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(54) **METHOD AND ARRANGEMENT FOR CONTROLLING ENERGY CONSUMPTION IN A MANUFACTURING PROCESS OF A FIBROUS WEB**

(57) The present invention relates to a method and arrangement for controlling energy consumption in a manufacturing process of a fibrous web, such as paper, board, tissue web or the like. Heated steam is consumed by heating of drying devices, which form at least one drying group inside a drying hood for removal of moisture from the fibrous web, and blowing devices remove humid exhaust air from the drying hood and feed dry heated replacement air into the drying hood. Heated steam is further consumed by heating of replacement air, gaseous process flow(s) and/or liquid process flow(s) to predetermined temperature ranges. The method comprises steps of: maintaining inside the drying hood an air humidity below a predetermined maximum humidity value; determining a total consumption of heated steam consumed by the drying devices and by heating of replacement air and/or the said process flow(s), and adjusting the removal of the humid exhaust air from the drying hood on a level where the total consumption of heated steam is minimised.

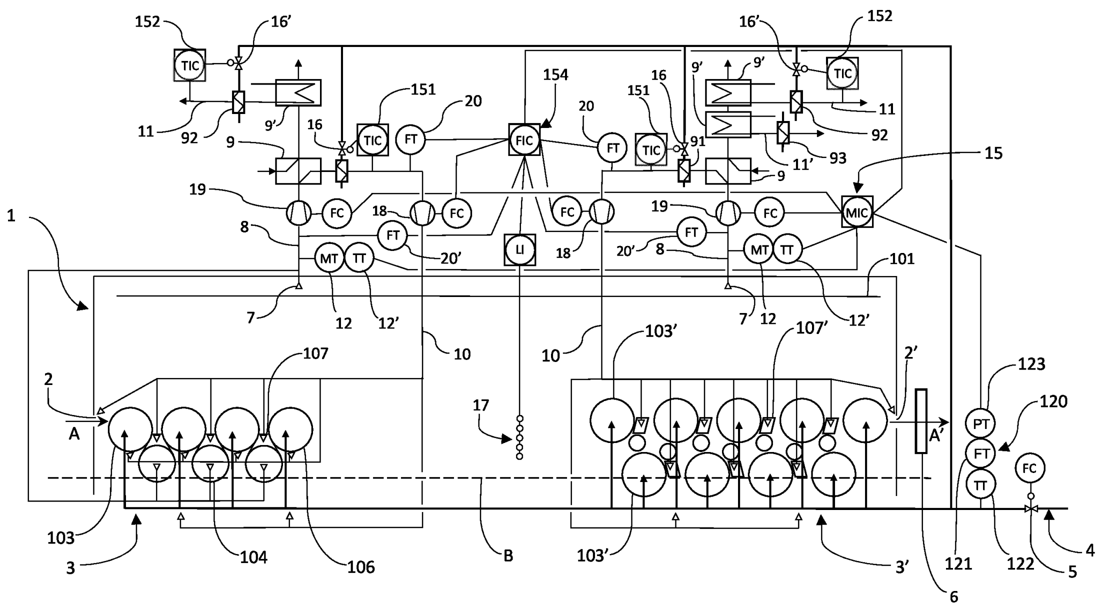

Figure 1

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Description

[0001] The present invention relates to a method and arrangement for controlling energy consumption in a manufacturing process of a fibrous web according to the preambles of enclosed independent claims.

[0002] Fibrous webs, such as paper and board webs, are dried after their formation in a drying section, which comprises usually a plurality of drying devices. For example, the drying section may comprise a plurality of heated drying cylinders, wherein the fibrous web is brought into a contact with heated surfaces of drying cylinders, and the heat energy is transferred from the cylinder surface to the fibrous web, while the moisture in the web is evaporated and the web is dried. The drying cylinders may be heated with pressurized heated steam, which is introduced inside the cylinders for heating their outer surface. Conventionally the drying cylinders are arranged in the drying section into drying groups, each drying group comprising a plurality of drying cylinders.

[0003] The drying groups are arranged inside a drying hood. Heat transfer from the drying devices and the evaporation of the web moisture create humid and warm atmosphere inside the drying hood. The drying hood prevents the escape of the humid and warm air and its mixing with the machine room air. However, warm humid air must be removed from the drying hood in order to keep the humidity of the hood atmosphere below the condensation point. If humidity would be condensed on the inner structures of the hood, it could result in formation of water drops that could fall on the web and cause web faults. In order to prevent this humid air is removed as exhaust air from the false ceiling of the hood, usually from a plurality of locations.

[0004] It is necessary to feed replacement air into the hood for avoiding formation of underpressure inside the hood. Replacement air is usually heated to a temperature, which is close to the temperature prevailing inside the hood. In this way it is possible to keep the conditions in the hood as constant as possible.

[0005] Replacement air is fed through ventilators and/or runnability components, which are arranged in connection with the drying groups. Dry replacement air is typically fed near to the web in order to enhance the drying and removal of moisture from the web.

[0006] The exhaust and replacement air are transferred from and into the hood by using blowing devices or the like which consume electric energy.

[0007] Conventionally the humidity content of the exhaust air, as well as of the drying hood atmosphere, has been kept as high as possible, but naturally below the condensation point. Typically, the humidity of the exhaust air is measured, and the flow of exhaust air is adjusted on the basis of the measurement result. Simultaneously, the flow of replacement air is adjusted to a volume where the zero pressure level of the hood is maintained approximately on the height of the web entry and exit openings of the drying hood, thus minimizing the risk of air entering or exiting the hood through these web entry and exit openings. Regulating circuits are used to control the flow ratio of the exhaust and replacement air, thus ensuring proper zero pressure level in the hood. A prior art arrangement is disclosed in FI 71372. However, it has been observed that maximisation of the humidity content of exhaust air does not necessarily provide optimal energy consumption in the process.

[0008] In a process of making fibrous webs, such as paper, board or the like, heated steam is not only used to heat the drying cylinders inside the drying hood. Heated steam may also be used to heat the replacement air to the correct temperature before it is fed inside the hood. Furthermore, heated steam may be used to heat various circulating liquid and/or gaseous flows, such as process waters, machine room air, etc.

[0009] Furthermore, drying section and other papermaking processes associated with it consume great amount of energy, mainly in form of thermal energy, typically in form of heated steam, but also in form of electric energy. This makes the control of energy consumption an important factor in paper or board making process. There is a constant need for new methods and arrangements that may improve the energy control, provide possibilities to intelligently use, optimise and/or combine the different energy forms available and possibly even reduce the total energy consumption.

[0010] An object of this invention is to minimise or possibly even eliminate the disadvantages existing in the prior art.

[0011] Another object of the present invention is to provide a cost-effective and functional alternative for controlling consumption of heated steam in a manufacturing process of a fibrous web.

[0012] A yet another object of the present invention is to provide a method and arrangement for versatile optimization of energy consumption in a drying section of a paper or board making machine.

[0013] These objects are attained with the invention having the characteristics presented below in the characterising parts of the independent claims.

[0014] Some preferred embodiments of the invention are presented in the dependent claims. The embodiments and advantages mentioned in this text relate, when applicable, to the method and the arrangement according to the invention, even though they are not always specifically mentioned.

[0015] A typical method according to the present invention for controlling energy consumption in a manufacturing process of a fibrous web, such as paper, board, tissue web or the like, where heated steam is consumed by heating of drying devices, which form at least one drying group, preferably several drying groups, inside a drying hood for removal of moisture from the fibrous web, and where blowing devices remove humid exhaust air from the drying hood and feed dry heated replacement air into the drying hood, and where heated steam is further consumed by heating of replacement air, gaseous

process flow(s) and/or liquid process flow(s) to predetermined temperature ranges,
wherein the method comprises further steps of:

- maintaining inside the drying hood an air humidity below a predetermined maximum humidity value,
- determining a total consumption of heated steam consumed by the drying devices and by heating of replacement air and/or the said process flow(s), and
- adjusting the removal of humid exhaust air from the drying hood on a level where the total consumption of heated steam is minimised.

[0016] Typical arrangement according to the present invention for controlling energy consumption in a manufacturing process of a fibrous web, such as paper, board, tissue web or the like, where a drying section comprises

- drying devices, which form at least one drying group, preferably several drying groups, and which are arranged inside a drying hood,
- at least a first blowing device for removal of humid exhaust air from the drying hood and at least a second blowing device for feeding of dry heated replacement air into the drying hood,
- a first heat exchanger for heating replacement air by the exhaust air,
- at least one additional heating cell for heating replacement air, gaseous process flow and/or liquid process flow by heated steam,

wherein the arrangement comprises

- exhaust air regulating circuit, which comprises means for measuring humidity of the exhaust air and means for adjusting exhaust air flow,
- a temperature regulating circuit, which comprises means for measuring and adjusting the temperature of the replacement air,
- replacement air regulating circuit, which comprises means for adjusting replacement air flow,
- a sensor array, which comprises at least one steam flow sensor, arranged to measure the amount of heated steam consumed by the drying devices and by the additional heating cell(s),
- a main control unit which is arranged in a functional contact with the exhaust air regulating circuit, the replacement air regulating circuit, and the sensor array, and which main control unit comprises means for calculating the total consumption of heated steam, and means for determining the exhaust air removal on a level where the total consumption of heated steam is minimised.

[0017] Now it has been surprisingly found out that a more versatile and intelligent control of the energy consumption in the papermaking process, especially in the drying section, can be achieved when the removal of the humid exhaust air from the drying hood is adjusted on a level where the total consumption of heated steam is minimised. The total consumption of the heated steam by various subprocess in the drying section and its vicinity, such as heating of drying cylinders, replacement air and various process flows, are intricately interlinked. It has been unexpectedly realised that exhaust air removal can be used as an effective and simple parameter for minimising the heated steam consumption.

[0018] The total amount of heated steam or heated steam energy, which is consumed by the drying devices and the heating of replacement air and/or the gaseous process flow(s) and/or liquid process flow(s) is determined in the method by using a sensor array, comprising at least one steam flow sensor or a plurality of steam flow sensors. The sensor array is arranged to measure the steam consumed by the drying devices and the additional heating cell(s). The steam flow sensor may be arranged to the main steam feed of the process, or the sensor array may comprise plurality of steam flow sensors, which are arranged to sub steam flows of the process, e.g. steam flows going to drying section, i.e. to all drying groups, or individual drying groups, as well as additional heating cells. In the latter case the total amount of consumed heated steam is obtained by addition of the measured individual sub steam flow values. In general, heated steam is mainly consumed by the drying cylinders and secondarily by the heating of the replacement air and/or other process flows in the additional heating cells.

[0019] In addition, the sensor array may further comprise at least one temperature sensor and/or at least one pressure sensor. According to one preferable embodiment the total consumption of heated steam may be determined by measuring the steam pressure and/or steam flow from a main steam feed into the process. The sensor array may comprise a plurality of temperature sensors and/or pressure sensors which are arranged to substeam flows of the process, e.g. steam flows going to individual drying groups and/or additional heating cells.

[0020] Inside the drying hood the humidity of the hood atmosphere is maintained below a maximum humidity value by using blowing devices for removing humid exhaust air from the drying hood and feeding dry heated replacement air into the drying hood. The predetermined maximum humidity value is controlled by the temperature of the hood atmosphere, which determines the condensation level which should not be exceed. In a preferable embodiment, the hood atmosphere is maintained within a predetermined humidity range, which defines a minimum humidity as well as the maximum humidity. In this manner the stability of the process may be ensured. At least one mathematical function for calculation of the predetermined maximum humidity value or humidity range as function of hood atmosphere temperature may be stored in the memory unit of the main control unit. When the temperature of the hood atmosphere changes the amount of humidity that can be contained in the hood atmosphere without condensation changes. The temperature of the hood atmosphere is mainly dependent of the heat from drying devices, but it is also indirectly influenced by the amount of exhaust air, which is removed from the hood by using at least one first blowing device, for example through one or more output connections in the ceiling of the hood.

[0021] Inside the drying hood the humidity of the hood atmosphere may typically be maintained below a maximum humidity value of 220 g/kg dry air, preferably below 190 g/kg dry air, more preferably below 180 g/kg dry air. The predetermined humidity range may be 80 - 220 g/kg dry air, preferably 110 - 190 g/kg dry air, more preferably 120 - 180 g/kg dry air, sometimes 140 - 160 g/kg dry air.

[0022] The present invention may further provide a versatile and intelligent control of total energy consumption in the papermaking process, especially in the drying section. According to one preferable embodiment the method may comprises further steps of:

- determining a total consumption of electric energy which is needed to operate the said blowing devices for removal of exhaust air and for feeding of replacement air,
- using the determined total consumption of heated steam and total consumption of electric energy to calculate a total energy value by using impact factors determined for heated steam and electric energy, and
- adjusting the exhaust air removal on a level where the total energy value is minimised.

[0023] It has been found out that the total energy value can be minimised by providing each of the used energy forms with an impact factor. The impact factors are used together with the actual consumed energy amounts to calculate a total energy value, and the exhaust air removal is adjusted to minimize the total energy value. In this manner it is possible to take into account a plurality of different aspects associated with the different energy forms, and to steer the energy consumption towards a desired outcome. In general, the present invention is suitable for controlling energy consumption in a manufacturing process of a fibrous web, such as paper, board, tissue web or the like, especially for controlling energy consumption in the drying section, where both heated steam and electric energy are consumed. In this embodiment the main control unit comprises means for calculating the total energy value by using impact factors determined for heated steam and electric energy, wherein the exhaust air removal is adjusted on a level where the total energy value is minimised.

[0024] In the present context the term "energy value" denotes a quantity, which is obtained for each used energy form by multiplying the consumed energy amount with the impact factor associated with the said energy form. The total energy value is obtained by adding together the separately calculated energy values for each energy form.

[0025] When minimising the total energy value, the total electric energy, which is needed to operate the blowing devices is also determined. In case the process comprises a plurality of drying groups comprising a plurality of steam heated drying devices, the total consumption of heated steam by all the drying groups is determined, and the total consumption of electric energy which is needed to operate the blowing devices associated with all the drying groups may preferably be determined. The arrangement thus further comprises means for determining the electric energy consumed by the blowing devices, and these means are arranged in functional contact with the main control unit. The arrangement comprises any means suitable for determining the electric energy consumed by the blowing devices. According to one preferable embodiment the electric energy consumption is determined by a direct measurement. In this manner accurate consumption values are obtained, when the consumption values are not based on calculated values, e. g. on basis of flow volumes. For example, the means for determining the electric energy comprise frequency converters or tachometers of the blowing devices or any suitable measurement means known as such.

[0026] The determined total amounts for heated steam energy and electric energy may be used to calculate the total energy value by using impact factors determined for heated steam energy and electric energy. After calculation of the total energy value, the exhaust air removal is adjusted on a level where the total energy value is minimized. The arrangement comprises a main control unit which is arranged in functional contact with an exhaust air regulating circuit and a replacement air regulating circuit. Furthermore, the main control unit is arranged to receive and process information from the sensor array and from the means determining the electric energy consumed by the blowing devices. The main control unit is further arranged to calculate the total energy value.

[0027] The impact factor for each energy form, such as heated steam or electric energy, may be experimentally or theoretically determined, for example, on basis of availability of the said energy form, as well as various economic factors, CO_2 emissions, ecological factors and/or any combinations thereof. If an energy form, e.g. heated steam, has a low impact factor it indicates the preferability of the said energy form, whereas a high impact factor indicates negative aspects associated with the energy form in question, such as limited availability or pollution risks. The impact factor may take into account one or more different aspects associated with the said energy form. For example, when the energy form has good availability but is associated with negative ecological aspects, such as pollution risks or CO_2 emissions, it may have a higher impact factor than the energy form which has more limited availability, but which is more environmentally acceptable. The use of impact factors in optimization of the energy consumption makes it possible to consider a vast range of variables in the manufacturing process of paper or board.

[0028] The impact factor may be determined experimentally, or the impact factor may be based on earlier experiences obtained from the manufacturing process. Alternatively, the impact factor may be theoretically determined, for example by using mathematical models for calculating CO_2 footprints or other corresponding mathematical process models and/or estimations. According to one embodiment the impact factor for each energy form is based on the availability of the said energy form. The simplest way to determine the impact factor, which is based on the availability of the energy form, is to correlate the impact factor at least partly with the unit costs associated with the said energy form. Usually when the availability of the energy form is good the unit costs are low, and when the availability of the energy form is limited the unit costs increase.

[0029] The impact factor(s) may be reassessed or determined continuously or at predetermined time intervals. For example, if the availability of the energy form fluctuates or changes as a function of time, a new impact factor may be determined at predetermined intervals, e.g. once an hour, twice a day or the like. For example, the impact factor for night-time may be lower than for the daytime, if the availability of the specific energy form, e.g. electric energy, is better during the night-time when the general consumption decreases. The regular or continuous determining or reassessment of the impact factors makes it possible to intelligently optimize the energy consumption in the paper or board manufacturing process by taking into account changing external conditions.

[0030] In case the impact factor(s) is/are determined or reassessed continuously the determined values may be filtered with a filtering unit, which is arranged to filter the impact factor values before the impact factor is used for calculating the energy values. The filtering unit may comprise averaging means for calculating an average impact factor within a certain time frame, which average impact factor is then used for calculating the energy value. The filtering unit may also use other different filtering techniques, which are as such known for a person skilled in the art.

[0031] According to one embodiment of the invention the main control unit of the arrangement may comprise memory means for storing impact factor values and/or means for calculating the impact factor values.

[0032] According to one embodiment the method may comprise a minimization cycle, where a start value for the total energy value is calculated at an appointed moment of time. After changing at least one flow parameter of the exhaust air removal, either increasing or decreasing, from a start value to a new updated value, new total consumptions are determined both for heated steam consumed and for the electric energy needed to operate the blowing devices. The determined new total consumptions for heated steam and electric energy are then used to calculate an updated total energy value, which is compared with the start value. If the updated total energy value is smaller than the start value, the updated total energy value is made to a new start value and the minimization cycle is repeated. If the updated total energy value is higher than the start value, the at least one flow parameter of the exhaust air removal is changed to an opposite direction and the minimization cycle is repeated.

[0033] The minimization cycle may be performed at predetermined time intervals. At least the minimization cycle is performed when the impact factor is given a new value or when other process parameters change, e.g. produced paper/board quality.

[0034] In general, the drying section of a paper machine or the like comprises drying devices, which are arranged inside a drying hood for removal of moisture from the fibrous web. The drying devices, such as drying cylinders, are preferably heated with pressurized heated steam, and the drying hood defines a thermally insulated closed space, which separates the hood atmosphere inside the hood from the surrounding machine room atmosphere. Usually the drying devices are grouped and arranged to form at least one drying group, preferably several of drying groups, for example at least three drying groups, more preferably at least five drying groups, wherein each group comprises a plurality of drying devices. The different drying groups are fed with steam at different steam pressure and/or temperature. In some embodiments the steam pressure of the fed steam increases from the first drying group to the last drying group, seen in the direction of the web movement. According to the one embodiment of the invention, when the process comprises a plurality drying groups, the total amount of heated steam consumed by all the drying groups is determined.

[0035] The arrangement according to the present invention comprises exhaust air regulating circuit for measuring humidity and adjusting exhaust air flow volume. The exhaust air regulating circuit comprises humidity and temperature sensors for measuring the humidity and temperature of the exhaust air, as well as means for adjusting the exhaust air flow volume. The humidity and temperature sensors are arranged in the exhaust air flow which is removed from the drying hood. Contrary to the conventional prior art solutions the exhaust air removal is not adjusted maximal humidity on the basis of the measured exhaust air temperature. In the present invention the exhaust air removal is adjusted on a level where the total amount of heated steam, and optionally the total energy value, is minimized. However, at the same time the humidity of the exhaust air, i.e. humidity of the hood atmosphere, is kept below the maximum humidity value or within the predetermined humidity range, associated with the prevailing hood atmosphere temperature. This may mean that a change in the exhaust flow volume may be done to maintain the humidity of the hood atmosphere below the maximum humidity value or within the humidity range. When the exhaust flow volume is changed, the energy values associated with the electric energy may change and performing the minimization cycle and recalculation of the total energy value is recommended. For example, an increase of exhaust air flow may increase the electric energy consumption by the blowing devices.

[0036] Heated replacement air is brought into the drying hood by using at least one second blowing device. The arrangement comprises further a replacement air regulating circuit for adjusting replacement air flow volume. According to one preferable embodiment the replacement air regulating circuit comprises at least a first flow sensor for measuring the exhaust air flow volume and a second flow sensor for measuring the replacement air flow volume, as well as control means for adjusting the replacement air flow volume on basis of the determined flow volume values. According to one preferable embodiment the flow volumes are determined by a direct measurement from the exhaust and replacement air ducts by using any suitable flow sensors. This provides accurate measurement values and improves the precision of the method. The control means are arranged to adjust the replacement air flow on the basis of the exhaust flow, preferably so that a zero pressure level is maintained on the level of the hood openings. The replacement air regulating circuit may also comprise a separate sensor that is arranged to measure the zero pressure level in the hood. The measurement result from the zero pressure sensor may be used for fine tuning of the replacement air flow to the proper level. The adjustment of zero pressure level forms not the basis for adjustment in the present invention, but the zero pressure level control may form a part of the present invention in some embodiments, ensuring that the zero pressure level is maintained at the level of hood openings, even if the exhaust and replacement air flows are changed. The main control unit preferably comprises means for calculating the replacement air flow on basis of the exhaust air flow by using mathematical functions known as such. The ratio between the exhaust air and the replacement air may be adjusted by using correction constants and functions that take into account leakage air flows into the hood.

[0037] According to one embodiment of the invention the heat energy from the exhaust air may be used to heat dry replacement air in a first heat exchanger before the replacement air is fed to the drying hood. In addition, the replacement air may be heated in an additional heating cell, e.g. steam-gas heat exchanger, by using energy from heated steam. The additional heating cell is arranged after the first heat exchanger, seen in the flow direction of the replacement air. A first temperature regulating circuit is employed for measuring and adjusting the temperature of the replacement air to a desired level. The first temperature regulating circuit comprises a temperature sensor, which is arranged to measure the temperature of the replacement air flow after the first heat exchanger and the optional additional heating cell but before its entry to the drying hood. The first temperature regulating circuit comprises also adjustment means for adjusting the temperature of the replacement air flow to a desired level. For example, if the temperature of the replacement air is too low, the first temperature regulating circuit increases the heated steam flow through the additional heating cell.

[0038] The replacement air may be heated to a temperature in a range of 80 - 130 °C, preferably 85 - 120 °C, more preferably 90 - 110 °C, sometimes 90 - 100 °C.

[0039] The exhaust air temperature may be measured before and optionally after the first heat exchanger.

[0040] According to one embodiment of the invention the heat energy from the exhaust air may be used to heat at least one gaseous process flow and/or liquid process flow in at least one second heat exchanger to the desired temperature range. The second heat exchanger may be arranged after the first exchanger in the flow direction of the exhaust air, which means that at the entry to the second heat exchanger the temperature of the exhaust air is lower than at the entry to the first heat exchanger. The second heat exchanger may be a gas-liquid heat exchanger, where exhaust air is used to warm liquid process flows, such as process water, circulation water, water for heating the machine room ventilation air, etc. The second heat exchanger may be a gas-gas heat exchanger, where exhaust air is used to warm gaseous process flows, such as replacement air, machine room air, etc. The second heat exchanger(s) may be arranged in a heat recovery towers, which may comprise a plurality of second heat exchangers, both gas-liquid heat exchangers and gas-gas heat exchangers.

[0041] Furthermore, heated steam may be used to heat gaseous process flow(s) and/or liquid process flow(s) to the desired temperature ranges in one or more additional heating cells. The arrangement may further comprise at least one second temperature regulating circuit, which comprises at least one temperature sensor for measuring the temperature of gaseous process flow and/or liquid process flow, arranged in the flow direction after the additional heating cell, as well as adjustment means for adjusting amount of the heated steam flow to the additional heating cell on the basis of the measured temperature value. If the measured temperature of the process flow is too low, the second temperature regulating circuit increases the heated steam flow through the additional heating cell. Each process flow may have its own second temperature regulating circuit for adjusting its temperature on a desired level.

[0042] The predetermined and desired temperature ranges gaseous process flow(s) and/or liquid process flow(s) may vary according to the process, production conditions and/or arrangements. Typically, liquid process flows, such as circulation waters may be heated to a desired temperature in a range of 40 - 60 °C, preferably 45 - 55 °C or 50 - 55 °C. The gaseous process flows, such as machine room air may be heated to a temperature in a range of 18 - 25 °C, typically 20 - 22 °C.

[0043] According to one embodiment of the invention the consumption of heated steam by the drying devices may be controlled independently from the consumption of heated steam by the heating of the replacement air, the gaseous process flow(s) and/or liquid process flow(s). The feed of heated steam to the drying cylinders is mainly dependent on the basis weight of the fibrous web and the machine running speed. The same final moisture content for the web may be achieved either by using a higher steam pressure and lower steam flow or by using a lower steam pressure and higher steam flow. There may be a separate steam feed regulating circuit that selects the steam feed to the drying cylinders or the drying groups according to the produced paper or board quality, drying speed, basis weight and/or moisture content. The steam feed may have a feed-back loop from a moisture sensor measuring the web moisture after the drying section. This means that preferably the arrangement according to the present invention does not directly control the steam feed to the drying cylinders. However, the implementation of the present invention may have an effect on steam consumption on the drying cylinders by changing the conditions, such as humidity and temperature, inside the hood. This change in conditions may have an effect on the drying results which is achieved, for example to the final moisture content of the web. Thus, the present invention may have an indirect impact on the steam consumption on the drying cylinders.

[0044] The following schematical non-limiting drawings further demonstrates certain aspects of the present invention. The invention may be better understood by reference to the drawings in combination with the detailed description of the embodiments presented herein.

Figure 1 shows schematically an arrangement for controlling energy consumption in a manufacture of a fibrous web according to one embodiment of the invention, and

Figure 2 shows schematically a minimization cycle according to one embodiment of the invention.

[0045] Figure 1 shows schematically an arrangement for controlling energy consumption in a manufacturing process of a fibrous web according to one embodiment of the invention. Fibrous web is brought in a drying hood 1 through an inlet opening 2 and out from the drying hood 1 through an outlet opening 2'. The machine room floor level is indicated in Figure 1 with a dash line B. Even if not shown, the hood space is closed also below the machine room floor level. The arrows A, A' show the running direction of the web.

[0046] Two different types of drying groups 3, 3' are arranged inside the drying hood 1. The first drying group 3 shown in Figure 1 is a single tier drying group comprising drying cylinders 103 in the upper row and turning rolls 104 in the lower row. Single tier drying groups are usually present at least in the beginning of the drying section, and in some cases throughout the whole drying section. The second drying group 3' shown in Figure 1 is a double tier drying group having two horizontal rows of drying cylinders 103'. Double tier drying groups are common in the end part of the drying section. For reasons of clarity only two drying groups are shown in Figure 1, but it is understood that there may be one or more further drying groups between those shown, even if not presented in the Figure 1.

[0047] As seen from Figure 1, the drying groups 3, 3' comprise a number of drying cylinders 103, 103', heated by steam. The number of drying cylinders 103, 103' is different between the drying groups 3, 3'. Steam is brought and fed to the drying cylinders 103, 103' of the drying groups 3, 3' via a main steam feed line 4, which comprises a main steam valve 5. The main steam valve 5 may be an on/off valve for controlling the main steam supply to the drying section. The steam flow to the drying cylinders 103, 103' is limited by plurality of steam control valves (not shown) located in connection with each drying group. The steam flow to the drying cylinders 103, 103' is regulated by a separate regulation circuit, for example on basis of the moisture content, i.e. dryness, of the web exiting the drying hood 1. The moisture content of the web after its exit from the drying hood 1 may be measured by any suitable moisture sensor 6, known as such.

[0048] In the process and arrangement seen in Figure 1 the main steam feed branches and provides also heated steam for additional heating cells 91, 92, 93, where the steam is used to heat replacement air 10 and/or various process flows 11, 11'.

[0049] A main control unit 15 of the arrangement is arranged in a functional contact with a sensor array 120 comprising one or more sensors and arranged to measure the total amount of the heated steam consumed. The sensor array 120 comprises at least one flow sensor 121, which has been arranged to measure a total steam flow in the main steam feed line 4. The sensor array may further comprise a temperature sensor 122 and/or pressure sensor 123, arranged in the main steam feed line 4. The sensor array 120 provides the main control unit 15 measurement data relating at least to the flow, preferably also to temperature and/or pressure of the heated steam. The main control unit 15 uses the obtained information for determining a total amount of heated steam consumed by the drying groups 3, 3' and by additional heating cells 91, 92, 93, which may be used for heating of the replacement air 10 and the process flow(s) 11, 11'.

[0050] In the drying hood 1 the web comes into contact with the heated surfaces of the drying cylinders 103, 103', and the moisture from the web is evaporated, whereby the humidity of the drying hood atmosphere increases. Outlet connections 7 are arranged in a ceiling 101 of the drying hood 1 and warm humid exhaust air 8 is removed through the outlet connections 7 from the drying hood 1. Removal of the exhaust air 8 keeps the humidity of the hood atmosphere within a predetermined temperature range below the condensation point in order to avoid condensation inside the drying hood 1. Part of the exhaust air 8 may be removed through the turning rolls 104 of the single tier drying group 103.

[0051] The temperature and humidity of the exhaust air 8 is measured by using a humidity sensor 12 and a temperature sensor 12'. The sensors 12, 12' form a part of an exhaust air regulating circuit. The sensors 12, 12' are arranged in a functional contact with a main control unit 15 and the measurement values obtained from the sensors 12, 12' are transferred to the main control unit 15. The main control unit 15 is arranged in a functional contact with a first blowing device 19, such as blower, fan or the like, and is capable of adjusting the flow speed or flow volume of the exhaust air 8 on basis of the information received from the sensors 12, 12'.

[0052] As seen from Figure 1 the main control unit may be arranged in functional contact with the sensors and first blowing devices two (or more) drying groups.

[0053] Dry heated replacement air 10 is introduced to the drying hood 1, to the immediate vicinity of the drying cylinders 103, 103'. For example, replacement air may be arranged to doctor ventilator beams 106 or to runnability components 107, 107', from which dry air is ejected in the vicinity of the drying cylinders and the web to be dried. Replacement air may also be introduced below the machine room floor level, as seen in Figure 1.

[0054] A replacement air regulating circuit 154 is arranged to adjust replacement air flow volume. The flow volume of the exhaust air 8 and the flow volume of the replacement air 10 are measured by using flow sensors 20, 20' which are arranged in a functional contact with the flow control unit 154. The flow control unit 154 may also be arranged in a functional contact with a pressure sensor 17 which measures a zero pressure level inside the drying hood 1. The replacement air regulating circuit 154 receives information, i.e. measurement data, from these sensors. The replacement air regulating circuit 154 is arranged in a functional contact with a second blowing device 18, such as a blower, fan or the like, for adjusting the flow speed or flow volume of the replacement air 10. On basis of the information from the flow sensors 20, 20', and optionally from the zero pressure sensor 17, the replacement air regulating circuit 154 adjusts the replacement air flow volume or speed on basis of the information so that the zero pressure level in the drying hood is maintained at the level of the inlet and outlet openings 2, 2' of the hood 1 and the mass flow balance between exhaust air 8 and replacement air 10 is maintained.

[0055] The replacement air regulating circuit 154 may further be arranged to receive and process information from the second blowing device 18 associated with the second or any successive drying groups arranged within the drying hood 1. The replacement air regulating circuit 154 may thus receive information, i.e. measurement data, from the sensors about the flow volumes of exhaust air and replacement air at each drying group and make necessary adjustments in flow speed to maintain the mass flow balance between the flows at each drying group. The replacement air regulating circuit may also control the mass flow balance between the different drying groups.

[0056] The replacement air regulating circuit 154 is arranged in functional contact with the main control unit 15. The main control unit 15 receives from the replacement air regulating circuit 154 information, which relates to flow volumes of the exhaust air 8 and replacement air 10 and to the mass flow balance between them.

[0057] The main control unit 15 is arranged to receive and to process in information from the first blowing device 19 which relates to its consumption of the electric energy. The main control unit 15 may further be receive and process information from the first blowing devices associated with the second or any successive drying groups arranged within the drying hood 1. The main control unit 15 is arranged to receive and to process information from replacement air regulating circuit 154 that relates to the consumption of electric energy by the second blowing device(s) 18 The main control unit 15 thus receives information, i.e. measurement data, which describes the total amount of electric energy consumed by all the blowing devices. The main control unit 15 uses the information for producing a total electric energy value.

[0058] Exhaust air 8 removed from the hood is arranged to flow through a first heat exchanger 9, where heat energy from the exhaust air 8 is transferred to replacement air 10. An additional heating cell 91 is arranged after the first heat exchanger 9 in the flow direction of the replacement air 10. A first temperature regulating circuit 151 is arranged to measure and adjust the temperature of the replacement air 10. The temperature of the replacement air 10 is measured by using a temperature sensor arranged after the additional heating cell 91 but before the entry of the replacement air 10 to the drying hood 1. The first temperature regulating circuit 151 is arranged in a functional contact with a valve 16, which regulates the flow of heated steam to the additional heating cell 91. On basis of the temperature measurement of the first temperature regulating circuit 151 controls the valve 16, i.e. its position between closed and fully open valve positions. The first temperature regulating circuit 151 contains set temperature range stored in its memory unit, and the measured temperature values are compared to the set range, and the valve position is adjusted accordingly. For example, if the temperature of the replacement air 10 is too low, the valve 16 is moved towards a fully open position in order to increase the heated steam flow through the additional heating cell 91. Alternatively, if the temperature of the replacement air 10 is too high, the valve 16 is moved towards closed position and the steam flow through the heat exchanger 91 is decreased or stopped.

[0059] After the first heat exchanger the exhaust air 8 is arranged to flow through one or more second heat exchangers 9'. In the second heat exchangers 9' the remaining heat energy from the exhaust air 8 may be used to heat up gaseous and/or liquid process flow(s) 11, such as machine room air flow, process water and/or circulation water flows. Also, an additional heating cell 92 may be arranged to heat the process flow 11. In the additional heating cell 92 heat energy from heated steam is transferred to the process flow 11. A second temperature regulating circuit 152 is arranged to measure the temperature of the process flow 11 after the additional heating cell 92. The second temperature regulating circuit 152 is in a functional contact with a steam valve 16'. On basis of the temperature measurement the second temperature regulating circuit 152 adjusts the position of the valve 16', in a similar manner as the first temperature regulating circuit 151 controls the valve 16. The second temperature regulating circuit 152 contains set temperature range with a predetermined lower and upper limit values for the temperature of the process flow 11 and the measured temperature values are compared to the set range.

[0060] Figure 1 shows a second process flow 11' with an associated additional heating cell 93. The temperature of the second process flow 11' is controlled with a similar second temperature regulating circuit as explained above and comprising at least a temperature sensor and means for adjusting steam flow to the additional heating cell 93. For the sake of clarity of the figure this temperature regulating circuit is not shown in detail in Figure 1. In principle, the arrangement according to the present invention may contain any number of second temperature regulating circuits for various process flows, functioning according to the same principles as explained above.

[0061] The main control unit 15 may be arranged to adjust the removal of exhaust air 8 on a level where the total consumption of heated steam is minimised. This means that the exhaust air is adjusted to a level, where the consumption of heated steam by the drying groups 103, 103' as well as by the additional heating cells is as small as possible.

[0062] The main control unit 15 may further be arranged to calculate the total energy value by using determined total amounts for heated steam and electric energy as well as impact factors determined for heated steam and electric energy. The impact factors may be stored in the memory unit of the main control unit or they can be determined or calculated by the main control unit by using mathematical functions stored in the memory unit. After the determining the total energy value, the main control unit 15 may adjust the exhaust air volume in order to minimize the total energy value. The steps of the minimization cycle are schematically explained in Figure 2.

[0063] Figure 2 shows schematically a minimization cycle according to one embodiment of the invention. In step A a start value for the total energy value is calculated at an appointed moment of time. After that flow parameter(s) of exhaust air removal are changed from a start value to a new updated value. The change leads to an increase or decrease of the exhaust air removal, which changes the temperature and humidity inside the drying hood. Consequently, the amount of heated steam consumed by drying devices and optionally also the amount of heated steam by the additional heating cell(s) changes. In step B a new amount of heated steam is determined. The new amount is multiplied with the impact factor associated with the heated steam, and the new energy value for heated steam is obtained in step C.

[0064] The change in exhaust air removal changes also the amount of electric energy, which is needed to operate the blowing devices. A new total amount of electric energy needed to operate the blowing devices is determined in step D. The new amount is multiplied with the impact factor associated with the electric energy, and the new energy value for electric energy is obtained in step E.

[0065] In step F the obtained new energy values for heated steam and electric energy are used to calculate an updated total energy value. In step G the start value for the total energy value and the updated total energy value are compared with each other. If the updated total energy value is smaller than the start value, the updated total energy value is made to a new start value and the minimization cycle is repeated. If the updated total energy value is higher than the start value, the exhaust air removal is returned towards the start value and the minimization cycle is repeated. The minimization cycle may be repeated until the difference between the start value and the updated value for the total energy value is less than a predetermined value.

[0066] Even if the invention was described with reference to what at present seems to be the most practical and preferred embodiments, it is appreciated that the invention shall not be limited to the embodiments described above, but the invention is intended to cover also different modifications and equivalent technical solutions within the scope of the enclosed claims

Claims

1. Method for controlling energy consumption in a manufacturing process of a fibrous web, such as paper, board, tissue web or the like, where

- heated steam is consumed by heating of drying devices, which form at least one drying group, preferably several drying groups, inside a drying hood for removal of moisture from the fibrous web,
- blowing devices remove humid exhaust air from the drying hood and feed dry heated replacement air into the drying hood, and
- heated steam is further consumed by heating of replacement air, gaseous process flow(s) and/or liquid process flow(s) to predetermined temperature ranges, wherein the method comprises steps of:
- maintaining inside the drying hood an air humidity below a predetermined maximum humidity value,
- determining a total consumption of heated steam consumed by the drying devices and by heating of replacement air and/or the said process flow(s), and
- adjusting the removal of the humid exhaust air

from the drying hood on a level where the total consumption of heated steam is minimised.

2. Method according to claim 1, **characterised in that** the method comprises further steps of:

- determining a total consumption of electric energy which is needed to operate the said blowing devices for removal of exhaust air and for feeding of replacement air,
- using the determined total consumption of heated steam and total consumption of electric energy to calculate a total energy value by using impact factors determined for heated steam and electric energy, and
- adjusting the exhaust air removal on a level where the total energy value is minimised.

3. Method according to claim 2, **characterised in that** the impact factors for heated steam and for electric energy are determined on basis of availability, economic factor(s), CO_2 emissions, ecological factors and/or any combinations thereof.

4. Method according to claims 2 or 3, **characterised in that** the impact factor(s) is/are reassessed continuously or at predetermined time intervals.

5. Method according to claim 2, 3 or 4, **characterised in that** the process comprises a plurality drying groups comprising a plurality of steam heated drying devices, wherein

- the total consumption of heated steam by all the drying groups is determined, and
- the total consumption of electric energy which is needed to operate the blowing devices associated with all drying groups is determined.

6. Method according to one of the preceding claims 2 - 5, **characterised in that** the method comprises a minimization cycle, comprising steps of:

- calculating a start value for the total energy value at an appointed moment of time,
- changing at least one flow parameter of the exhaust air removal from a start value to a new updated value,
- determining a new total consumption of heated steam and determining a new total consumption of electric energy needed to operate the blowing devices,
- using the determined new total consumptions for heated steam and electric energy to calculate an updated total energy value,
- comparing the start value and the updated total energy value, and
- if the updated total energy value is smaller than the start value, making the updated total energy value a new start value and repeating the minimization cycle, or
- if the updated total energy value is higher than the start value, changing the at least one flow parameter of the exhaust air removal to an opposite direction and repeating the minimization cycle.

7. Method according to claim 6, **characterised in that** the minimization cycle is performed at predetermined time intervals.

8. Method according to one of the preceding claims 1 - 7, **characterised in that** the consumption of heated steam by the drying devices is controlled independently from the consumption of heated steam by the heating of the replacement air, the gaseous process flow(s) and/or liquid process flow(s).

9. Method according to any of preceding claims 1 - 8, **characterised in that** the total consumption of heated steam is determined by measuring the steam pressure and/or steam flow from a main steam feed.

10. Method according to any of preceding claims 1 - 9, **characterised in** using heat energy from the exhaust air to heat replacement air in a first heat exchanger before the replacement air is fed to the drying hood, and/or to heat the said process flows in at least one second heat exchanger.

11. Arrangement for controlling energy consumption in a manufacturing process of a fibrous web, such as paper, board, tissue web or the like, where a drying section comprises

- drying devices, which form at least one drying group, preferably several drying groups, and which are arranged inside a drying hood,
- at least a first blowing device for removal of humid exhaust air from the drying hood and at least a second blowing device for feeding of dry heated replacement air into the drying hood,
- a first heat exchanger for heating replacement air by the exhaust air,
- at least one additional heating cell for heating replacement air, gaseous process flow and/or liquid process flow by heated steam,

wherein the arrangement comprises

- exhaust air regulating circuit, which comprises means for measuring humidity of the exhaust air and means for adjusting exhaust air flow,
- a temperature regulating circuit, which comprises means for measuring and adjusting the

temperature of the replacement air,
- replacement air regulating circuit, which comprises means for adjusting replacement air flow,
- a sensor array, which comprises at least one steam flow sensor, arranged to measure the amount of heated steam consumed by the drying devices and by the additional heating cell(s),
- a main control unit which is arranged in a functional contact with the exhaust air regulating circuit, the replacement air regulating circuit, and the sensor array, and which main control unit comprises means for calculating the total consumption of heated steam, and means for determining the exhaust air removal on a level where the total consumption of heated steam is minimised.

12. Arrangement according to claim 11, **characterised in that** the arrangement further comprises means for determining the electric energy consumed by the blowing devices, which means are arranged in functional contact with the main control unit, and that the main control unit comprises means for calculating a total energy value by using impact factors determined for heated steam and electric energy, wherein the exhaust air removal is adjusted on a level where the total energy value is minimised.

13. Arrangement according to claim 11 or 12, **characterised in that** the arrangement comprises at least one second heat exchanger arranged after the first exchanger in the flow direction of the exhaust air, wherein the second heat exchanger is arranged to heat at least one gaseous process flow and/or liquid process flow by the exhaust air.

14. Arrangement according to claim 11, 12 or 13, **characterised in that** the arrangement comprises at least one second temperature regulating circuit, which comprises

- a temperature sensor for measuring the temperature of gaseous process flow and/or liquid process flow, arranged in the flow direction after the additional heating cell, and
- adjustment means for adjusting amount of the heated steam to the additional heating cell on the basis of the measured temperature value.

15. Arrangement according to claim 12, 13 or 14, **characterised in that** the main control unit comprises memory means for storing impact factors and/or means for calculating the impact factors.

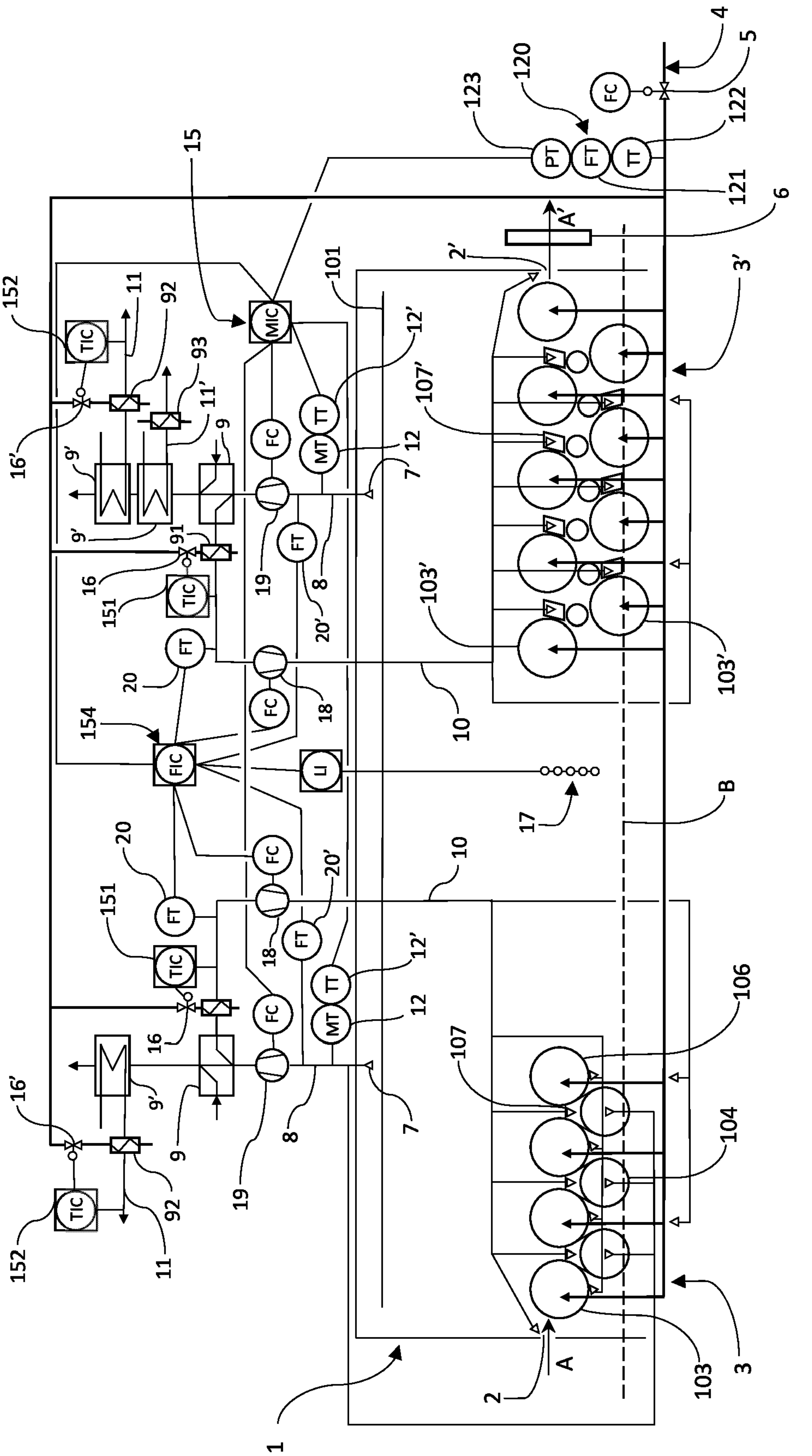
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Figure 1

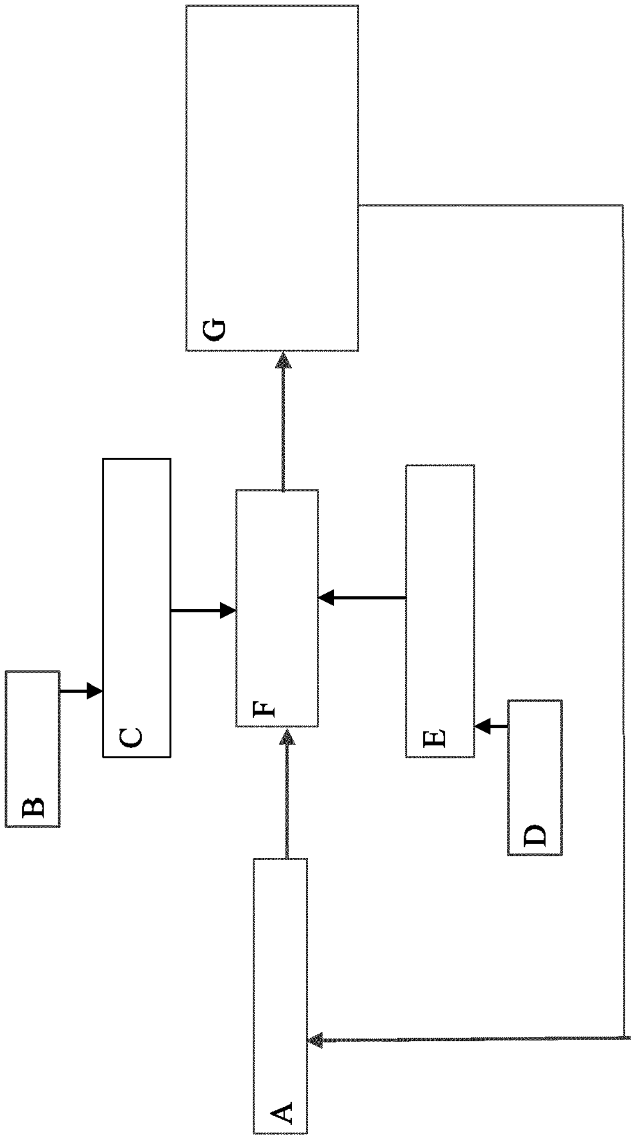

Figure 2

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EUROPEAN SEARCH REPORT

Application Number
EP 19 17 2693

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
A	FR 2 953 227 A1 (THERMOPAP [FR]) 3 June 2011 (2011-06-03) * page 4, line 26 - page 8, line 29 * -----	1-15	INV. D21F5/00 D21F5/02 D21F5/20 D21G9/00 D21F5/04
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TECHNICAL FIELDS SEARCHED (IPC)
D21F
D21G

The present search report has been drawn up for all claims

1

Place of search	Date of completion of the search	Examiner
Munich	13 November 2019	Maisonnier, Claire

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
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A : technological background
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ANNEX TO THE EUROPEAN SEARCH REPORT ON EUROPEAN PATENT APPLICATION NO. EP 19 17 2693

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For more details about this annex : see Official Journal of the European Patent Office, No. 12/82

REFERENCES CITED IN THE DESCRIPTION

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