takes place after the transitional region between U_{kr1} and U_{kr2} , only firmly bound water, i.e. water that is bound inside of the fibres of the wood, is released. The psychrometric difference is increased in order to achieve this, such that the bound water is caused to migrate towards the surface of the wood, from where it is removed by evaporation. The volume of water that is transported away per unit of time during this drying phase is significantly lower than it was in the preceding drying phase, as is shown by the low gradient of the lower part of the curve in the drawing. This means also that a significantly lower air speed, denoted in the drawing by " $n:\max-n$ " can be permitted than was permitted during the first drying phase, and thus that the consumption of energy can be further reduced.

[0030] This low air speed, or possibly one that is slightly lower, is maintained also in the following drying phases, generally known as the "equilibration phase", the "conditioning phase", and the "cooling phase".

[0031] It can be noted that it is appropriate that moisture and heat are transmitted to the wood during the conditioning phase solely through raising the temperature in the chamber by means of the heating battery, rather than by increasing the supply of heat to the drying air by means of the arrangement for heating the drying air.

[0032] This description of the invention is not to be seen as a limitation of the innovative concept: it is to be seen as an aid in understanding the innovative concept. The invention is not limited to what has been described above and what has been revealed in the single drawing: it can be changed and modified in a number of different ways within the scope of the innovative concept in which the reduction in speed of the fans, naturally, does not need to follow a graph that has the appearance of a step: the reduction can just as well follow a linear graph or a graph having a suitable form.

Claims

1. A method for adapting the requirement for drying air in a wood dryer, whereby wood in the form of a package is placed into a drying chamber that is closed to the surrounding atmosphere and in which a water-containing atmosphere with a wet temperature, a dry temperature and the psychrometric difference that is associated with this is maintained by means of drying air that is caused to pass through the wood, **characterised in that** during the drying process the water content of the wood is measured, alternatively the release of water from the wood is measured wherein the speed of the forced drying air is regulated downwards by a recorded reduction in the current water content of the wood or by a recorded reduction of the release of water of the wood.
2. The method according to claim 1, whereby the water content of the wood or the release of water of the wood is measured instantaneously and that recorded measured values received there from are recorded in a control system that is part of the wood dryer.
3. The method according to claim 2, whereby the recorded measured values are used for a feedback-controlled adjustment and adaptation of the control system of the wood dryer.
4. The method according to claim 1, whereby the release of water of the wood is measured repeatedly and the air speed is reduced stepwise downwards by recording a reduction of the release of water of the wood.
5. The method according to claim 1, whereby the reduction of the release of water of the wood is measured by recording a reduction of the relative fall in temperature ΔT through the package of wood.
6. The method according to claim 1, whereby the reduced release of water is measured by recording a reducing requirement for ventilation $\Delta \Theta$ in the drying chamber.
7. The method according to claim 1, whereby the reduced release of water is measured by recording a reducing requirement of heating power ΔP to maintain a pre-determined temperature within the drying chamber.
8. The method according to claim 1, whereby the reduced release of water is measured by recording a significantly reducing fall in temperature ΔT_B across a heating battery that is a component of the drying arrangement.
9. The method according to claim 1, whereby the reduced release of water is measured by recording an essentially constant or only slowly falling moisture ratio of the wood.
10. The method according to claim 1, whereby the reduced release of water is measured by recording an essentially constant or only somewhat reducing weight of the wood.

