



(12) **EUROPEAN PATENT APPLICATION**

(43) Date of publication:
21.07.2021 Bulletin 2021/29

(51) Int Cl.:
D21C 1/04 (2006.01) **D21C 3/04 (2006.01)**
D21C 3/22 (2006.01) **D21C 5/00 (2006.01)**
D21C 7/06 (2006.01) **D21C 7/14 (2006.01)**

(21) Application number: **21151129.0**

(22) Date of filing: **12.01.2021**

(84) Designated Contracting States:
AL AT BE BG CH CY CZ DE DK EE ES FI FR GB GR HR HU IE IS IT LI LT LU LV MC MK MT NL NO PL PT RO RS SE SI SK SM TR
Designated Extension States:
BA ME KH MA MD TN

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(30) Priority: **15.01.2020 FI 20205036**

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(54) **COOKING APPARATUS AND PROCESS FOR TREATING BIOMASS CONTAINING LIGNOCELLULOSE**

(57) A cooking apparatus for treating biomass containing lignocellulose, comprises one or more cooking reactors (100, 100') adapted to cook biomass in a cooking chemical which includes formic acid and acetic acid. A heating arrangement (106) is adapted to adjust heat energy transfer to each cooking reactor (100, 100') by adjusting the temperature of the cooking chemical as a function of time and by feeding the temperature-adjusted cooking chemical into each cooking reactor (100, 100').

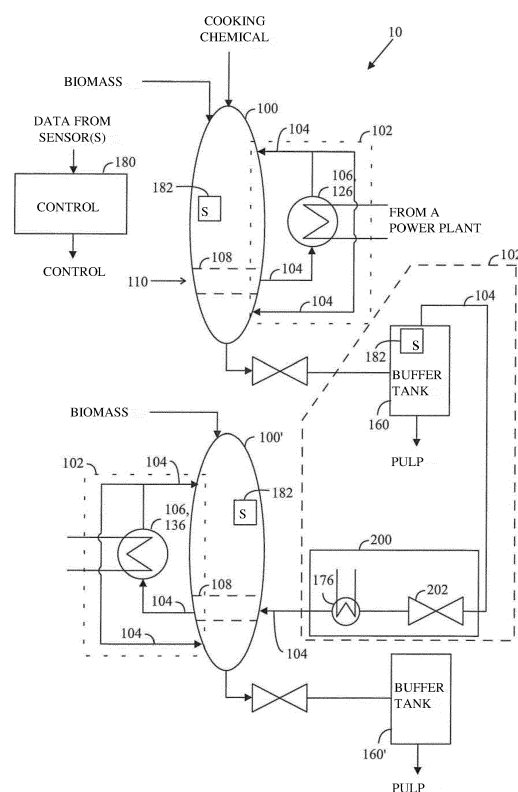


FIG. 1

Description

Field

[0001] The invention relates to a cooking apparatus and process for treating biomass containing lignocellulose

Background

[0002] In pulping, cooking process liquid is circulated through a heat exchanger which heats up the liquid used in cooking. For commercial batch cooking, a total cooking time and temperature have been defined, producing a good-quality end product. In conventional pulp manufacturing, the heating time is approximately an hour. Industrially selected favourable conditions take into account the good quality of the end product, increasing e.g. the cooking temperature may degrade the quality of the end product. A degraded quality may present itself e.g. as poor tensile strength in paper whose pulp has been cooked at a deviating temperature. A degraded quality of the end product may also show as a high kappa number, non-uniform quality of the pulp, and deteriorated pulp viscosity. Likewise, alkaline hydrolysis may gain strength, adding to a secondary peeling reaction and lowering pulp yield. This leads to a need to develop the batch cooking process.

Brief disclosure

[0003] It is an object of the invention to implement an improved batch cooking process for pulp. The object is achieved by what is disclosed in the independent claims. Preferred embodiments of the invention are disclosed in the dependent claims.

List of figures

[0004] The invention will now be described in more detail in connection with preferred embodiments and with reference to the accompanying drawings, in which:

Figure 1 shows an example of a cooking apparatus and circulating a cooking chemical between cooking reactors;

Figure 2 shows an example of a cooking apparatus and circulating a cooking chemical at the end of a cooking process;

Figure 3 shows an example of a cooking reactor in which a cooking chemical is circulated a number of times towards a cooking reactor;

Figure 4 shows an example of calcination;

Figure 5A shows an example of overheating a cooking chemical in a plurality of ways;

Figure 5B shows an example where woodchips are fed in a cooking reactor;

Figure 6 shows an example a kappa number as a

function of an H-factor with different cooking times; Figure 7 shows an example of a proportion of pentosans as a function of an H-factor with different cooking times;

Figure 8 shows an example of a temperature profile of a cooking with different cooking times;

Figure 9 shows an example of formation of furfural with different cooking times;

Figure 10 shows an example of a flowchart of a cooking method; and

Figure 11 shows an example of a controller.

Description of embodiments

[0005] The following embodiments are presented by way of example. Even though the description may refer to "an" embodiment or embodiments at different points, this does not necessarily mean that each such reference refers to the same embodiment or embodiments or that the feature only applies to one embodiment. Individual features of different embodiments may also be combined in order to enable other embodiments.

[0006] In the present solution, the goal is to improve the organosolv cooking process in order to obtain C5 sugars hydrolysing into the cooking liquor from the hemicellulose of biomass during cooking, with better selectivity, yield and, at the same time good quality pulp. The organosolv technology uses organic acids, and it is an environmentally friendly technology to produce pulp. When the temperature profile of a cooking process is controlled, the above can be reached. When the temperature of the cooking process can be quickly raised to the actual cooking temperature, the cooking process is enhanced. According to traditional understanding, raising the temperature fast at the beginning of a cooking process causes the quality of the end product to deteriorate, but this does not in fact happen in the organosolv process, at least, in which a mixture of formic acid, acetic acid, water, and furfural is used as the cooking chemical, that is, the solvent.

[0007] Figure 1 shows an example of a cooking apparatus 10 treating lignocellulose-containing biomass. The cooking apparatus 10 comprises at least one cooking reactor 100, 100' operating on the batch principle. Lignocellulose-containing biomass may be wood-based or a so-called non-wood biomass, or a combination of these. The biomass comprises woodchips from e.g. deciduous trees, conifer trees or bamboo, chopped into pieces of a desired size,

[0008] Grass-stemmed plants used as a biomass generally refer to non-wood based fibre sources, such as straw, grass, reed, bast fibres, leaf fibres, seed hairs. Straws include for instance cereal straws, such as straws of wheat, barley, oat, rye and rice. Grass refers to esparto, sabai or lemon grass, for instance. Examples of reeds include papyrus, common reed, sugar cane and bamboo. Examples of bast fibre sources include stalks of common flax, stalks of oil flax, kenaf, jute and hemp. Leaf fibre

sources include for example abaca and sisal. Seed hair fibre sources include for example cotton and cotton linter fibres. Further, non-woody fibre sources include for instance reed canary grass, timothy, cocksfoot, yellow sweet clover, smooth brome, red fescue, white sweet clover, red clover, goat's rue and alfalfa.

[0009] Each cooking reactor 100, 100' receives a biomass batch which is cooked in the cooking reactor 100, 100' by using a cooking chemical comprising formic acid, acetic acid, furfural, and water.

[0010] The composition of the solvent used in the cooking includes approximately 30 - 75 % of formic acid, approximately 6 - 55 % of acetic acid, approximately 13 - 22 % of water, and approximately 0.01 - 3 % of furfural. In an embodiment, the solvent includes approximately 38 - 55 % of formic acid, approximately 30 - 45 % of acetic acid, approximately 15 - 20 % of water, and approximately 0.01 - 2 % of furfural. Further, in an embodiment the solvent includes approximately 41 - 52 % of formic acid, approximately 31 - 42 % of acetic acid, approximately 15 - 18 % of water, and approximately 0.01 - 2 % of furfural. The concentrations presented may be freely combined as desired, so long as the numbers presented do not exceed 100 %.

[0011] The cooking temperature is between approximately 116°C - 170°C. In an embodiment, the cooking temperature may be between approximately 120°C - 165°C.

[0012] In an embodiment, shown by the example of Figure 5, the cooking apparatus comprises a dosing device 90 for the cooking chemical, which may control the feeding in of the different substance components of the cooking chemical, such as formic acid and acetic acid, to the cooking reactor 100, 100'. The different substance components of the cooking chemical may be dosed into the cooking reactor 100, 100' in different quantities as a function of time to enhance the cooking process, which chemically affects the cooking process, or how much heating energy is transferred to the cooking reactor 100, 100'. The dosing of the substance components of the cooking chemical may be carried out with valves which may be controlled by a controller 180 (shown in Figure 1)

[0013] The cooking chemical is caustic and dissolves the lignin and hemicellulose of the biomass and thus facilitates defibration and pulp manufacturing. It is additionally possible to feed vapour into the cooking reactor 100 from one or more points to achieve and maintain the correct cooking temperature. The cooking temperature is determined based on the raw material being used and on the desired end product. The temperature window is 116°C - 170°C. In an embodiment, the temperature window may be 120°C - 165°C, for example. The end result of cooking is pulp which, after cooking, may be e.g. washed and then hydrolysed or bleached. Pulp obtained in this way may be used for instance in the board and paper industry or as a raw material for (bio)ethanol or that of other fermentation processes. In addition to pulp, the obtained end products include C5 sugars and furfural

the formation of which may be adjusted by the disclosed batch cooking process.

[0014] At first, one of the cooking reactors 100 of Figure 1 is examined. In an embodiment, the cooking apparatus 10 comprises a circulation arrangement 102, directly connected to the cooking reactor 100, which may also be referred to as a first circulation arrangement. Pipes 104 of the circulation arrangement 102 connect the cooking reactor 100 and a heating arrangement 106 for feeding a cooking chemical from the cooking reactor 100 to the heating arrangement 106, 126 and to feed the cooking chemical heated in the heating arrangement 106, 126 to the cooking reactor 100. This way, the circulation arrangement 102 is adapted to transfer the cooking chemical through the pipes 104 from the cooking reactor 100 to the heating arrangement 106, 126 which adjusts the transfer of heat energy to the cooking reactor 100 by adjusting the temperature of the cooking chemical as a function of time and by feeding the temperature-adjusted cooking chemical to the cooking reactor 100.

[0015] The cooking arrangement 106, 126 heats the cooking chemical and adjusts its temperature when the cooking chemical is in the heating arrangement 106, 126 as the cooking chemical is flowing through the heating arrangement 106, 126. Further, the circulation arrangement 102 transfers the temperature-adjusted cooking chemical back to the cooking reactor 100.

[0016] The circulation arrangement 102, connected to the cooking reactor 100' and being similar to the circulation arrangement 102 of the cooking reactor 100 (thus the same reference number), can move cooking chemical in a similar fashion through pipes 104 from the cooking reactor 100' to the heating arrangement 106, 136 which adjusts the temperature of the cooking chemical as a function of time to enhance the cooking process carried out in the cooking reactor 100'.

[0017] In an embodiment, the heating arrangement 106 may heat the temperature of the cooking chemical higher than the temperature applied for cooking in said cooking reactor 100.

[0018] Figure 1 shows an embodiment which includes a circulation arrangement 102' between the cooking reactors 100, 100', which may be referred to as a third circulation arrangement. In this example, the cooking apparatus 10 comprises first and a second cooking reactor 100, 100', and to adjust the heat energy transferred to the second cooking reactor 100' by means of a cooking chemical, the cooking apparatus 10 comprises a buffer tank 160 and a heat generator 200. When the cooked substance is discharged from the cooking reactor 100, usually from the bottom of the cooking reactor 100, to the buffer tank 160 which has a lower pressure than the cooking reactor 100, the cooking chemical vaporises.

[0019] Said buffer tank 160 may discharge the vaporised cooking chemical through its upper part through the pipe 104 to the heat generator 200 which may heat the cooking chemical or adjust the temperature of the cooking chemical as a function of time. The heat generator

200 may comprise a steam compressor 202 which by its compression increased the temperature of the cooking chemical or adjusts the temperature of the cooking chemical as a function of time. The heat generator 200 may additionally comprise a heater 176 which heats or adjust the temperature of the cooking chemical as a function of time. The heated or temperature-adjusted cooking chemical may be fed to the centre part of the second cooking reactor 100'. The cooking chemical heated or temperature-adjusted by the heater 176 may be fed to the second cooking reactor 100' through its upper part (see Figure 5). The cooking chemical heated or temperature-adjusted by the heater 176 may also be used to calcinate the biomass batch in the second cooking reactor 100' in the similar manner as in described in connection with Figure 4. As the cooking chemical moves from the buffer tank 160 to the cooking reactor 100', it condenses, which released energy which may be utilized in the heating of the cooking process.

[0020] The cooking chemical, temperature-adjusted as a function of time, may absorb more effectively into the biomass, which enhances and/or accelerates the defibration of the biomass, and may shorten the cooking time. When cooking chemical vapour is fed to the bottom of the cooking reactor 100' by means of a blower (not shown in the figures), the saturation point of the vapour is increased (compression in connection with evaporation). This way the condensing temperature of the cooking chemical vapour is increased and the cooking reactor may be heated more/more efficiently by using energy from the preceding cooking, which may have been boosted by adjusting the temperature of the cooking chemical as a function of time. Typically, an MVR evaporator (Mechanical Vapor Recompression) 202 requires 10 kWh - 13 kWh of electricity / 1t of evaporation (for the compressor). With just steam, without a recompressor, 640 kWh of energy / 1 t of evaporation would be needed, where t is for tons.

[0021] In an embodiment, shown in Figure 2, the cooking chemical is, in relation to each cooking reactor 100, on a separate cooking chemical container 150 from which the cooking chemical, temperature-adjusted as a function of time, is transferred to the cooking reactor 100 possibly through the pipe 104 of the circulation system 102", or a pipe running between the cooking reactor 100 and cooking chemical container 150. The circulation system 102" of Figure 2 transfers the post cooking process cooking chemical back to the cooking reactor 100 from which the cooking chemical had exited. The circulation system 102" may be considered a third circulation system. Figure 5A shows an example where the cooking chemical of the cooking chemical container 150 may also be transferred to the second cooking reactor 100' as least partly, whereby the cooking chemical is transferred to one or more cooking reactors 100, 100'. The circulation system 102" (like any other circulation system 102) is not, however, required (in which case the link, or the pipe 104 marked with a dotted line, does not exist between the

buffer tank 160 and cooking chemical container 150), but the cooking chemical container 150 and the associated heating arrangement 106, 156 operate without circulation. In the embodiment of Figure 2, the separate cooking chemical container 150 and heating arrangement 106, 156 act as a preheater. The separate cooking chemical container 150 may receive cooking chemical directly through circulation or indirectly from one or more cooking reactors 100. In addition to, or instead of, circulation the cooking chemical container 150 may receive new uncirculated cooking chemical. The temperature of the cooking chemical in the separate cooking chemical container 150 is adjusted as a function of time with the heating arrangement 106, 156. Pipes 152 connect the cooking chemical container 150 and the heating arrangement 106 for feeding a cooking chemical from the cooking chemical container 150 to the heating arrangement 106, and to feed the cooking chemical, temperature-adjusted in the heating arrangement 106, 156, back to the cooking chemical container 150. The cooking chemical container 150 is used as a cooking chemical accumulator, which is at least approximately at the same pressure as the cooking reactor 100.

[0022] As shown in Figures 2, 3, and 5A, the cooking chemical, temperature-adjusted as a function of time, may be fed to one or more cooking reactors 100 by pumping it from the cooking chemical container 150 or by means of pressurised gas. Pumping by means of a pump (not shown in the figures) represents a more peaceful discharge of a temperature-adjusted cooking chemical from the cooking chemical container 150 to the cooking reactor 100, which means that the temperature-adjusted cooking chemical may be transferred to the cooking reactor 100 within minutes, for example between 5 and 10 minutes, depending on the design of the apparatus.

[0023] In Figures 2, 3 and 5A, pressurised gas is denoted by N₂, which also acts as an example that an inert type may be used as the pressurised gas. When the potential valve 120 between the cooking chemical container 150 and cooking reactor 100 has been opened and pressurised gas is fed into the chemical container 150, the pressurised gas forces the temperature-adjusted cooking chemical from the cooking chemical container 150 to the cooking reactor 100. Such a method for transferring temperature-adjusted cooking chemical to a cooking reactor is usually more abrupt than pumping, and the transfers takes from seconds to minutes.

[0024] As shown in Figures 1 to 5A, each cooking reactor 100 comprises at least one screen 108 whose flow-through area is adapted for passing cooking chemical through at a high flow rate, allowing the heating arrangement 106, 126, 136 in such a case to operate with high efficiency.

[0025] In an embodiment, shown in Figures 1 to 5A, each cooking reactor 100, 100' comprises at least one screen 108 preventing biomass from accessing the heating arrangement 106 from the cooking reactor 100, 100' but allowing cooking chemical to pass towards the heat-

ing arrangement 106, 126, 136. The screen 108 may be band-like structure surrounding the cooking reactor 100 along its inner surface. Each screen 108 is adapted to optimize the flow of cooking chemical from the cooking reactor 100 to the heating arrangement 106, 126, 136. At the same time, the corresponding flow of temperature-adjusted cooking chemical is naturally also optimized from the heating arrangement 106, 126, 136 to said one or more cooking reactors 100, 100', by means of which the heating power may be optimized to minimize the temperature rise time of the cooking reactor.

[0026] In an embodiment, each screen 108 is adapted to maximize the flow of cooking chemical from the cooking reactor 100 to the heating arrangement 106, 126, 136. At the same time, the corresponding flow of temperature-adjusted cooking chemical is naturally also maximized from the heating arrangement 106, 126, 136 to said one or more cooking reactors 100, 100', which maximizes the heating power to allow the temperature rise time of the cooking reactor to be minimized.

[0027] So, the screen 108 is so dimensioned it will not clog it up with biomass, which it prevents from accessing the heating arrangement 106, 126, 136 but at the same time the screen 108 allows cooking chemical to pass through with optimized/maximized flow rate. Such a situation is a typical optimisation situation which a person skilled in the art may as such easily solve without unreasonable trouble by, for example, testing, simulating, or theoretically.

[0028] The flow of cooking chemical, temperature-adjusted as a function of time, to said one or more cooking reactors 100, 100' may in any embodiment be optimized in relation to the heat capacity of the substance being cooked in said one or more cooking reactor 100, 100'.

[0029] In an embodiment, the flow of cooking chemical, temperature-adjusted as a function of time, to said one or more cooking reactors 100, 100' may in any embodiment be maximized in relation to the heat capacity of the substance being cooked in said one or more cooking reactor 100, 100'.

[0030] This dimensioning may be carried out as a separate matter irrespective of one or more screens 108. After all, the matter being cooked includes the different components of the cooking chemical and biomass, and the mass, temperature and specific heat capacity affect how much the temperature of the matter being cooked changes when the cooking chemical, temperature-adjusted as a function of time, arriving from the heating arrangement 106, 126, 136 (,156, 176) and having a specific mass and temperature at instant of time, is added to the matter being cooked. When a particular mass is moved to the cooking reactor 100, 100', at the same time a specific amount of energy is transferred there as heat (e.g. x kJ where x is a numerical value for the amount of energy, and kJ refers to the unit of energy, kilojoule). The fact the flow of temperature-adjusted cooking chemical to a cooking reactor 100, 100' may be continuous in an embodiment, also optimization/maximisation is advanta-

geous to perform as a function of time so that instead of mass, for example, the issue is flow as a ratio mass unit per time unit. In such a case, heat is transmitted to the cooking reactor 100, 100' as the desired amount of energy per time unit (e.g. kJ/s where kJ is for kilojoules and s is for seconds). In an embodiment, the flow of temperature-adjusted cooking chemical to a cooking reactor 100, 100' may be discontinuous. The flow of temperature-adjusted cooking chemical to said one or more cooking reactors 100, 100' may additionally be optimized/maximized in relation to the heat capacity related to the material heating up in the cooking process of said one or more cooking reactor 100. Part of the heat energy of the temperature-adjusted cooking chemical, after all, leaks to heating up the cooking reactor 100, 100'.

[0031] By means of the flow of temperature-adjusted cooking chemical, in accordance with the above, the straightforward goal is not to shorten the cooking time, although this, too, may be possible, but with the optimized flow of the temperature-adjusted cooking chemical, it is possible to control in a managed manner the temperature rising to the cooking temperature in the desired manner and to maintain the cooking temperature at the desired level, which may vary as a function of time.

[0032] By means of the flow of temperature-adjusted cooking chemical the goal is not necessarily to shorten the cooking time, although this, too, may be worth pursuing in one or more embodiments, but with the maximized flow of an overheated cooking chemical, it is possible to control in a managed manner the fast temperature rising of the cooking temperature to the cooking temperature and to maintain the cooking temperature at the desired level, which may vary as a function of time.

[0033] In an embodiment, the flowthrough area of said at least one screen 108 may be maximized from the viewpoint of the flow of the cooking chemical passing through said at least one screen 108, and to maximize the flow of the cooking chemical moving to the cooking reactor 100, 100', adjusted from the viewpoint of the transfer of heat energy in relation to the power of the heating arrangement 106, 126, 136, which adjusts the temperature of the cooking chemical as a function of time to feed the maximized heat energy to said at least one cooking reactor 100, 100' to enhance the cooking process.

[0034] In an embodiment, an example of which is shown in Figure 3, at least one of said at least one or more cooking reactor 100 may comprise a plurality of screens 108 at different exit points 110, 112 of the cooking reactor 100. The exit points 110, 112 are in zones. In this case, the circulation arrangement 102 transfers cooking chemical from said at least one cooking reactor 100 through said various screens 108 to the heating arrangement 106. By using a number of screens 108 it is possible to increase their filtering surface area, allowing a greater flow through the screens 108.

[0035] In accordance with Figure 3, the cooking chemical may be circulated back to the cooking reactor 100 so that it is received in one or more cooking reactors 100

at the input points, which are outside the zones corresponding to the exit points 110, 112. The temperature-adjusted cooking chemical may be circulated back to the same cooking reactor, as shown in Figure 3, or to another cooking reactor. So, the temperature-adjusted cooking chemical may be in the same or different cooking reactor 100, 100' from which the cooking chemical was taken to be temperature-adjusted. So, the cooking chemical may be circulated back to said one or more cooking reactor 100, 100'.

[0036] Each zone in a cooking reactor 100 may be at a different distance from the common point of this cooking reactor 100. A zone may comprise a cross section in the direction of the longitudinal axis of the cooking reactor 100, each cross section being at a different distance from an end on the longitudinal axis of the cooking reactor 100.

[0037] In an embodiment, an example of which is shown in Figure 3, the circulation arrangement 102 may return the cooking chemical received through different screens 108 and temperature-adjusted in the heating arrangement 106 at different input points of the cooking reactor 100, where the input points differ from the exit points 110, 112. When a temperature-adjusted cooking chemical is returned in a transfer between cooking reactors 100, 100', one or more input points may differ in zone either absolutely or relatively from the exit points 110, 112. If the different cooking reactors 100, 100' are equal in size, the zone location may be determined absolutely (e.g. 2 m from the top part of the cooking reactor), but if the cooking reactors 100, 100' are of different sizes, the location of a zone may be determined relatively (e.g. 2/3 of the total length of the cooking reactor from the top part).

[0038] In an embodiment, an example of which is shown in Figure 3, the heating arrangement 106 may comprise a plurality of heaters 114, 116 in the same cooking reactor 100. The circulation arrangements 102 marked on different sides of the cooking reactor 100 may in an embodiment comprise one common heater, in other words, either one of the heaters 114, 116. The circulation arrangement 102 may transfer cooking chemical in the pipes 104 from the exit points 110, 112 of at least two screens 108 to different heaters 114, 116. The heaters 114, 116 may be e.g. heat exchangers receiving their heat energy from a power plant.

[0039] In an embodiment, an example of which is shown in Figure 3, the heating arrangement 106 may comprise a plurality of separate heater arrangements 126, 136, 156, 166, 176. The separate heater arrangements 126, 136, 156, 166, 176 may increase the temperature of the cooking chemical in the various stages of the cooking process. In an embodiment, the heater arrangements 126, 136, 156, 166, 176 are heat exchangers receiving their heat energy from a power plant.

[0040] In addition to the temperature-adjusted cooking chemical, coming from the heating arrangement 156, 176 and including different substance components and having a particular mass and temperature, may be added to the substance being cooked. The cooking chemical flow

from these heating arrangements 156, 176 may be maximized like the cooking chemical flow of other heating systems 126, 136. In such a case, it is possible to adjust the reception of the heat energy of the cooking process carried out in the cooking reactor 100, 100' as desired as a function of time. By adjusting the different substance components of the cooking chemical, chemical reactions taking place in the cooking process may be controlled. Because the different substance components (formic acid, acetic acid, and other possible substances such as water etc) have a different relative heat capacity, by selecting substance components it is possible, in addition to the actual temperature, to adjust the supply of heat energy to the cooking reactor 100, 100'.

[0041] In an embodiment, the heating arrangement 106 referred to in the examples and shown in the figures may optimize the adjustment of the cooking chemical feed, carried out as a function of time, based on the heat capacity and cooking temperature of the substance cooked in said one or more cooking reactors 100, 100' to speed up the cooking process. Likewise, the optimization/maximization of the flow of the cooking chemical, the temperature optimization of the cooking chemical, performed as a function of time, may be optimized in relation to the heat capacity of the substance being cooked in said one or more cooking reactors 100, 100'. Therefore, the goal of adjusting the temperature of the cooking chemical is not necessarily to shorten the cooking time, although this, too, may be the goal in one or more embodiments described in this document, but with the optimized temperature adjustment of the cooking chemical, it is possible to control in a managed manner the temperature in the cooking reactor 100, 100' rising to the cooking temperature and to maintain the cooking temperature during cooking at the desired level, which may also vary as a function of time. By combining the maximization of the flow and the optimization of the temperature of the cooking chemical as a function of time, the cooking process may be further enhanced.

[0042] As mentioned in the above, in the embodiment of Figure 2, the separate cooking chemical container 150 and the heating arrangement 106, 156 act as a preheater. This means that the preheater may receive at least part of the cooking chemical used in said one or more cooking reactor 100, 100', temperature-adjust the received cooking chemical, and feed the cooking chemical, temperature-adjusted as a function of time, to said one or more cooking reactors 100, 100' after said one or more cooking reactors 100, 100' have received a batch of biomass.

[0043] In an embodiment, an example of which is shown in Figures 4 and 5, said one or more cooking reactor 100, 100' may receive, from said one or more separate cooking chemical container 150, heated or temperature-adjusted cooking chemical to calcinate the biomass prior to cooking the biomass. In calcination, heated or temperature-adjusted vaporised cooking chemical is led through the biomass, whereby at least part of the water in the biomass is vaporised off the biomass. The

vaporised water may be led away from the cooking reactor 100, 100' through a desired route. In this case, the water in the cooking reactor 100, 100' will not consume heat energy intended for cooking. After calcination, cooking may commence. As the cooking chemical is condensing, energy is released, which may be utilised in the heating of the cooking process. At the same time the cooking chemical may absorb more effectively into the biomass, which accelerates the defibration of the biomass, and intensifies the cooking process.

[0044] Figure 5A shows a combination of many of the examples described in the above, one or more of which may be implemented. For example, the circulation arrangement 102 is in a general case adapted to transfer cooking chemical through pipes 104 from one or more cooking reactors 100 to the heating arrangement 106 which adjusts the temperature of the cooking chemical as a function of time.

[0045] In an embodiment, the circulation arrangement 102 transfers cooking chemical through pipes 104 from one or more cooking reactors 100 to the heating arrangement 106 which adjusts the temperature of the cooking chemical higher than the temperature used for cooking in said one or more cooking reactors 100 prior to the commencing of the cooking process, and feeds the cooking chemical whose temperature is higher than the temperature used for cooking in said one or more cooking reactor 100, to the cooking reactor 100.

[0046] Once the biomass has been taken in the cooking reactor 100, 100' at the start of the cooking process, its temperature may be much lower than the cooking temperature. The temperature of the biomass may be the same as the surrounding temperature, which may be e.g. -10°C - $+40^{\circ}\text{C}$. Likewise, the temperature of the cooking chemical may be lower than the cooking temperature, especially at the beginning. Thus the temperature of the cooking chemical may be higher than the actual cooking temperature when it is fed in the cooking reactor 100, 100'. During the cooking process, the temperature evens out and the temperature of the cooking chemical may be adjusted lower. By adjusting the temperature as a function of time, it is possible in the heating arrangement 106 according to any example and/or figure to raise the temperature of the substance, and in particular the biomass, that is being cooked in a desired manner, and possibly faster than in prior art to the cooking temperature, which enhances and possibly even shortens the cooking time. At the same time, the cooking temperature may be controlled and, if need be, use higher temperatures than intended as the actual cooking temperature, at least momentarily.

[0047] Generally speaking, the circulation arrangement 102, 102', 102" transfers the cooking chemical, temperature-adjusted as a function time, back to at least one of said one or more cooking reactors 100, 100', which is described in the examples of Figures 1 to 5A. The circulation arrangement 102, 102', 102" comprises e.g. a pump and/or ejector by means of which the cooking chemical can be made to flow in the pipes 104 and

through the heating arrangement 106, 126, 136, 176.

[0048] Figure 5B shows the feeding of woodchips to the cooking reactor 100. The woodchips are received at a reception part 500, from where a screw conveyor 502 carries the woodchips to a feed part 504 of the cooking reactor. From the feed part 504, the woodchips are transferred along with hot steam to the cooking reactor 100, 100'. Steam preheats the woodchips whereby the cooking process in the cooking reactor 100, 100' is intensified, and the temperature rise to the actual cooking temperature can be accelerated. The heating arrangement 106, 126 heats the cooking chemical by steam, as explained in the above.

[0049] Figure 6, where a kappa number is on the vertical axis and H factor on the horizontal axis, shows an example of the results with heating rise times of 20 minutes and 60 minutes. Figure 7 shows an example of the proportion of pentosans as a function of an H-factor. When the H-factor 25, for example, is examined, it is found out on the basis of Figures 6 and 7 that a short temperature rise time leads to a more selective delignification, that is, the kappa number is lower while the pentosan content remains the same. The H-factor, which depends on the temperature and the temperature rise time, is relative to the leaching rate of lignin, and more generally to the progress of cooking.

[0050] Figure 8 shows an example of the temperature profile of cooking with different cooking times. The temperature and H-factor are on the vertical axis, and time on the horizontal axis. The H-factor rises fast with one cooking to the value of 24, which means that even a short cooking time may result in a high-quality end product.

[0051] Figure 9 shows an example of formation of furfural with different cooking times. The amount (g/kg) of furfural is on the vertical axis, and kappa number on the horizontal axis. With a short temperature rise time (20 minutes), a low kappa number is achieved without the amount of furfural within the matter being cooked rising as high as with a long temperature rise time (60 minutes).

[0052] Figure 10 shows an example of a flowchart of a cooking method. At step 1000, biomass is cooked in one or more cooking reactors 100, 100' operating on the batch principle in a cooking chemical that includes formic acid, acetic acid, water, and furfural. At step 1002, the transfer of heat energy to the cooking reactor 100, 100' is adjusted by adjusting the temperature of the cooking chemical as a function of time for feeding into the cooking reactor 100, 100'. At step 1004, the temperature-adjusted cooking chemical is fed 1004 to one or more cooking reactors 100, 100'.

[0053] Figure 11 shows an example of a controller 180, shown in Figure 1. The controller 180 may comprise one or more processors 1100 and one or more memories 1102 which may store one or more computer programs suitable for process control. The controller 180 may, by means of said one or more computer programs, control the cooking performed in the cooking reactor 100, 100', temperature adjustment of the cooking chemical as a

function of time carried out in the heating arrangement 102, and feeding the temperature-adjusted cooking chemical into one or more cooking reactors 100, 100'. The cooking process control in each cooking reactor 100, 100' may be based on e.g. temperature data originating from sensors 182. The flow of the cooking chemical in the pipes 104 may be controlled by valves and/or pumps, which for their part may be controlled by the controller 180.

[0054] The cooking method shown in Figure 10 may be implemented as a logic circuit solution or as a computer program. The computer program may be placed on a computer program distribution means for the distribution thereof. The computer program distribution means is readable with a data processing device, and it may encode computer program commands for controlling the operation of the measuring device.

[0055] In the embodiment in which the cooking process is enhanced by using overheating, the cooking chemical overheated in any heating arrangement may be a few degrees hotter than the temperature of the cooking performed in the cooking reactor 100, 100'. In an embodiment, the temperature of an overheated cooking chemical is approximately 5° C hotter than the cooking temperature in the cooking reactor 100, 100'. In an embodiment, the temperature of an overheated cooking chemical is approximately 10° C hotter than the cooking temperature in the cooking reactor 100, 100'. Overheating a cooking chemical may compensate for the lack of energy caused by phase transfer.

[0056] In an embodiment, the delignification of lignocellulosic biomass may, as disclosed in the above, use a shorter than normal cooking time, because delignification is, surprisingly, more effective and more selective when temperature adjustment of the cooking chemical as a function of time is applied. It may be advantageous to apply a short cooking time when biomass is delignified by a so-called organosolv method, that is, an organic solvent such as a mixture consisting at least of formic acid, acetic acid, water, and furfural. The selectivity of delignification also depends on the variation of temperature as a function of time. The selectivity of delignification may be affected e.g. by the temperature rise time at the beginning of cooking. The faster the temperature rise time is at the beginning of the cooking process, the more effectively and/or faster the desired level of delignification may be reached so that the pentose sugars react to furfural as little as possible.

[0057] Fast heating is possible by adjusting the heating of the cooking chemical as a function of time. In an embodiment, this means overheating, which may be performed before feeding a cooking chemical in a cooking reactor or after cooking has started. The heating arrangement used for heating the cooking step is designed for controlled heating as a function of time, which makes fast heating possible. In such a case, the rise of the temperature at the beginning of the cooking step may be e.g. accelerated compared to prior art. The heating arrange-

ment used for heating the cooking step may also be designed for partial vaporization of the cooking chemical, whereby the condensing cooking chemical heats the matter being cooked fast. The screens of the cooking reactors may be dimensioned for circulation larger than customary.

[0058] In this way, a shorter than usually temperature rise may be reached in a cooking reactor without necessarily compromising the quality of the end product. Intensified processing, in relation to conventional pulp manufacturing, which may express itself as a short cooking time and/or controlled end product quality, is surprising because e.g. a fast temperature rise to the desired cooking temperature has usually been considered detrimental (impaired quality, requirement for large circulation and more powerful heat exchanger than previously). The quality of the end product is affected by the temperature profile of the cooking process, that is, the temperature as a function of time in addition to temperature alone. Because the quality of the end product is also controllable, it may be reduced, kept the same, or improved by having the feed of heat energy into the cooking process adjustable. This being the case, the temperature of the cooking reactor may be controlled as a function of time, which affects the cooking time and/or the quality of the end/product.

[0059] Those skilled in the art will find it obvious that, as technology advances, the basic idea of the invention may be implemented in many different ways. The invention and its embodiments are thus not restricted to the above-described examples but may vary within the scope of the claims.

Claims

1. A cooking apparatus for treating biomass containing lignocellulose, wherein the cooking apparatus (10) comprises one or more cooking reactors (100, 100') operating on the batch principle and arranged to cook biomass in a temperature window of 116°C - 170°C by using a cooking chemical which includes 30 to 75 % of formic acid, 6 to 55 % of acetic acid, 13 to 22 % of water, and 0.01 to 3 % of furfural, **characterized by** a heating arrangement (106) which is adapted to adjust the amount of C5 sugars and furfural included in the cooking reactor (100, 100') by adjusting heat energy transfer and the temperature of the cooking chemical as a function of time into each cooking reactor (100, 100') and by feeding the temperature-adjusted cooking chemical into each cooking reactor (100, 100').
2. A cooking apparatus as claimed in claim 1, **characterized in that** the heating arrangement (106) is adapted to adjust the amount of included C5 sugars and furfural in relation to a desired delignification of

the cooking process by adjusting heat energy transfer to each cooking reactor (100, 100').

3. A cooking apparatus as claimed in claim 1, **characterized in that** the heating arrangement (106) is adapted to heat the temperature of the cooking chemical higher than the cooking temperature used for cooking in said one or more cooking reactors (100, 100').
4. A cooking apparatus as claimed in claim 1, **characterized in that** the cooking apparatus (10) comprises a circulation arrangement (102) which is adapted to transfer cooking chemical through pipes (104) from said one or more cooking reactors (100, 100') to the heating arrangement (106) and to transfer the cooking chemical, adjusted from the viewpoint of heat energy transfer, back to at least one of said one or more cooking reactors (100, 100').
5. A cooking apparatus as claimed in claim 1, **characterized in that** at least one of said one or more cooking reactors (100) comprises at least one screen (108) adapted to optimize the flow of the cooking chemical flow adjusted from the viewpoint of the transfer of heat energy by optimizing the transfer of heat energy to optimize the cooking time and/or quality of the end product.
6. A cooking apparatus as claimed in claim 5, **characterized in that** the flowthrough area of said at least one screen (108) is maximized from the viewpoint of the flow of the cooking chemical passing through said at least one screen (108), and to maximize the flow of the cooking chemical moving to the cooking reactor, adjusted (100) from the viewpoint of the transfer of heat energy in relation to the power of the heating arrangement (106) for heating the cooking chemical to feed the optimized heat energy to said at least one cooking reactor (100) to minimize a temperature rise.
7. A cooking apparatus as claimed in claim 4, **characterized in that** at least one of said one or more cooking reactors (100) comprises a plurality of screens (108) at different points (110, 112) of the cooking reactor (100); and the circulation arrangement (102) is adapted to transfer cooking chemical from said at least one cooking reactor (100) through said various screens (108) to the heating arrangement (106).
8. A cooking apparatus as claimed in claim 7, **characterized in that** the circulation arrangement (102) is adapted to return the cooking chemical temperature-adjusted in the heating arrangement (106) and taken through the various screens (108) to different input points in the cooking reactor (100, 100').

9. A cooking apparatus as claimed in claim 7, **characterized in that** the heating arrangement (10) comprises a plurality of heaters (114, 116), and the circulation arrangement (102) is adapted to transfer through the pipes (104) cooking chemical at (110, 112) two different screens (108), at least, to different heaters (114, 116).
10. A cooking apparatus as claimed in claim 1, **characterized in that** the heating arrangement (10) is adapted to optimize the heat transfer of the cooking chemical based on a heat capacity and cooking temperature of the material being cooked in said one or more cooking reactors (100, 100').
11. A cooking apparatus as claimed in claim 1, **characterized in that** the heating arrangement (10) comprises at least one cooking chemical container (150), and each cooking chemical container (150) is adapted to receive at least part of the cooking chemical used in said at least one or more cooking reactors (100, 100'), the heating arrangement (106, 156) is adapted to adjust the temperature of the cooking chemical fed in the cooking chemical container (150), and the cooking chemical container (150) is adapted to feed the temperature-adjusted cooking chemical to said one or more cooking reactors (100, 100') after said one or more cooking reactors (100, 100') have received a biomass batch.
12. A cooking apparatus as claimed in claim 11, **characterized in that** said one or more cooking reactor (100) is adapted to receive temperature-adjusted cooking chemical from said at least one separate cooking chemical container (150) to calcinate the biomass.
13. A cooking apparatus as claimed in claim 11, **characterized in that** the cooking apparatus (10) comprises a first cooking reactor (100) and a second cooking reactor (100'), and a buffer tank (160) of the first cooking reactor is adapted to release the vaporized cooking chemical through pipes (104) to a heat generator (200) which is adapted to adjust the temperature of the cooking chemical and to feed the temperature-adjusted cooking chemical to the second cooking reactor (100').
14. A cooking method for lignocellulose-containing biomass, wherein cooking (1000), in one or more cooking reactor (100, 100') operating on the batch principle, biomass in a temperature window of 116°C - 170°C by using a cooking chemical which includes 30 to 75 % of formic acid, 6 to 55 % of acetic acid, 13 to 22 % of water, and 0.01 to 3 % of furfural, **characterized by** adjusting (1002) the amount of C5 sugars and furfural contained in the cooking reactor (100, 100') by

adjusting heat energy transfer and the temperature of the cooking chemical as a function of time into each cooking reactor (100, 100'); and feeding (1004) the temperature-adjusted cooking chemical into one or more cooking reactors (100, 100').

15. A cooking method as claimed in claim 1, **characterized by** adjusting by the heating arrangement (106) the amount of C5 sugars and furfural included in the cooking reactor (100, 100') in relation to a desired delignification of the cooking process by adjusting heat energy transfer to each cooking reactor (100, 100').

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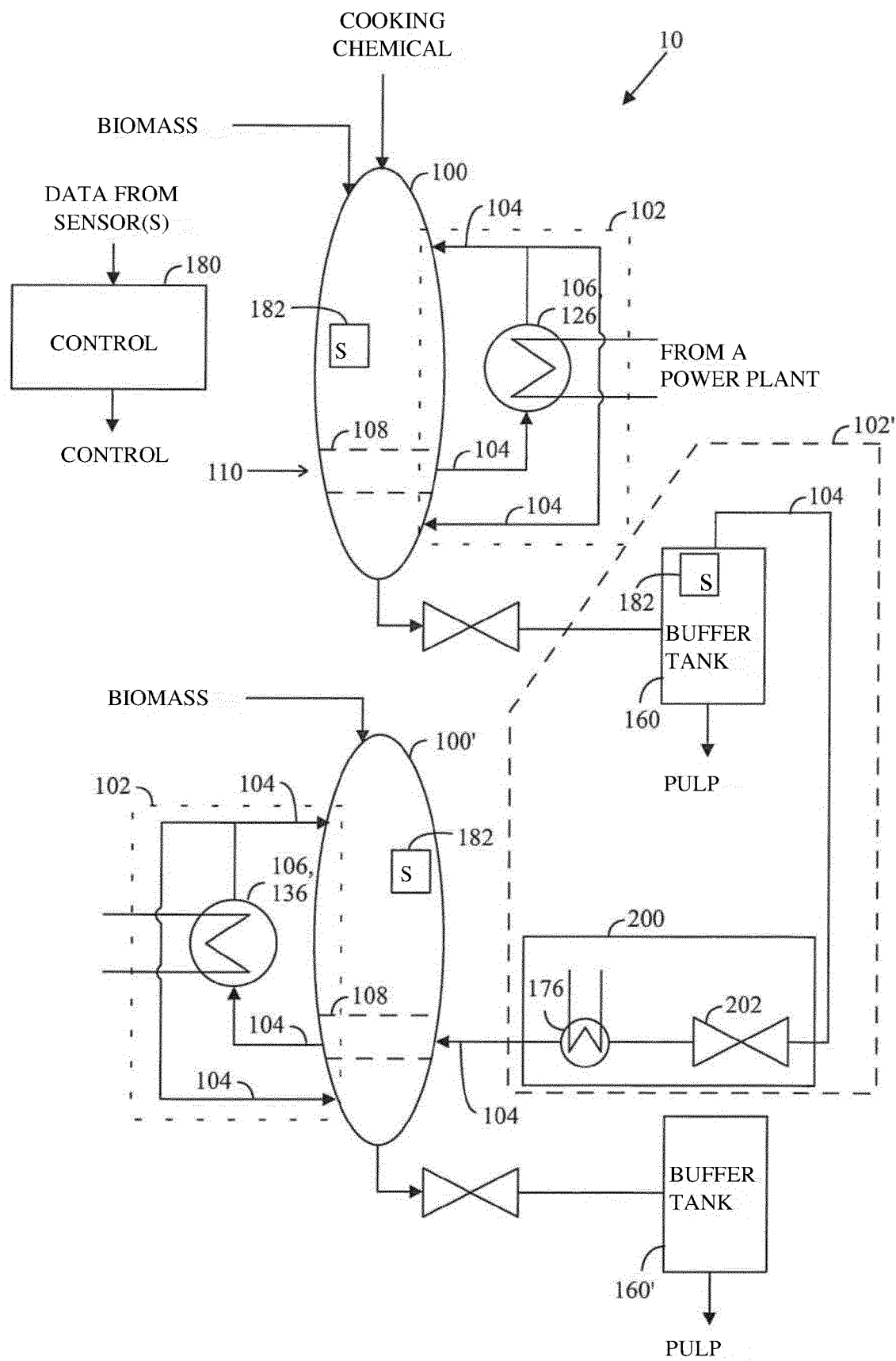


FIG. 1

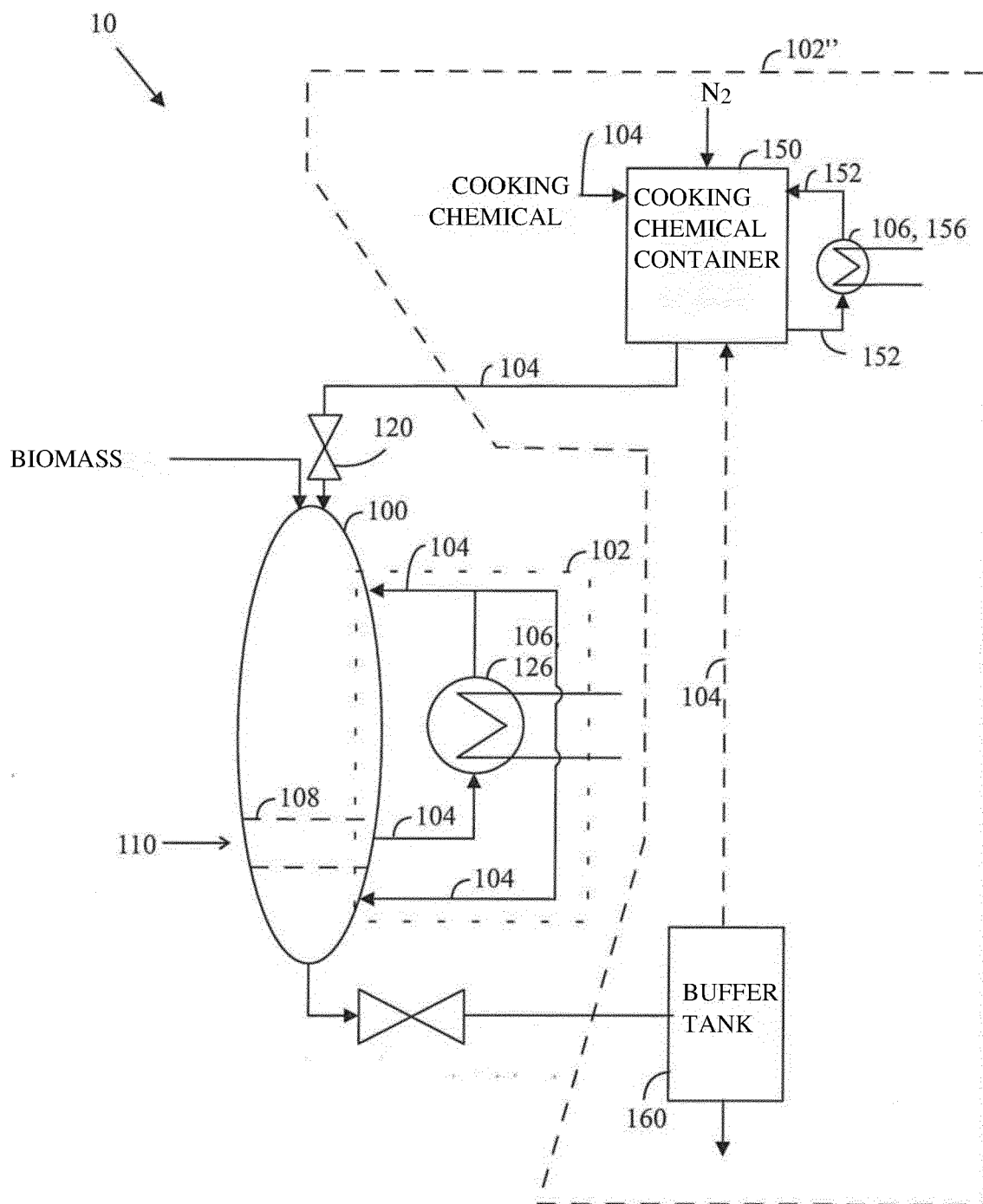


FIG. 2

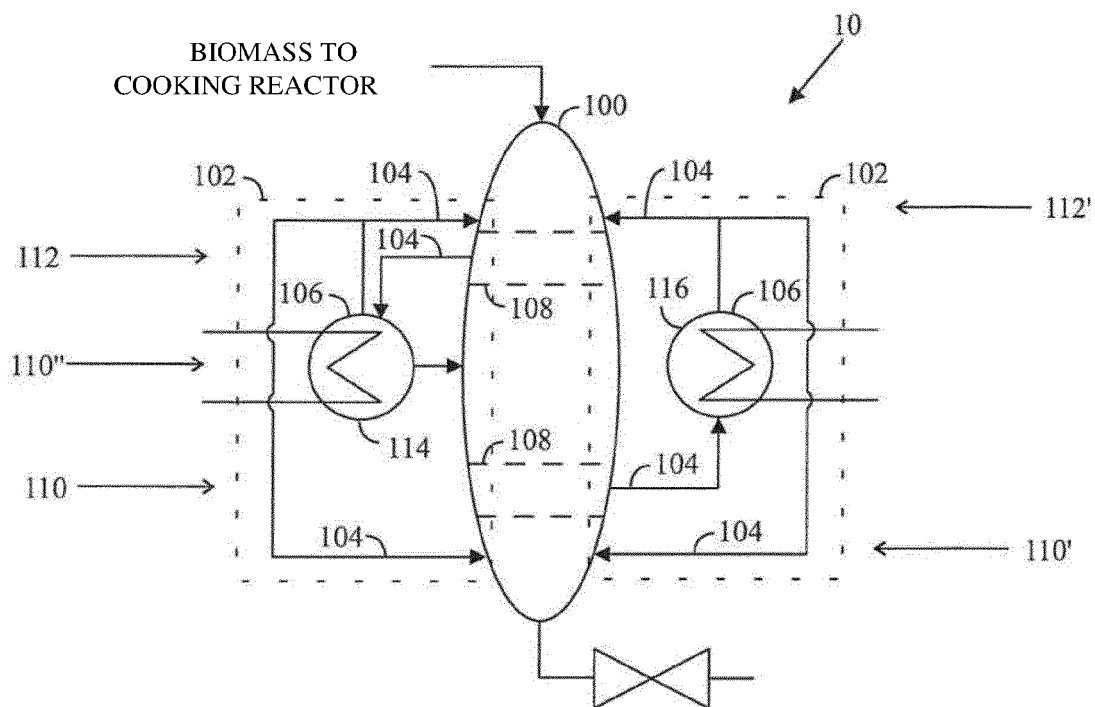


FIG. 3

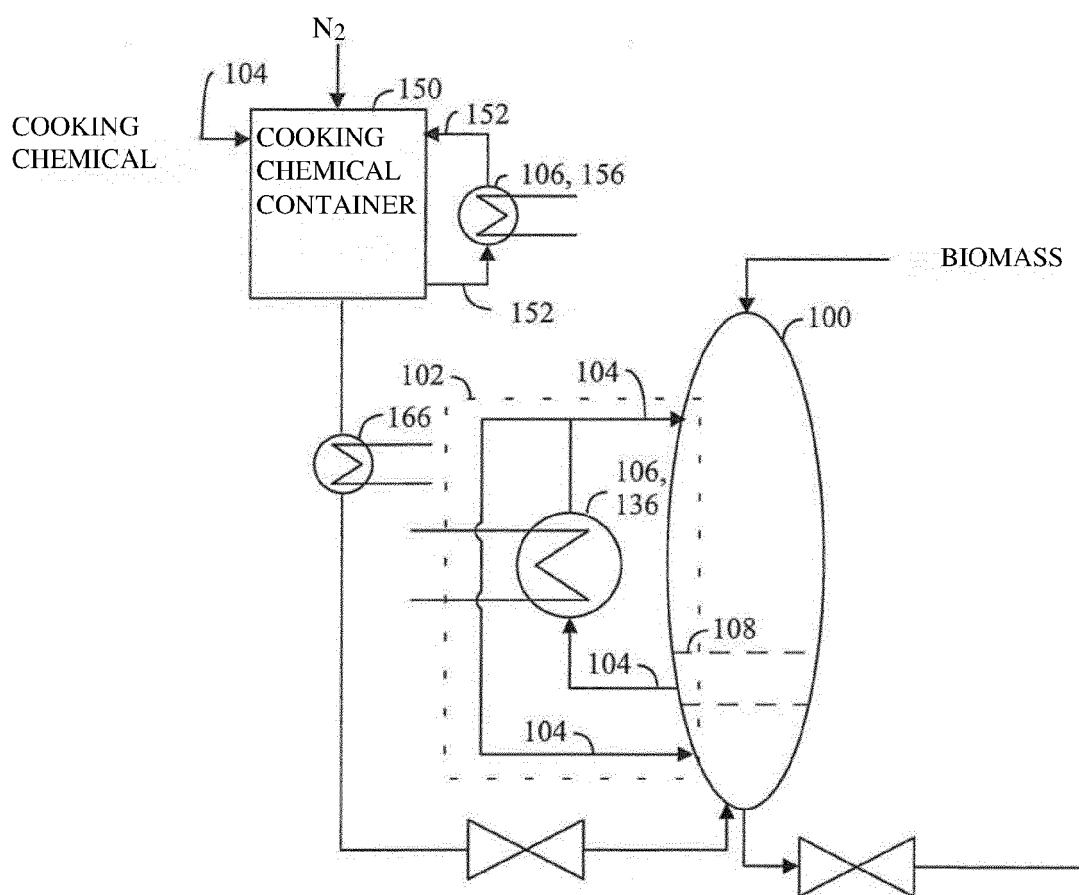


FIG. 4

SUBSTANCE COMPONENTS OF
COOKING CHEMICAL

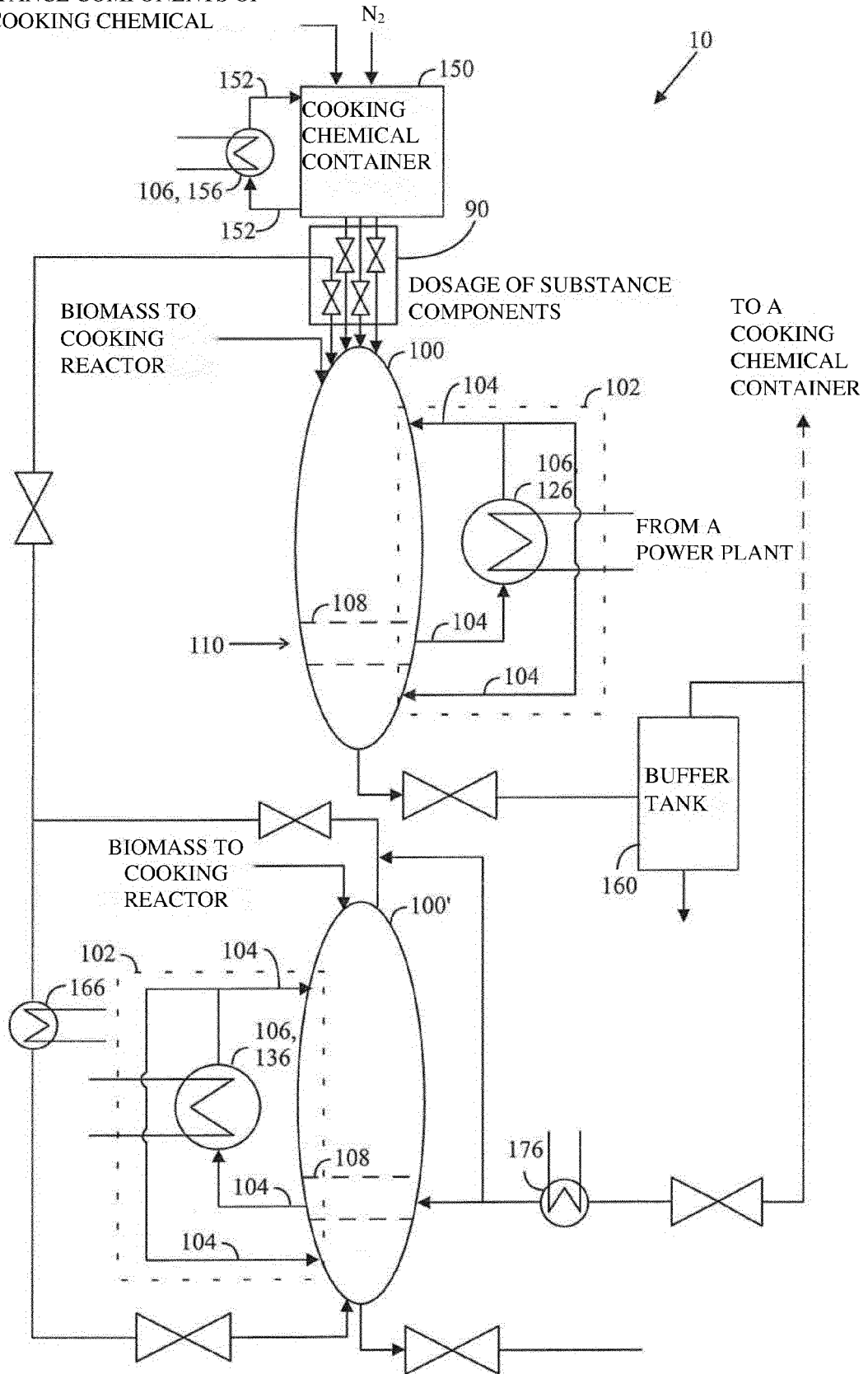


FIG. 5A

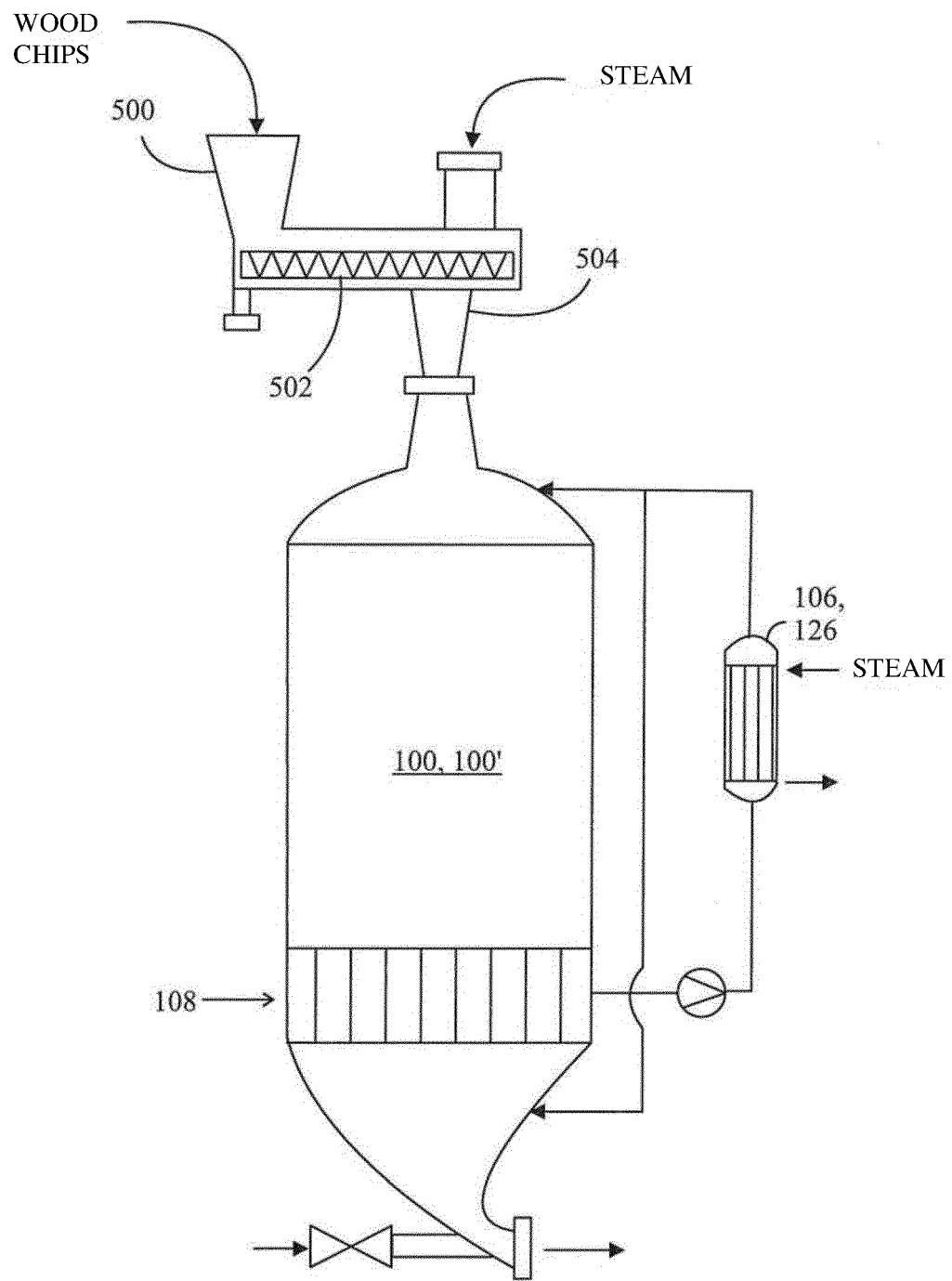


FIG. 5B

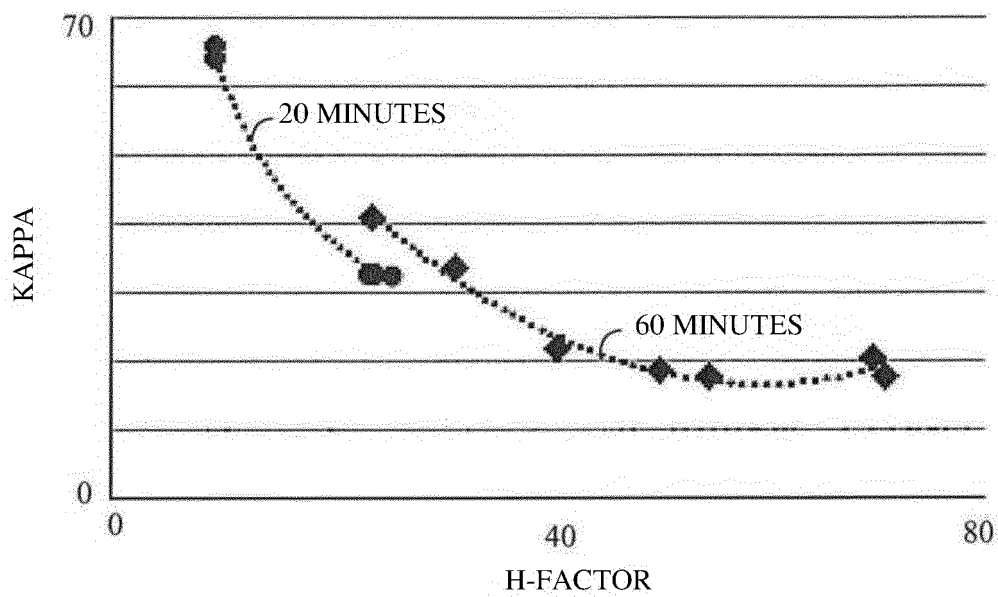


FIG. 6

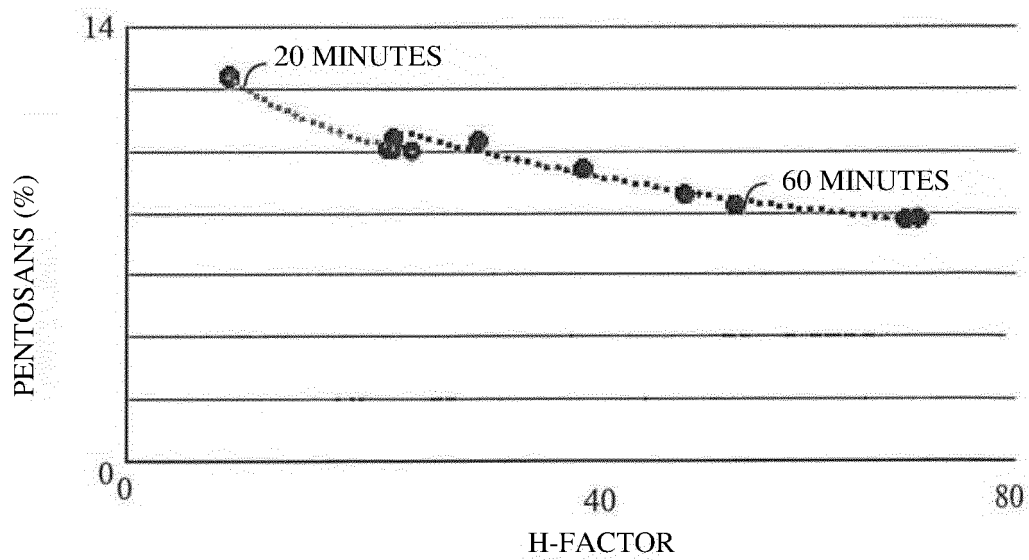


FIG. 7

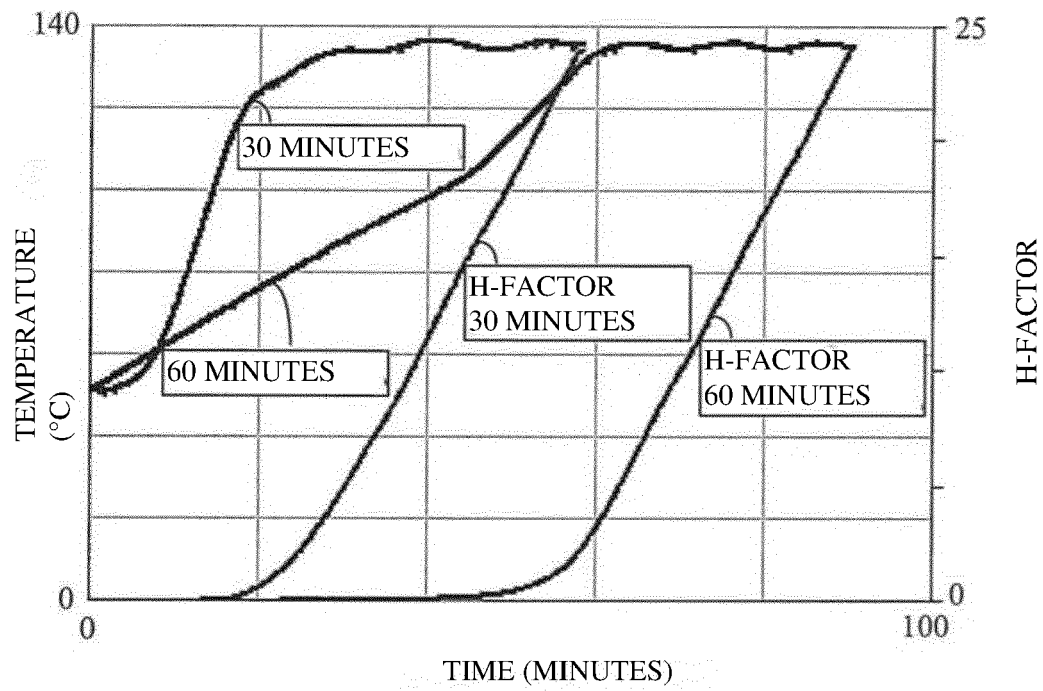


FIG. 8

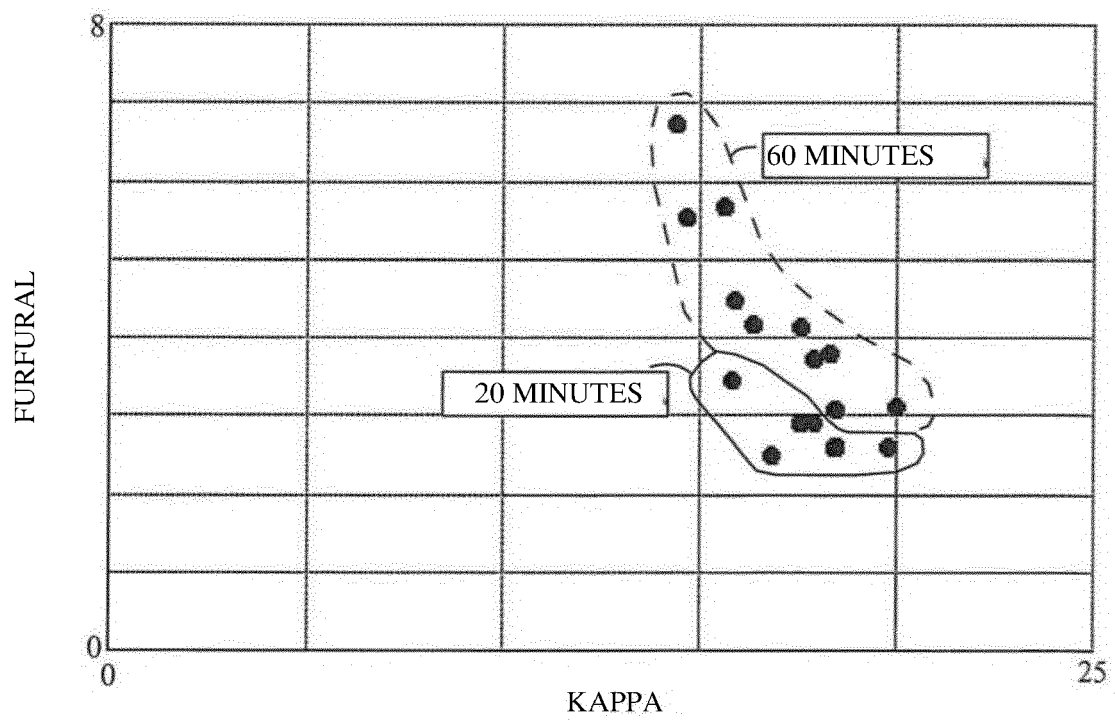


FIG. 9

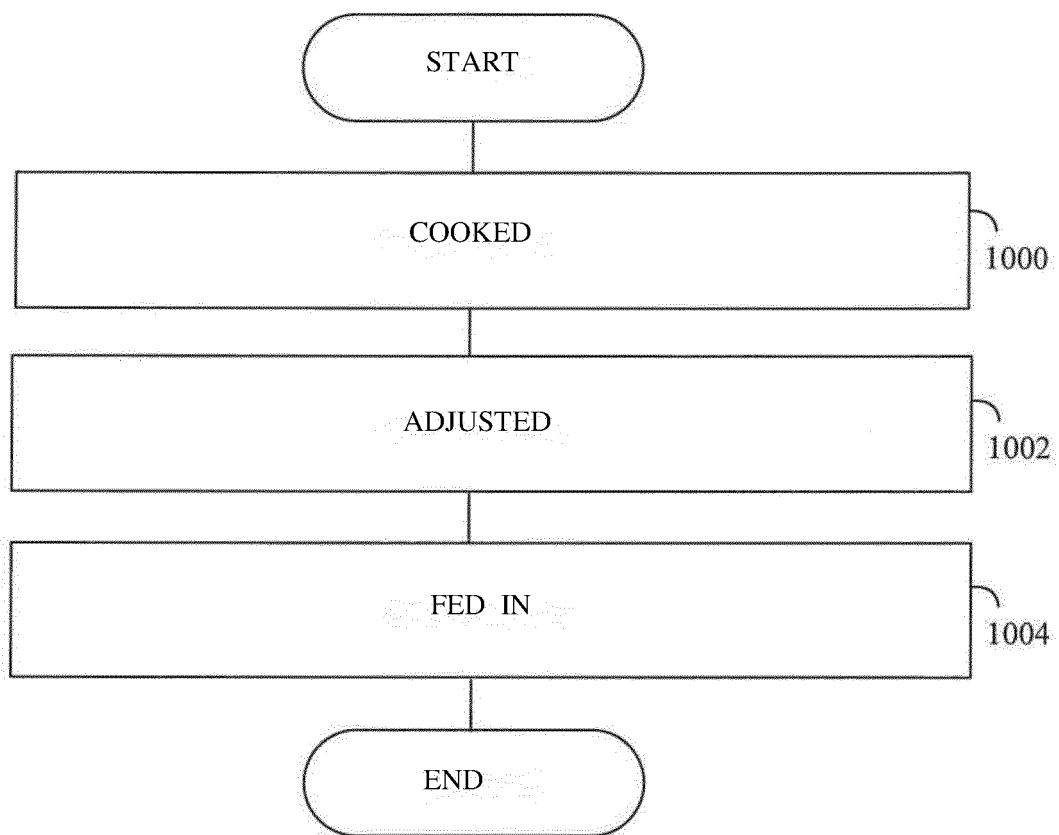


FIG. 10

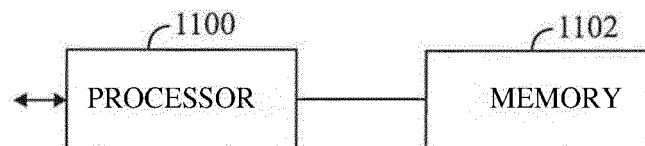


FIG. 11



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Place of search Munich		Date of completion of the search 4 June 2021	Examiner Karlsson, Lennart
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The members are as contained in the European Patent Office EDP file on
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