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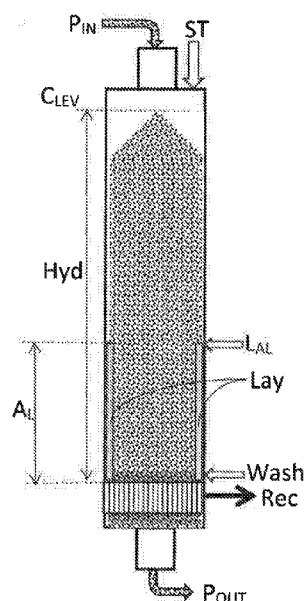


Fig. 3a

(57) Abstract: The invention relates to a method for inhibiting build-up of deposits of sticky reaction products on the interior reactor surfaces in an acidic prehydrolysis zone of continuous vertical reactor vessels or digesters and a reactor design that enables implementation of the inventive method. According to the inventive method and reactor, a layer (Lay) of alkaline liquid is established on the inner wall of the reactor in the prehydrolysis zone, which alkaline layer prevents sticky deposits from forming and adhering to the inner wall of the vertical reactor.

METHOD FOR OPERATING A CONTINUOUS VERTICAL REACTOR COMPRISING A PREHYDROLYSIS ZONE AND THE REACTOR DESIGN AS SUCH

5 Field of the Invention

The invention relates to an improved method for operating a continuous vertical reactor or digester with a prehydrolysis zone, avoiding build-up of sticky deposits on the wall of the reactor, as well as a reactor design that enables implementation of the inventive method.

10 Background of the Invention

In older digester systems with a prehydrolysis zone followed by alkaline kraft cooking, severe problems with formation of sticky deposits have been encountered towards the end of the prehydrolysis zone caused by reaction products of further degradation and condensation of dissolved carbohydrates. In early implementations of prehydrolysis kraft systems, the
15 extraction screens following the hydrolysis were frequently being blocked by the sticky deposits formed. Most often the extraction screens became blocked after only one to three days of operation, requiring shut down and cleaning of extraction screens.

Prehydrolysis kraft cooking has been implemented both in two-vessel systems and in single-
20 vessel systems, where the hydrolysis takes place in almost the entire first vessel of a two-vessel systems and in the upper part of the single-vessel system, i.e. the latter requiring a swing from acidic conditions to alkaline conditions in the same vessel. In the two-vessel systems the swing from acidic conditions to alkaline conditions takes place between vessels or starting in the bottom part of the first vessel directly ahead of transfer to second vessel.

25

Several solutions have been suggested to overcome operational difficulties, and some recent prehydrolysis kraft cooking systems use a two-vessel design where the upper part of the first reactor is a strictly acidic concurrent treatment, and the lower part of the first reactor is a countercurrent wash and neutralization zone. The disadvantage with this approach is that
30 almost 50 % of the entire first vessel is used for the pH swing process only.

A solution to prevent clogging of screens is shown in the U.S. Patent No. 8,449,717, where a chemical additive, which may dissolve sticky deposits, is added into the withdrawal

compartment in the screen section. This addition has, however, no impact on sticky deposits forming on the inside wall of the prehydrolysis zone.

Another approach is the Compact Prehyd system, which was developed by the company Valmet and is disclosed in the European Patent No. EP2707539, where instead the prehydrolysis zone is ended by adding cooler alkaline liquor that abruptly ends the hydrolysis by rapid temperature decrease and pH increase, and no withdrawal of hydrolysate is made at the end of the hydrolysis.

10 Summary of the Invention

Recent experience from chemical treatment in continuous processes using vertical reactors has shown that alkaline liquor added through the wall of reactor will not penetrate the descending compressed column of lignocellulosic raw material – normally in the form of wood chips – unless forced radial flows are imposed upon the descending column. A radial flow may be imposed by conventional cooking circulations using extractions screens in the wall of the reactor, extracting treatment liquor, and by adding displacement liquor through a central pipe in the center of the descending column. Most surprisingly, it has been seen in screen-less black liquor impregnation vessels that alkali added to the descending column of cellulosic material through nozzles in the wall of the reactor will form a liquid layer that is maintained all the way down to the bottom and that this layer is broken up first when it is subjected to the wiping force of a bottom scraper. In black liquor impregnation, especially if applied at temperatures above 120 °C, a lot of the alkali content is consumed by the released wood acidity, and some of the alkali is consumed by partial delignification reactions, and hence alkali is most often added to maintain a sufficiently high pH, preventing lignin to precipitate on the cellulosic material. In fact, in a black liquor impregnation vessel where alkali is added through nozzles in the wall of the reactor (or impregnation vessel), it has been seen after shut down that alkali streaks have been established on the inside wall of the reactor from the nozzles, and that the width of these alkali streaks has been kept constant all the way from the nozzles and down to a bottom scraper.

30

Now, this behavior of liquors added to vertical reactors may be applied as a solution to the clogging problem that has been addressed over more than half a century in prehydrolysis zones where build-up of sticky deposits soon clog the equipment and requires shut down and subsequent cleaning using for example hot strong alkaline liquid.

The inventive method

The invention relates to the problem with formation of sticky deposits in prehydrolysis, which deposits clog up surfaces, screens and liquor withdrawal compartments. In contrast to prior art
5 solutions where only acid, often diluted sulfuric acid, is added to a liquid-phase prehydrolysis, or where autohydrolysis is activated by adding hot steam releasing wood acidity under slightly higher temperatures, a boundary layer of anti-fouling liquid is established on the reactor wall in the prehydrolysis zone to prevent sticky reaction products of the hydrolysis to be deposited on the surface of the equipment. Conventionally, especially in autohydrolysis in
10 steam-phase any alkali charge is avoided as that would neutralize the released wood acidity from establishing the required pH for the prehydrolysis. This applies also for liquid-phase prehydrolysis where any content of alkali may prevent the added acid to establish the necessary pH for an effective hydrolysis.

15 An anti-fouling liquid is within this context a liquid that is either neutral or alkaline. Examples of suitable anti-fouling liquids are neutral or alkaline solutions, liquid surfactants, solvents, water and mixtures thereof. In a preferred embodiment, the anti-fouling liquid is alkaline, advantageously with a pH above 8, and even more preferably above 9. An alkaline boundary layer is advantageous in that it will counteract formation of deposits by keeping
20 solubilized the hydrolysis reaction products, dissolved substances from the biomass and possible precursors that are prone to form deposits.

In a preferred embodiment, the anti-fouling liquid used is any of alkali, SO₂, sulfite or bisulfite solution, water, or mixtures thereof. Alkali usage has the positive effect of dissolving
25 any acidic sticky compounds and keeping them solubilized, and if applied as a layer on the reactor wall it will not impede the hydrolysis of the bulk part of the material volume. The released acid compounds, mainly from acetyl groups in the hemicellulose part of the lignocellulosic raw material, will keep the pH low in the bulk of the raw material to enable the prehydrolysis. Applying a sulfite solution resulting in sulfonation of certain compounds, e.g.
30 aromatic moieties from lignin, is known to make them more soluble and thus less prone to precipitate under prehydrolysis conditions. Water may also be used, especially if a continuous flushing flow, i.e. mechanical removal from the surface of reactor wall, is sufficient. Hence, the liquid may be any mixture of alkali, SO₂/sulfite/bisulfite and water. If kraft white liquor is

to be used as alkali source, oxidized white liquor is preferred to avoid the risk of formation of gaseous hydrogen sulfide.

In a preferred embodiment, a control member is used for regulating the flow of the anti-fouling liquid in said supply channel. Further, the anti-fouling liquid needs to be preheated close to the prehydrolysis temperature before being introduced into the prehydrolysis reactor.

The inventive method is used for inhibiting the formation of sticky deposits in an acidic prehydrolysis zone of continuous vertical reactors, wherein lignocellulosic material is fed continuously to the top of said reactor and said lignocellulosic material being subjected to hydrolysis in at least a part of the continuous vertical reactor and at least hydrolyzed lignocellulosic material is fed out from the bottom of said continuous vertical reactor. According to the inventive method, a layer of alkaline liquid boundary layer is established at the interior wall of the continuous vertical reactor in a position corresponding to at least 30 % of the lower final part of the total vertical length of the prehydrolysis zone, i.e. the lowermost 30 % of the prehydrolysis zone, and wherein said layer of alkaline liquid is maintained at the wall of the reactor until the lower end of the prehydrolysis zone. By this establishment of the layer on the inner wall of the reactor in at least 30 % of the lower part of the prehydrolysis zone, the sticky reaction products that have formed in upper part will be kept dissolved and formation of sticky deposits on the interior wall will be suppressed.

In a further embodiment of the inventive method, the layer of alkaline liquid can be established at the wall of the continuous vertical reactor in a position corresponding to at least 50 % of the lower part of the total vertical height of the prehydrolysis zone. This creates a longer (higher) vertical layer, that may be needed when hydrolyzing cellulosic material that releases sticky deposits to a larger extent early in the prehydrolysis process.

The supplied alkaline liquor, when it enters the reactor, is preferably preheated to a temperature close to the temperature of the cellulose material in the prehydrolysis zone of the reactor. The pH of the alkaline liquor layer at the end of the prehydrolysis zone should at least be in the range of 8-10. The pH of the liquor as supplied to the reactor can be higher according to the general aspects of the invention, i.e. depending on the type of lignocellulosic raw material, the hydrolysis temperature and the solids-to-liquid ratio in the bulk of the lignocellulosic raw material.

The inventive reactor design

The inventive reactor design according to the invention is applied in a continuous vertical reactor or digester, wherein lignocellulosic material is fed continuously to an inlet in the top of the reactor and at least hydrolyzed lignocellulosic material is fed out from an outlet in the bottom of the reactor, said reactor comprising an acidic prehydrolysis zone in at least the upper part of the reactor. According to the inventive reactor design, a layer of alkaline anti-fouling liquid is established on the inner reactor wall by injecting alkaline liquid from an alkali liquid source through distribution nozzles arranged around the circumference of the interior wall of the continuous vertical reactor in a position corresponding to at least 30 % of the lower part of the total vertical height of the prehydrolysis zone.

Further, according to a preferred embodiment of the reactor design, the distribution nozzles can be arranged around the circumference of the interior wall of the continuous vertical reactor in a position corresponding to at least 50 % of the lower part of the total vertical height of the prehydrolysis zone.

In yet a preferred embodiment, the distribution nozzles can be arranged around the circumference of the interior wall of the continuous vertical reactor behind a vertical guide plate that directs the flow of alkaline anti-fouling liquid downwards and in parallel with the interior wall of the continuous vertical reactor. This design is preferably implemented in new reactors being designed to apply the layer of anti-fouling liquid. The design with a guide plate will assure that a layer of alkaline liquor is readily formed in the reactor before it is being exposed to the descending plug of lignocellulosic material.

25

In a further embodiment of the inventive reactor design, at least one additional layer of alkaline liquid can be established by injecting alkaline anti-fouling liquid through a second set of distribution nozzles arranged around the circumference of the interior wall of the continuous vertical reactor in a position located at a distance from and below the first established layer of alkaline liquid at least 10% of the total vertical height of the prehydrolysis zone.

In a further embodiment of the inventive reactor design, no extraction screens are located in the wall of the prehydrolysis zone between the positions for alkali injection and the end of the

prehydrolysis zone. The extraction screens may interfere in a negative way with the established anti-fouling liquid boundary layer at the interior wall of the continuous vertical reactor and causing a radial flow. However, it may be possible to overcome this obstacle by designing the extraction screens and its attachments such that they will guide the antifouling liquid to continue along the interior wall of the continuous vertical reactor also below the extraction screens or, as described above, provide another set of distribution nozzles around the circumference of the interior wall in close vicinity to the extraction screens in order to provide for a continuous boundary layer of anti-fouling liquid to continue also below the extraction screens.

10

Brief Description of Drawings

The following schematic drawings explain the prior art and the invention, wherein:

Fig. 1a shows a prior art steam phase prehydrolysis zone in a reactor.

15 Fig. 1b shows a prior art liquid phase prehydrolysis zone in a reactor.

Fig. 1c shows a prior art liquid phase prehydrolysis zone in upper part of a reactor.

Fig. 2a shows a single reactor/digester according to prior art with an upper prehydrolysis zone and a subsequent kraft cooking zone.

20 Fig. 2b shows the screen section between the upper prehydrolysis zone and a subsequent kraft cooking zone in Fig. 2a.

Fig. 2c shows the displacement flow profile established in the screen section in Fig. 2b.

Fig. 3a shows a steam phase prehydrolysis zone in a reactor according to the invention.

Fig. 3b shows a liquid phase prehydrolysis zone in a reactor according to the invention.

25 Fig. 3c shows a liquid phase prehydrolysis zone in upper part of a reactor according to the invention.

Fig. 4 shows a first alternative seen in a vertical cross section of the vertical reactor for forming the alkaline layer on the inner surface of the reactor wall.

Fig. 5 shows a second alternative seen in a vertical cross section of the vertical reactor for forming the alkaline layer on the inner surface of the reactor wall.

30 Fig. 6 shows the inventive nozzles, as seen in a horizontal cross section of the vertical reactor, arranged around the circumference of the interior wall of the continuous vertical reactor.

Fig. 7 shows a third alternative, as seen in a horizontal cross section of the vertical reactor, for forming the alkaline layer on the inner surface of the reactor wall.

Fig. 8 shows a fourth alternative, as seen in a horizontal cross section of the vertical reactor, for forming the alkaline layer on the inner surface of the reactor wall.

Fig. 9 shows a fifth alternative, as seen in a horizontal cross section of the vertical reactor, for forming the alkaline layer on the inner surface of the reactor wall.

- 5 Fig. 10 shows a sixth alternative, as seen in a horizontal cross section of the vertical reactor, for forming the alkaline layer on the inner surface of the reactor wall.

Detailed Description of Invention

Prior art

- 10 Figs. 1a-1c show three different conventional prior art implementations of a prehydrolysis zone in a vertical reactor. In all these figures, lignocellulosic material, flow P_{IN} , is fed to the top of the vertical reactor, and steam ST is also added to establish the temperature needed to attain the necessary conditions for prehydrolysis. An upper level, C_{LEV} , of lignocellulosic material is established. The vertical height of the prehydrolysis zone is indicated by Hyd. The
- 15 lignocellulosic material is finally fed out from the bottom of the vertical reactor in flow P_{OUT} .

- Fig. 1a shows a vertical reactor where the prehydrolysis zone Hyd is established in a steam phase prehydrolysis zone Hyd. This steam phase prehydrolysis zone ends near the bottom where typically the hydrolysed lignocellulosic material is diluted with a washing/diluting liquid, indicated by Wash, and some of the dissolved organic material from the hydrolysis
- 20 process, mainly carbohydrates from hemicellulose, is withdrawn in a bottom screen SC, indicated by the flow Rec.

- Fig. 1b shows a vertical reactor where most of the prehydrolysis zone Hyd is established in a liquid-phase prehydrolysis zone. A short steam-phase heating zone can precede the liquid-phase zone as indicated. An upper level C_{LEV} of lignocellulosic material and an upper level L_{LEV} of liquid are established. The liquid-phase prehydrolysis zone ends near the bottom where some of the dissolved organic material from the hydrolysis process, mainly carbohydrates from hemicellulose, can be withdrawn in a bottom screen SC, indicated by the flow Rec. The liquid-phase prehydrolysis differs from the autohydrolysis in a steam-phase
- 25 prehydrolysis zone by the fact that acid is added, typically H_2SO_4 , and that the required temperature is about 20-40 °C lower than that in a steam-phase hydrolysis zone; the latter typically held at 160-190 °C.
- 30

The embodiments shown in Figs. 1a and 1b are conventionally applied in two-vessel reactor systems, where the first vessel is used for prehydrolysis and a second vessel most often is used for alkaline kraft cooking. However, other type of cooking processes can follow in the second vessel, such as sulfite cooking, and different variants of kraft cooking such as MCC, EMCC, Lo-Solids or Compact Cooking.

Fig. 1c shows a vertical reactor where only the upper part of the vertical reactor is used as a prehydrolysis zone, Hyd, in this case a liquid-phase prehydrolysis zone. This embodiment is applied in single-vessel reactor systems where a prehydrolysis zone is established in the upper part, typically 30-60 % of the vertical height of the reactor. An upper level C_{LEV} of lignocellulosic material and an upper level L_{LEV} of liquid are established. The liquid-phase prehydrolysis zone Hyd ends at a screen section SC located after a concurrent prehydrolysis zone, but before a countercurrent cooking zone Cook below the screen section SC, where some of the dissolved organic material from the prehydrolysis zone, mainly carbohydrates from hemicellulose, can be extracted in the screen section SC, indicated by the flow Rec.

Fig. 2a shows another visualization of a prior art single-reactor system which is similar to the single reactor shown in Fig. 1c. As can be seen, there are also additional screen sections SC2 and SC3 implemented in the cooking zone, but those have no impact on the prehydrolysis zone or the current invention, and are therefore not described in more detail. The screen section SC ending the prehydrolysis zone is shown in more detail in Fig. 2b. The screen section SC in Fig. 2b comprises two screen rows, an upper screen row and a lower screen row. Liquor withdrawn from the lower screen row is lead to a circulation pump after which alkaline liquor is added, here in form of white liquor WL. The pressurized alkaline liquor is reintroduced into the reactor in three positions: first via a central pipe CP, secondly via nozzles to the upper screen row, and thirdly via nozzles to the lower screen row. The pressurized alkaline liquor supplied to the central pipe and the upper screen row will also pass through a heater He, before being added to the reactor. As indicated in Fig. 2c, a radial displacement pattern is developed with a flow of heated alkaline liquor from the central pipe and the upper screen row, which then will be extracted through the lower screen row. This kind of solution will add alkaline liquor to the end of the prehydrolysis zone.

The invention

The improvement according the invention is shown in Figs. 3a, 3b, and 3c, which represent a modification of the systems shown in Figs. 1a, 1b and 1c, respectively.

Thus, the system shown in Fig. 3a has everything similar to that in Fig. 1a, except for the
5 introduction of an anti-fouling liquid layer, Lay, that is established over a vertical height A_L in the reactor in the prehydrolysis zone, by adding an alkaline liquor L_{AL} .

The system shown in Fig. 3b has everything similar to that in Fig. 1b, except for the
10 introduction of an anti-fouling liquid layer, Lay, that is established over a vertical height A_L in the reactor in the prehydrolysis zone, by adding an alkaline liquor L_{AL} .

And finally, the system shown in Fig. 3c has everything similar to that in Fig. 1c, except for the introduction of an anti-fouling liquid layer, Lay, that is established over a vertical height A_L in the reactor in the prehydrolysis zone, by adding an alkaline liquor L_{AL} .

15 Fig. 4 shows a first embodiment in which a nozzle NZ supplies alkaline liquor to the upper part of a chamber formed between a vertical guide plate GP and a step out in the reactor wall. The width C_T of the chamber establishes an alkaline liquor volume that flows vertically downwards passing the lower lip of the guide plate GP. Below the lower lip, the descending column of lignocellulosic material can expand slightly as indicated and a liquor layer with a
20 thickness L_T is maintained on the reactor wall. This embodiment is preferably implemented in new reactor vessels where the step out in the reactor wall can be included when the reactor is designed.

Fig. 5 shows a second embodiment visualizing how a nozzle NZ supplies alkaline liquor
25 through the wall of a reactor, but without any step out or guide plate. The thickness of the liquor layer established is indicated by L_T . This embodiment is preferably implemented as an upgrade in already installed reactor vessels where the alkaline layer is intended to be implemented to reduce the problem with sticky deposits, and where the costs for changing the reactor wall with a step out would be excessively high.

30

Fig. 6 shows a horizontal cross section of the reactor with the nozzles NZ evenly distributed around the circumference of the interior wall of the reactor, as implemented in a reactor with a step out according to Fig. 4. The distance between two neighboring nozzles is determined by the amount of alkaline liquor supplied and the production rate in the reactor, i.e. how fast the

column of lignocellulosic material moves downward. The established alkaline boundary layer around the circumference of the inner reactor wall below the step out is indicated by the solid line L_T in Fig. 4. To start with is the total volume of alkaline liquor added by all nozzles determined by calculating the void volume occurring below the step out as the plug descends, 5 assuming no radial expansion of the lignocellulosic raw material column. This volume is preferably the minimum volume added, but it may be increased or decreased by 5-20 % depending on the type of lignocellulosic material treated in the reactor, i.e. if it is chopped annual plants or wood chips from hardwood or softwood. The flow of alkaline liquor needed may be adjusted after inspection of the interior wall of the reactor during shut down when the 10 reactor is empty. The chemicals added will result in a different coloring on the wall when a layer is established, and the color on the wall above the nozzles will be different from the color below the nozzles.

In Fig. 7 is shown in a horizontal cross section of the reactor with the nozzles NZ evenly 15 distributed around the circumference of the interior wall of the reactor, as implemented in a reactor without a step out or without a vertical guide plate, i.e. according to Fig. 5. In this embodiment the nozzles NZ penetrate the reactor wall at a 90-degree angle in the horizontal plane, and directed to the very center of the reactor. Alternatively, the nozzles can also be slightly angled in a vertical plane as shown in Fig. 4, i.e. at an angle α .

20

Fig. 8 shows a horizontal cross section of the reactor with the nozzles NZ evenly distributed around the circumference of the interior wall of the reactor, as implemented in a reactor without a step out or without a vertical guide plate, i.e. according to Fig. 5. In this embodiment the nozzles NZ penetrate the reactor wall at a pointy angle β in the horizontal 25 plane, and directed to establish a tangential flow along the interior wall of the reactor. Alternatively, the nozzles can also be slightly angled in a vertical plane as shown in Fig. 5, i.e. at an angle α .

Fig. 9 shows a horizontal cross section of the reactor with the nozzles NZ evenly distributed 30 around the circumference of the interior wall of the reactor, as implemented in a reactor with a step out and a vertical guide plate GP, i.e. according to Fig. 4. In this embodiment, the nozzles NZ penetrate the reactor wall at a pointy angle β in the horizontal plane, and directed to establish a tangential flow along the interior wall of the reactor and into the chamber formed

between the reactor wall and the guide plate GP. Alternatively, the nozzles can also be slightly angled in the vertical plane as shown in Fig. 5, i.e. at an angle α .

With the application of a guide plate GP the number of nozzles can be reduced as indicated in Fig. 10, as the chamber may be evenly filled around the circumference by the tangentially flow established and before the descending column with lignocellulosic material meets the alkaline liquid layer below the lower lip of the guide plate.

The invention may be modified in several different ways in comparison with the preferred embodiments shown in Figs. 4 to 10.

One alternative embodiment is to supply anti-fouling liquid at more than one vertical position in the reactor. In such an embodiment, a first group of nozzles for anti-fouling liquid supply can be arranged in a height position at about 70-90 %, preferably 80 %, above the end of the prehydrolysis zone, and a second set of nozzles be arranged in a height position at about 50-70 %, preferably 60 %, above the end of the prehydrolysis zone, and even a third set of nozzles may be arranged in a height position at about 30-50 %, preferably 40 %, above the end of the prehydrolysis zone. These multiple additions at different height positions all contribute to consolidation of the layer of anti-fouling liquid and maintaining the integrity of the boundary layer all the way down to the end of the prehydrolysis zone. Applying several positions for addition of anti-fouling liquid at different heights of the reactor can also include an extraction screen located directly above the second and/or a third addition position. Such additional extraction screens allow extraction of the anti-fouling liquid layer established above the screen together with liberated sugars dissolved in the hydrolysate, while the anti-fouling liquid layer is reestablished again by nozzles arranged below such screens.

CLAIMS

1. A method for inhibiting build-up of deposits of sticky reaction products on the interior reactor surfaces in an acidic prehydrolysis zone of a continuous vertical reactor vessel wherein lignocellulosic material is fed continuously to the top of said reactor and said
5 lignocellulosic material being subjected to a prehydrolysis in at least a part of the continuous vertical reactor and at least prehydrolyzed lignocellulosic material is fed out from the bottom of said continuous vertical reactor, **characterized in that** a layer (Lay) of anti-fouling liquid is established at the interior wall of the continuous vertical reactor in a position corresponding to at least 30 % of the lower final part of the total
10 vertical length of the prehydrolysis zone (Hyd), and wherein said layer of anti-fouling liquid is maintained at the wall of the reactor until the lower end of the prehydrolysis zone.
2. The method according to claim 1, **characterized in that** the layer of anti-fouling
15 liquid is established at the wall of the continuous vertical reactor in a position corresponding to at least 50 % of the lower final part of the total vertical length of the prehydrolysis zone (Hyd).
3. The method according to claim 2, **characterized in that** the layer of anti-fouling
20 liquid is established at the wall of the continuous vertical reactor in a position corresponding to below 10 % of the upper first part of the total vertical length of the prehydrolysis zone.
4. The method according to claim 3, **characterized in that** the position corresponding to
25 below 10 % of the upper first part of the total vertical length of the prehydrolysis zone lies at least 5 meters below the upper level (C_{LEV}) of lignocellulosic material established in the continuous vertical reactor.
5. The method according to claim 4, **characterized in that** the position corresponding to
30 below 10 % of the upper first part of the total vertical length of the prehydrolysis zone lies at least 5 meters below the upper level (L_{LEV}) of hydrolysis liquid established in the continuous vertical reactor.

6. The method according to claim 1, **characterized in that** the pH of an alkaline liquid when establishing the anti-fouling liquid layer lies in the range 8-14, preferably in a pH range of 9-10.

5 7. A continuous vertical reactor wherein lignocellulosic material is fed continuously to an inlet in the top of said reactor and at least hydrolyzed lignocellulosic material is fed out from an outlet in the bottom of said continuous vertical reactor, said reactor comprising an acidic prehydrolysis zone (Hyd) in at least the upper part of the reactor, **characterized in that** a layer (Lay) of anti-fouling liquid is established by injecting
10 alkaline liquid from an alkali liquid source through distribution nozzles (NZ) arranged around the circumference of the interior wall of the continuous vertical reactor in a position corresponding to at least 30 % of the lower final part of the total vertical length of the prehydrolysis zone (Hyd).

15 8. The continuous vertical reactor according to claim 7, **characterized in that** the distribution nozzles (NZ) are arranged around the circumference of the interior wall of the continuous vertical reactor in a position corresponding to at least 50 % of the lower final part of the total vertical length of the prehydrolysis zone (Hyd).

20 9. The continuous vertical reactor according to claim 8, **characterized in that** the distribution nozzles are arranged around the circumference of the interior wall of the continuous vertical reactor behind a vertical guide plate (GP) that directs the flow of anti-fouling liquid downwards and in parallel with the interior wall of the continuous vertical reactor.

25 10. The continuous vertical reactor according to claim 7, **characterized in that** at least one additional layer of alkaline liquid is established by injecting alkaline liquid from an alkali liquid source through a second set of distribution nozzles arranged around the circumference of the interior wall of the continuous vertical reactor in a position
30 located at a distance from the first established layer of alkaline liquid at least 10 % of the total vertical length of the prehydrolysis zone.

11. The continuous vertical reactor according to claim 7, **characterized in that** no extraction screens (SC) are located in the wall of the prehydrolysis zone between the positions for injection of anti-fouling liquid and the end of the prehydrolysis zone.

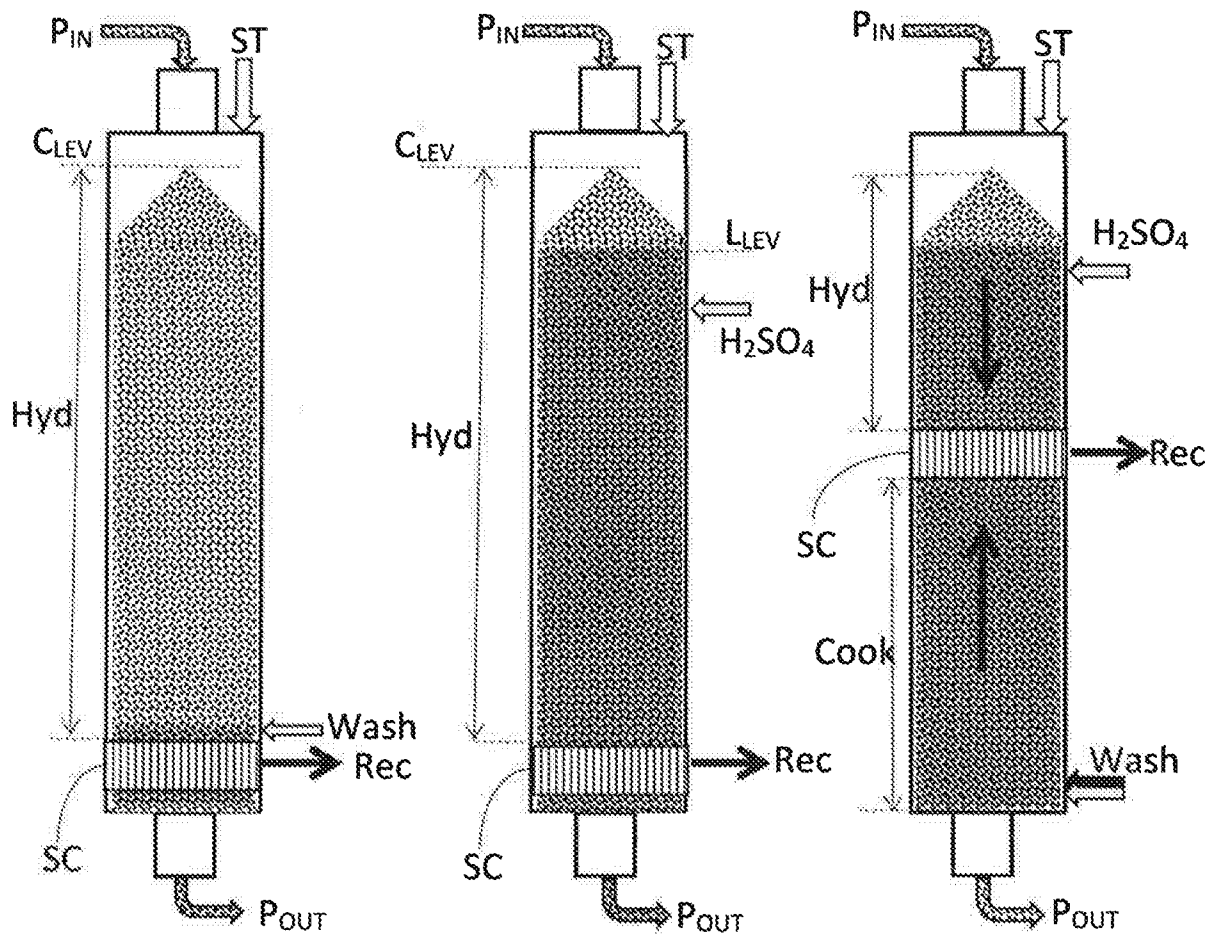
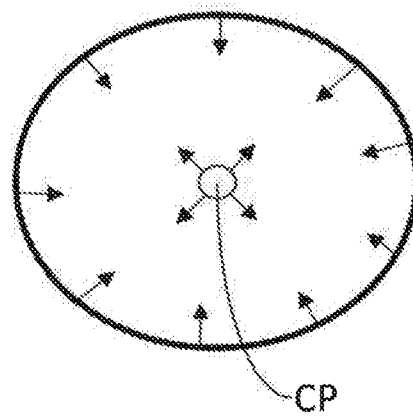
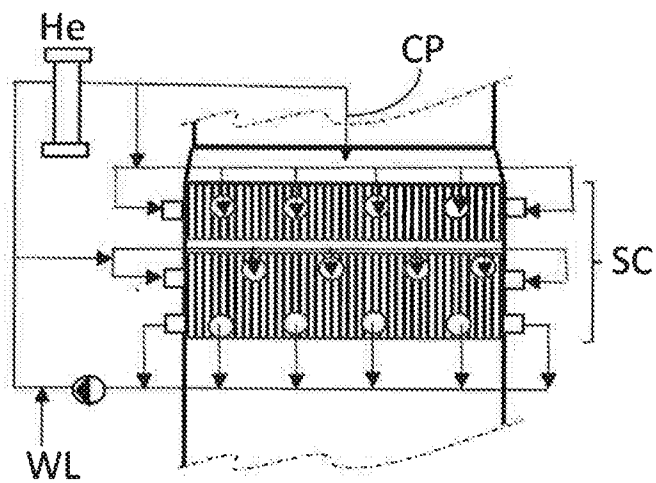
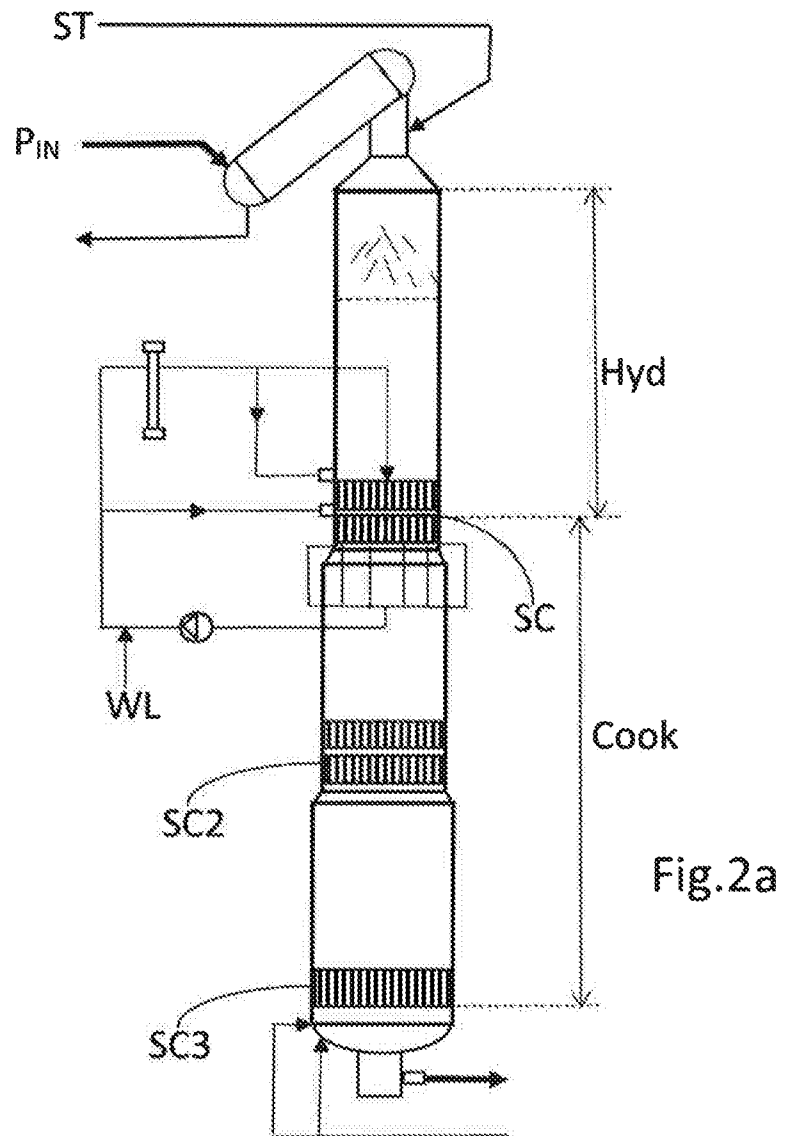


Fig. 1a

Fig. 1b

Fig. 1c



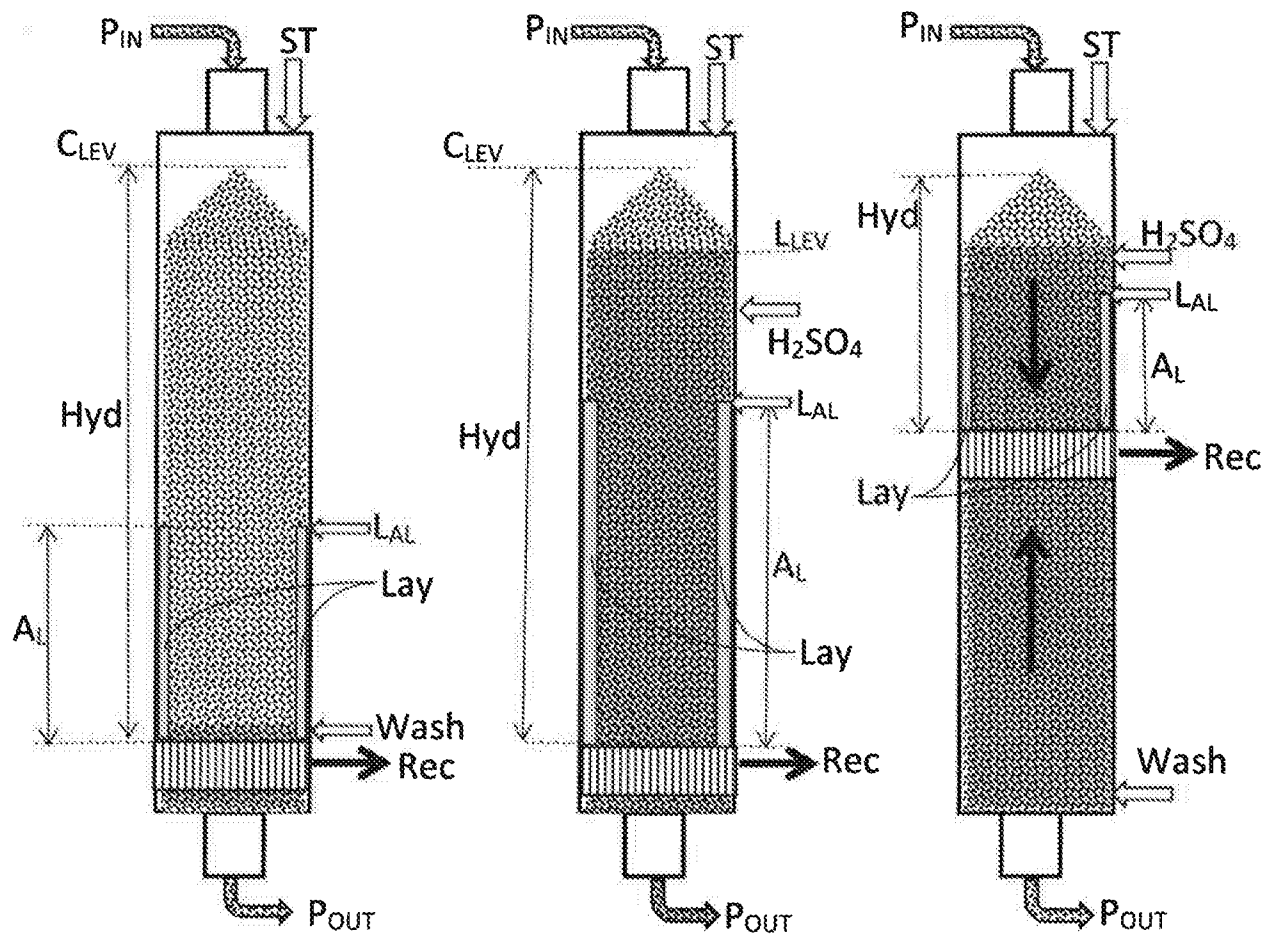


Fig. 3a

Fig. 3b

Fig. 3c

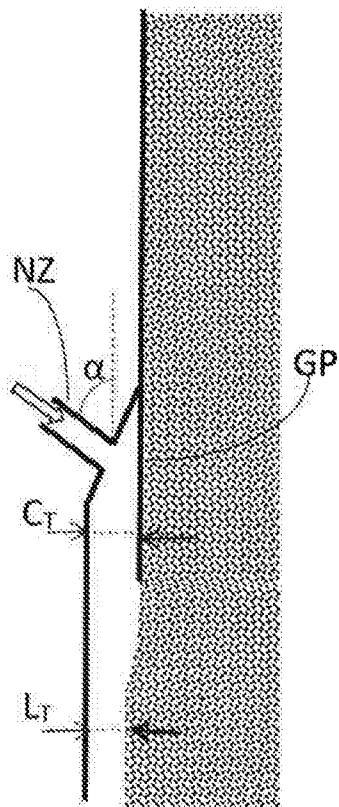


Fig. 4

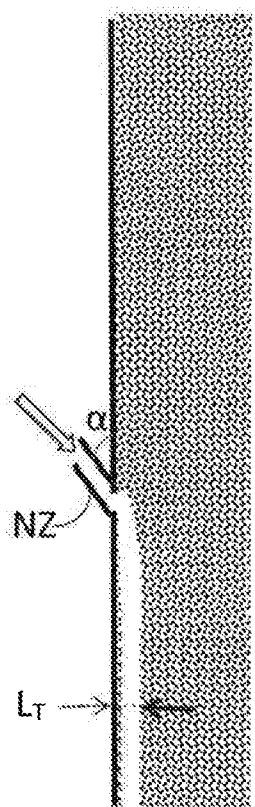


Fig. 5

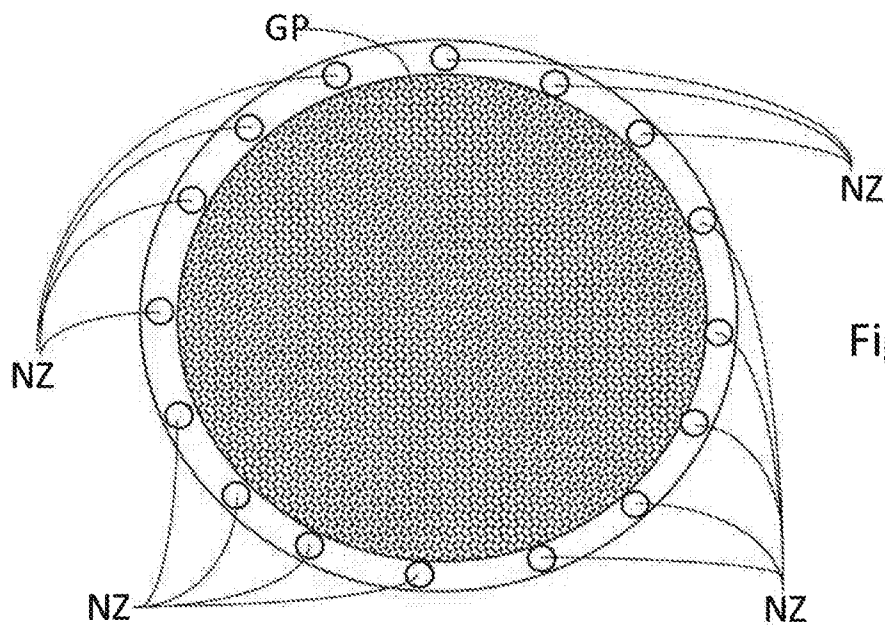


Fig. 6

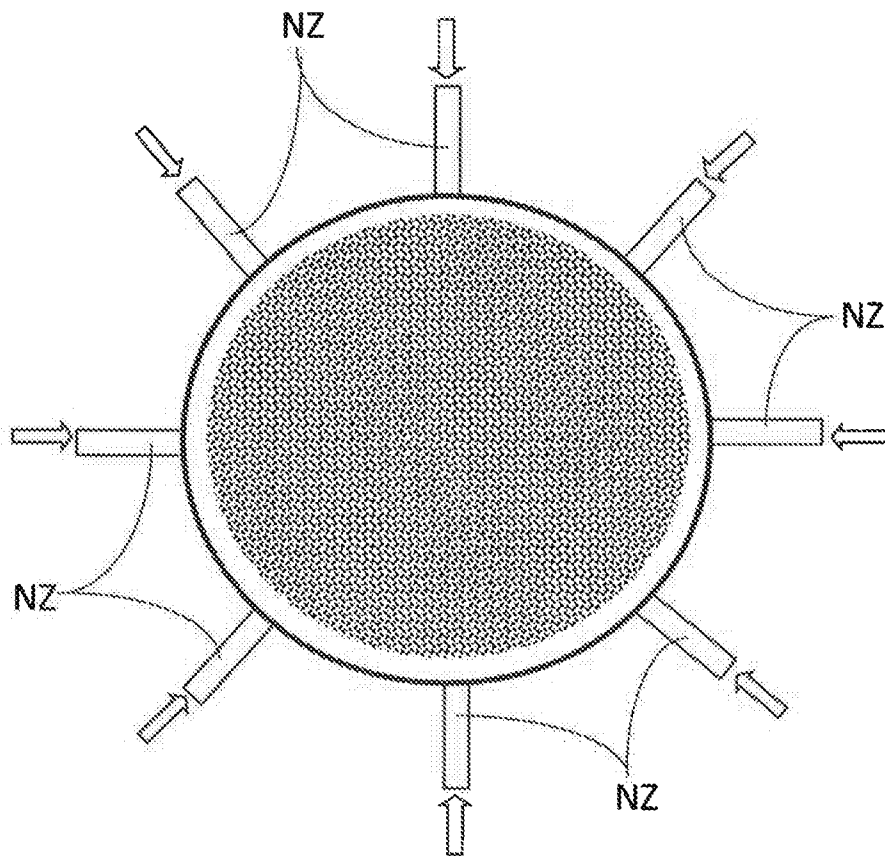


Fig. 7

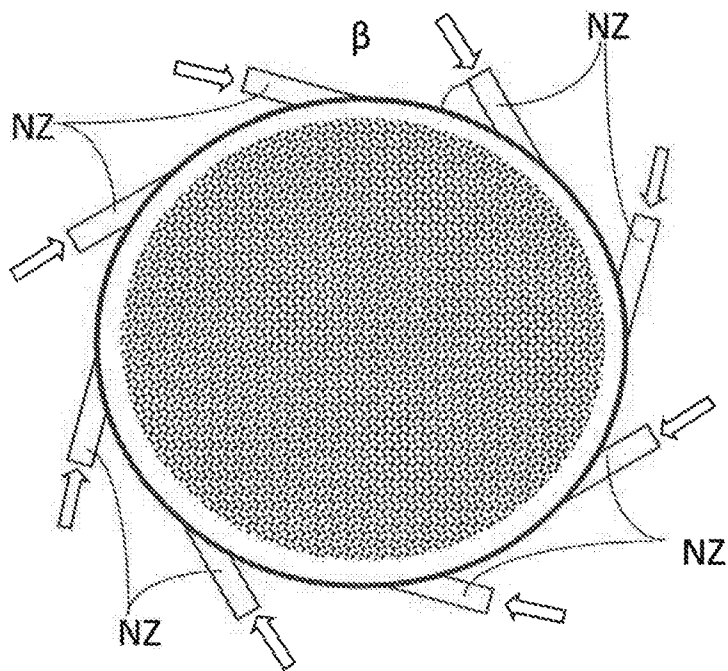


Fig. 8

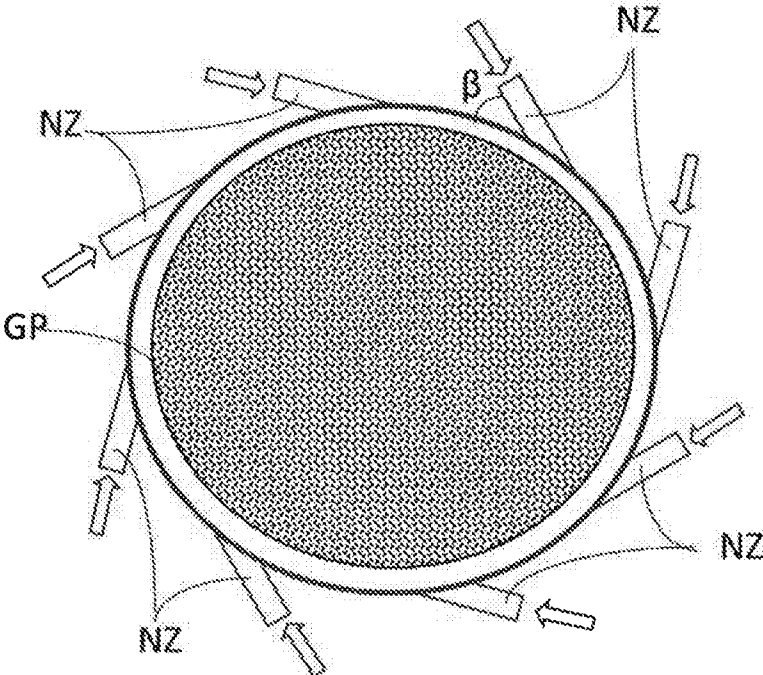


Fig. 9

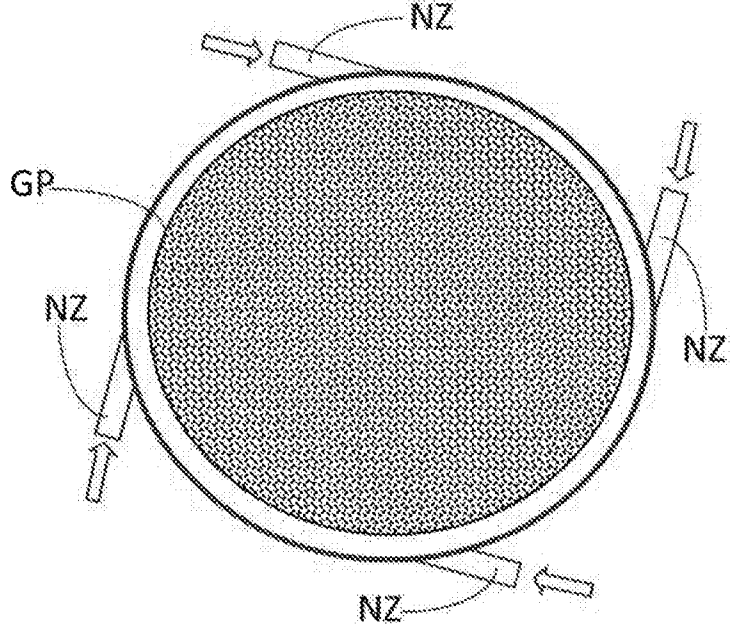


Fig. 10

INTERNATIONAL SEARCH REPORT

International application No.
PCT/SE2018/050715

A. CLASSIFICATION OF SUBJECT MATTER

IPC: see extra sheet

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC: D21C

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

SE, DK, FI, NO classes as above

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

EPO-Internal, PAJ, WPI data, COMPENDEX

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 3413189 A1 (AKE BACKLUND ERNST), 26 November 1968 (1968-11-26); column 1, line 39 - line 48; column 3, line 50 - line 60 --	1-11
A	WO 2012158075 A1 (METSO PAPER SWEDEN AB ET AL), 22 November 2012 (2012-11-22); whole document --	1-11
A	EP 2034090 A1 (ANDRITZ INC), 11 March 2009 (2009-03-11); whole document --	1-11
A	US 5676795 A1 (WIZANI WOLFGANG ET AL), 14 October 1997 (1997-10-14); whole document -- -----	1-11

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

* Special categories of cited documents:	"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"A" document defining the general state of the art which is not considered to be of particular relevance	"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
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"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)	"&" document member of the same patent family
"O" document referring to an oral disclosure, use, exhibition or other means	
"P" document published prior to the international filing date but later than the priority date claimed	

Date of the actual completion of the international search
06-09-2018

Date of mailing of the international search report
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Continuation of: second sheet

International Patent Classification (IPC)

D21C 1/04 (2006.01)

D21C 1/02 (2006.01)

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No.

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