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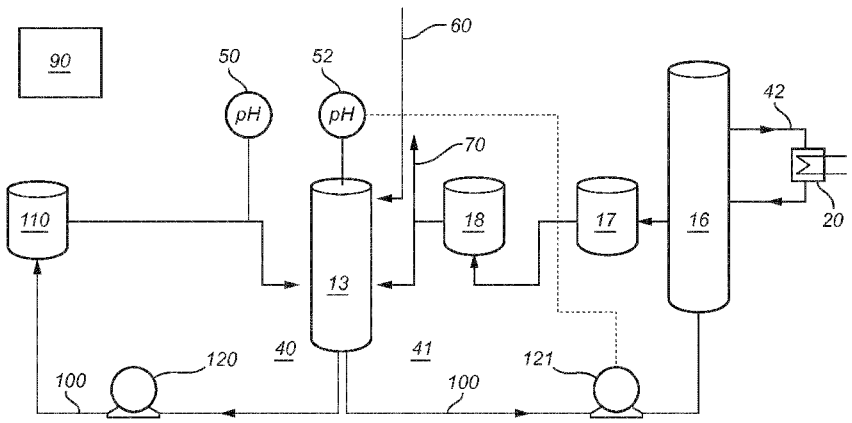


Fig. 1

(57) Abstract: The present invention relates to a process for retting fibrous biomass to release cellulosic fibers present therein. The process comprises digesting the fibrous biomass in at least one bio-digestive step by use of anaerobic digestive bacteria to release the cellulosic fibers. In the bio-digestive step, a retting aqueous liquor comprising anaerobic digestive bacteria is supplied to packed fresh fibrous biomass. The packed fresh fibrous biomass to be digested in the biomass bio-digestive step has a degree of packing corresponding to a density in dry state of 135 kg/m^3 to 450 kg/m^3.

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COTTONIZATION BY BIODIGESTION OF PACKED FIBROUS BIOMASS

Field of the invention

The present invention relates to a process for retting fibrous biomass to release cellulosic fibers present therein.

Background

Natural plant fibers may be spun into yarn for use in textiles. Firstly, however, the fibers must be released from the surrounding biomass. As long-known and used, natural fibers from, e.g., flax, hemp, jute, rhea, among other fibrous biomasses may be released by employing the action of micro-organisms and moisture. Micro-organisms and moisture will dissolve and rot away much of the cellular tissues and pectins surrounding fiber bundles. By removing binding polymers, such as lignin and pectins, separation of fibers from each other is facilitated, such that the fibers may be used for, e.g., spinning yarns. This type of process is sometimes called cottonization.

Historically, the most widely practiced method of retting has been water retting. In water retting crushed bundles of stalks are submerged in water. Upon submersion, water penetrates to the central stalk portion, swells the inner cells, bursting the outermost layer. This leads to increased absorption of moisture and growth of retting microorganisms, i.e. anaerobic digestive bacteria. In retting, microorganisms are of importance in digesting cellular tissues and especially pectins to release the fibers. However, the retting time must be carefully judged and there is a delicate balance between under-retting and over-retting. Under-retting makes separation of the fibers difficult, whereas over-retting weakens the fibers as the fibers themselves are also digested.

Given that traditional water retting is time consuming and hard to control, there has been an interest in the art to develop industrially applicable retting.

GB 825,704 relates to biological water-retting of flax and other fibrous plants. In the disclosed process, retting liquor, which has been used for retting flax or other fibrous plants, is rendered suitable for use in a further retting operation by subjecting it to aeration whilst in admixture with activated sludge.

In WO 2009/109994 a process of extraction of plant materials bound in tissues by employing anaerobic sludge is disclosed. More particularly, the process is held to enable the faster extraction of plant fibers such as banana fiber, pineapple leaf fiber, jute

and allied fibers, sisal fiber and tender coconut husk fiber. Further, the process is held to be a clean and non-polluting anaerobic process.

However, there is still a need for a further improved retting process with improved retting efficiency avoiding over-retting. As disclosed in WO 2009/109994, the need for clean and non-polluting process is also a major concern in the art.

Summary of the invention

Consequently, the present invention seeks to provide a more efficient process for retting fibrous biomass to release cellulosic fibers present therein. The process comprises digesting the fibrous biomass in at least one bio-digestive step by use of anaerobic digestive bacteria to release the cellulosic fibers. Fresh fibrous biomass is digested in the bio-digestive step to release cellulosic fibers by supplying thereto a retting aqueous liquor comprising anaerobic digestive bacteria. Preferably, at least 75 wt% of the fibrous biomass is biomass originating from bast plants. Examples of bast plants include: hemp, flax, jute, rhea, nettle, kenaf, and sisal. Before being added to the process, the fresh biomass may be crushed to facilitate the retting. Preferably at least 75 % by weight of the cellulosic fibers obtained in the process are bast fibers.

The bio-digestive step is performed by supplying retting aqueous liquor comprising anaerobic digestive bacteria. The biomass supplied to the bio-digestive steps will in itself contain anaerobic digestive bacteria, and this will form an anaerobic digestive culture that develops and proliferates over time in the process. Alternatively, it is also possible to supply external anaerobic digestive bacteria cultures, if needed. Thus, a retting aqueous liquor comprising anaerobic digestive bacteria is supplied to fresh fibrous biomass. Typically, the bio-digestive step is performed in a vessel. In the bio-digestive step the retting aqueous liquor is typically passed through the fibrous biomass. In passing the retting aqueous liquor through the fibrous biomass the anaerobic digestive bacteria will digest the bio-mass surrounding the fibers to release them. Further, the bacterial concentration of anaerobic digestive bacteria will increase, as the bacteria proliferate in digesting the bio-mass. Apart from released cellulosic fibers, the digestion in the final fiber releasing bio-digestive step results in an aqueous liquor comprising anaerobic digestive bacteria and dissolved and/or dispersed non-fibrous biomass, resulting from the digestion of the fibrous biomass. Due to the proliferation, the concentration of anaerobic digestive bacteria in the aqueous liquor comprising anaerobic digestive bacteria and dissolved and/or dispersed non-fibrous biomass,

resulting from the digestion of the fibrous biomass, is higher than the concentration of anaerobic digestive bacteria in the first retting aqueous liquor.

Fibrous biomass is typically not very dense and has low density, typically less than 90 kg/m^3 in dry state, e.g. around 55 kg/m^3. In order to improve the capacity of the present retting process in a given retting system, the fibrous biomass is according to an embodiment packed into the vessel to increase the amount of material to be processed in the vessel. The degree of packing, when being digested in the bio-digestive step, may correspond to a density in dry state of at least 135 kg/m^3, preferably at least 180 kg/m^3. Dense packing of the fibrous biomass will however increase the flow resistance through the fibrous biomass. A too high degree of packing is thus less preferred. According to an embodiment, the degree of packing corresponding to a density in dry state of 135 kg/m^3 to 450 kg/m^3, preferably 180 kg/m^3 to 360 kg/m^3, is used. As recognized by the skilled person dried fibrous biomass typically still comprises some moisture. The actual moisture content of dried fibrous biomass depends on the ambient temperature and humidity and is typically in the range 8 to 15 wt%. However, based on the standard ASTM D2495-07 as reapproved in 2012, the actual moisture content of the fibrous biomass may be determined. The herein stated densities in "dry state" relates to the dry weight, i.e. the weight of the fibrous biomass excluding any moisture content as determined in accordance with ASTM D2495-07, for a given volume of packed fibrous biomass. As an example, a degree of packing corresponding to a density in dry state of 135 kg/m^3 corresponds to a density, for a fibrous biomass comprising 10 wt% moisture, of 150 kg/m^3.

The biomass may be packed into a fluid permeable net basket to be positioned into a vessel before the fresh biomass bio-digestive step. Use of a fluid permeable net basket will facilitate insertion of fibrous biomass to be retted in the fresh biomass bio-digestive step into a vessel and will also facilitate removal of released cellulosic fibers therefrom. In addition, it will facilitate the handling of the fibers in any further fiber treatment step after the retting process. Alternatively, the fluid permeable net basket may be emptied while remaining in the vessel, such as manually or by means of piston or some other emptying means. Further, use of fluid permeable net basket will facilitate the provision of retting aqueous liquor to the biomass and improve the distribution of thereof. This is advantageous as the permeability of packed biomass may be reduced. As the net basket is fluid permeable, retting aqueous liquor introduced into the vessel will be brought into contact with fibrous biomass present in the net basket as well. The retting aqueous liquor may be introduced into the vessel by means of a pump.

According to an embodiment retting aqueous liquor is further forced to re-circulate through the packed fibrous biomass once the fibrous biomass has been inserted into the vessel. The aqueous liquors may be re-circulated for at least 5 minutes, such as for at least 10 minutes. Further, the aqueous liquors may be re-circulated for up to 1 hour, such as for up to 30 minutes. After the re-circulation, the retting aqueous liquor may be left in the vessel for up to 12 hours, such as up 8 hours, in order to ret the fibrous biomass. Thus, the retting aqueous liquor may be used in a batch wise manner, while being continuously flowing through the fibrous biomass in some embodiments. After having being left in the vessel, the retting aqueous liquor may be re-circulated once more before being withdrawn. According to an embodiment a flow of 50 to 300 liters of liquor is re-circulated per kg (dry state) of packed fibrous biomass and hour. More preferably 80 to 250 liter/kg, h. This increases the efficiency of the retting. According to one embodiment a pump may be used for forcing the liquor through the packed fibrous biomass. Apart from re-circulating the retting aqueous liquor, the pump may be used in introducing retting aqueous liquor into the packed fibrous biomass. According to one embodiment the liquor is forced through the packed fibrous biomass at a pressure of 1.5 to 10 bar(a), more preferably 2 to 8 bar(a), and most preferably 2 to 6 bar(a), in re-circulating or introducing the retting aqueous liquor.

According to an embodiment, the net basket is removable. By simply lifting removable net basket out of the vessel, the released cellulosic fibers may be removed. In addition, it will facilitate the handling of the fibers in any further fiber treatment step after the retting process.

The packing of the fibrous biomass will increase the flow resistance. In the present process, the flow of aqueous retting liquor through the fibrous biomass is, according to an embodiment, continuous. Further, the exposure to the aqueous retting liquor should be as even as possible. It may thus be advantageous to introduce the aqueous retting liquor in the center of the packed fibrous biomass and to push it through the fibrous biomass. As an example, the aqueous retting liquor may be supplied via a perforated, typically cylindrically shaped, distribution pipe centered in the vessel. By packing the fibrous biomass around the distribution pipe, aqueous retting liquor may be radially pushed from the distribution pipe trough the fibrous biomass. If a net basket is used, the perforated feed pipe may be part of the net basket. Introducing the aqueous retting liquor in the center of the packed fibrous biomass will further lower risk for clogging as dispersed material will be pushed out of the fibrous biomass rather than into it. A pump may be used to feed the aqueous retting liquor to the distribution pipe.

Alternatively, the aqueous retting liquor may be introduced in between the wall of the vessel and the fluid permeable net basket. A pump may be used to feed the aqueous retting liquor to the vessel. By applying pressure the aqueous retting may be radially pushed through the fibrous biomass towards the distribution pipe then acting as outlet.

Once released, the cellulosic fibers are removed from the process. According to an embodiment, the removed cellulosic fibers are further treated in a post retting, fiber refining step. Before the post retting, fiber refining step, the aqueous retting liquor is withdrawn from the released fibers. However, apart from the released fibers, some microorganism as well as dissolved and/or dispersed non-fibrous biomass may still remain within the fibers once the aqueous retting liquor have been withdrawn from the released fibers. The post retting, fiber refining step thus serves to remove, at least partly, remaining microorganisms as well as dissolved and/or dispersed non-fibrous biomass. In the post retting fiber refining step, the fibers are treated with an aqueous composition at elevated temperature, i.e. at least 30°C, such as at least 60°C.

In order to efficiently remove remaining microorganisms as well as dissolved and/or dispersed non-fibrous biomass, the temperature in the post retting fiber refining step may be from 60 to 160°C, such as from 100 to 160°C, or from 110 to 130°C. Though, atmospheric pressure may be used, the pressure in the post retting, fiber refining step preferably exceeds atmospheric pressure. The pressure in the post retting fiber refining step may thus be at least 101 kPa, such as 101 to 600 kPa, preferably 140 to 270 kPa.

The fibers to be treated with an aqueous composition may be dispersed in the aqueous composition, i.e. not being packed. Agitation may then improve the removal of remaining microorganism as well as dissolved and/or dispersed non-fibrous biomass. However, as this may be less efficient in an industrial process it may be preferred to perform the post retting, fiber refining step with packed fibers. As remaining microorganisms, as well as dissolved and/or dispersed non-fibrous biomass, may be stacked within the packed fibers, it may be preferred to perform the post retting, fiber refining step at elevated temperature and pressure. Further, the aqueous composition may comprise a cleansing agent, such as a detergent or an alkaline agent, to improve removal of remaining microorganism, as well as dissolved and/or dispersed non-fibrous biomass.

Further, in order to release stuck dissolved and/or dispersed non-fibrous biomass, such as non-cellulose components, e.g. pectin, lignin and hemi-cellulose, it

may be preferred to degrade them, e.g. degrading and/or solving remaining non-fibrous biomass. According to an embodiment, the fibers are thus treated with an alkaline aqueous composition in the post retting fiber refining step. The alkaline aqueous composition comprises an alkaline agent. The alkaline agent may be selected from the group consisting of hydroxides of an alkali metal, e.g. NaOH or KOH, hydroxides of an alkaline earth metal, e.g. $Ca(OH)_2$, and amines, e.g. ammonia. Preferably, the alkaline agent is selected from the group consisting of hydroxides of an alkali metal, e.g. NaOH or KOH, and a hydroxide of an alkaline earth metal, e.g. $Ca(OH)_2$. More preferably the alkaline agent is NaOH (sodium hydroxide). The alkaline aqueous composition may be provided by diluting an appropriate amount of alkali by water. As an example, 20 g to 150 g, such as about 50 g, concentrated, aqueous NaOH (48 wt.%) per kg of fresh fibrous biomass may be applied. The alkali may be diluted with 4 to 10 liter, such as about 6 liter, water per kg of fresh fibrous biomass. Thus, the alkali concentration in the post retting, fiber refining step may be 0.1 to 5 wt.%, such as 0.2 to 2 wt.%. Further, the alkaline aqueous composition may comprise at least one detergent.

By combining a temperature higher than 100°C and a pressure higher than 101 kPa, the post retting, fiber refining step effectively remove remaining microorganisms as well as dissolved and/or dispersed non-fibrous biomass, to further refine the released cellulose fibers, especially if an alkaline aqueous composition is used. The preceding bio-digestion retting step implies that the post retting, fiber refining step is less time consuming and requires less alkali compared to a single, alkaline chemical retting step. Use of less alkali and shortened treatment, further implies that the provided fibers have higher tensile strength, as the bio-digestion is more selective.

As the post retting, fiber refining step typically is performed at elevated pressure and temperature it may be performed in an autoclave. It is however, also possible to perform in the same vessel, as being used in the bio-digestive step.

Subsequent to the post retting, fiber refining step, the temperature is lowered and the aqueous composition is removed. As a last step, the refined fibers may be treated with a softener. The fibers are typically treated with the softener at a temperature of 30 to 60°C, such as 40 to 50°C. Before being treated with a softener, the pH is made acidic. This may be achieved by adding an acid, such as a carboxylic acid, e.g. acetic acid, to the refined fibers. Softeners for cellulose fibers are known to the skilled person. Examples of suitable softeners include fatty acid condensation products (e.g. Vitagon RS 20) and wet waxing agents (e.g. ®RUCO-FIL AWU, a paraffin and polyethylene composition).

According to an embodiment, the process includes at least two bio-digestive steps for digesting the fibrous biomass, such as 2 to 8, or 3 to 5, bio-digestive steps. The bio-digestive steps include a fresh biomass bio-digestive step and a final fiber releasing bio-digestive step. In the bio-digestive steps, anaerobic digestive bacteria are used to release the cellulosic fibers. To provide an effective retting process, the concentration of anaerobic digestive bacteria is higher in the fresh biomass bio-digestive step than in the final fiber releasing bio-digestive step. By having at least two bio-digestive steps, employing different concentrations of anaerobic digestive bacteria, the fresh biomass bio-digestive step may be performed with a concentration of anaerobic digestive bacteria which may result in over-retting if employed throughout the process, but which is efficient for retting the fresh biomass. Further, a final fiber releasing bio-digestive step employing a lower concentration of anaerobic digestive bacteria implies that a slower finishing step may be performed to avoid under- as well as over-retting. The advantage of employing higher concentration of anaerobic digestive bacteria in the fresh biomass bio-digestive step is efficient, initial bio-digestion, whereas the advantage of employing lower in the final fiber releasing bio-digestive step is the reduced risk for over-retting, whilst still efficiently releasing the fibers.

In the process, fresh fibrous biomass is digested in the fresh biomass bio-digestive step to provide a partly digested fibrous biomass. Preferably, at least 75 wt% of the fibrous biomass is biomass originating from bast plants. Examples of bast plants include: hemp, flax, jute, rhea, nettle, kenaf, and sisal. Before being added to the process, the fresh biomass may be crushed to facilitate the retting. Further, partly digested fibrous biomass obtained in accordance with the fresh bio-digestive step is digested in the final fiber releasing bio-digestive step to provide released cellulosic fibers. Preferably at least 75 % by weight of the cellulosic fibers obtained in the final fiber releasing bio-digestive step is bast fibers.

The bio-digestive steps are performed by supplying retting aqueous liquor comprising anaerobic digestive bacteria. The biomass supplied to the bio-digestive steps will in itself contain anaerobic digestive bacteria, and this will form an anaerobic digestive culture that develops and proliferates over time in the process. Alternatively, it is also possible to supply external anaerobic digestive bacteria cultures, if needed. Thus, a first retting aqueous liquor comprising anaerobic digestive bacteria is supplied to a batch of partly digested fibrous biomass for treating the same in a final fiber releasing bio-digestive step. Typically, the final fiber releasing bio-digestive step is performed in a first vessel. In the final fiber releasing bio-digestive step the first retting aqueous

liquor is typically passed through the partly digested fibrous biomass. In passing the first retting aqueous liquor through the partly digested fibrous biomass the anaerobic digestive bacteria will further digest the bio-mass surrounding the fibers to release them. Further, the bacterial concentration of anaerobic digestive bacteria will increase, as the bacteria proliferate in digesting the bio-mass. Apart from released cellulosic fibers, the digestion in the final fiber releasing bio-digestive step results in a second retting aqueous liquor comprising anaerobic digestive bacteria. This second retting aqueous liquor is withdrawn from the final fiber releasing bio-digestive step. Due to proliferation, the concentration of anaerobic digestive bacteria in the second retting aqueous liquor is higher than the concentration of anaerobic digestive bacteria in the first retting aqueous liquor.

The second retting aqueous liquor is supplied, be it directly or indirectly via intermediate bio-digestive step(s) as further elaborated below, to a batch of fresh fibrous biomass for treating the same in the fresh biomass bio-digestive step. In this manner, the fresh fibrous biomass digested in the fresh biomass bio-digestive step is exposed to a higher concentration of anaerobic digestive bacteria than the partly digested fibrous biomass digested in the final fiber releasing bio-digestive step. Typically, the second retting aqueous liquor is supplied to a second vessel in which a batch of fresh fibrous biomass is present. In the fresh biomass bio-digestive step the second retting aqueous liquor is typically passed through the partly digested fibrous biomass. Aqueous liquor withdrawn from the fresh biomass bio-digestive step will comprise dissolved and/or dispersed digested non-fibrous biomass released from the fibers in the bio-digestive steps.

While the retting aqueous liquor may be supplied continuously to and continuously withdrawn from the vessel(s), it may also be supplied and with drawn in batch wise manner, i.e. intermittently. In an embodiment, wherein the retting aqueous liquor is supplied in batch wise manner, the retting aqueous liquor be left in the vessel once having been supplied thereto before being withdrawn there from. Further, as already explained, the retting aqueous liquor may be re-circulated.

According to an embodiment, a batch of partly digested fibrous biomass is subjected to the final fiber releasing bio-digestive step in a first vessel simultaneously with a subsequent batch of fresh fibrous biomass being subjected to the fresh biomass bio-digestive step in a second vessel. The batches may be digested in a first bio-digestive cycle. The first vessel is separate from the second vessel. As already stated the second retting aqueous liquor generated in the first vessel may be transferred to the

second vessel. To accomplish this, there is typically a continuous flow of retting liquor from the first vessel to the second vessel. However, the retting liquor may also be transferred intermittently. In passing through the partly digested fibrous biomass, the concentration of anaerobic digestive bacteria will increase. Thus, the concentration of anaerobic digestive bacteria in the retting aqueous liquor passing through the second vessel will be higher than the concentration of anaerobic digestive bacteria in the retting aqueous liquor passing through the first vessel.

The first and second vessels may thus be in flow communication via a pipe system. The pipe system is arranged to supply the first retting aqueous liquor for the final fiber releasing bio-digestive step to one of the vessels and to supply the second retting aqueous liquor from the final fiber releasing bio-digestive step for the fresh biomass bio-digestive step to other of the vessels. Further, each of the first and second vessels may be capable of first being used for conducting the fresh biomass bio-digestive step and then for conducting the final fiber releasing bio-digestive step. The pipe system may be controlled to supply the second retting aqueous liquor to the respective vessel when operated to perform the fresh biomass bio-digestive step. Further, the pipe system may be controlled to supply the first retting aqueous liquor to the respective vessel when operated to perform the final fiber releasing bio-digestive step.

Typically, a batch of fresh fibrous biomass is placed in the vessel to which the second retting aqueous liquor is to be supplied e.g. the first vessel. Fresh fibrous biomass may be placed in the first vessel by positioning a fluid permeable net basket comprising a batch of fresh fibrous biomass in the vessel. Further, fresh fibrous biomass may be placed in the first vessel by putting it into a fluid permeable net basket positioned in the vessel. Simultaneously, a batch of partly digested fibrous biomass is present in the vessel to which the first retting aqueous liquor is to be supplied, e.g. the second vessel. After a given time, such as 12 to 36 hours, the first bio-digestive cycle is completed and released fibers are removed from the vessel to which the first retting aqueous liquor was supplied and replaced be a new batch of fresh fibrous biomass. Thereafter, the pipe system is controlled to supply the second retting aqueous liquor to this vessel and to supply the first retting aqueous liquor to the other vessel in a second bio-digestive cycle. A given batch of fresh fibrous biomass thus spends a first bio-digestive cycle in a vessel to which the second retting aqueous liquor is supplied. Subsequently, the partly digested fibrous biomass spends a second bio-digestive cycle in the same vessel, but to which the first retting aqueous liquor now is supplied.

As already explained, aqueous liquor withdrawn from the biomass bio-digestive step(s), e.g. the fresh biomass bio-digestive step, will comprise dissolved and/or dispersed non-fibrous biomass released from the fibers in the bio-digestive step(s).

According to an embodiment, the process further comprises a separate step of anaerobically degrading dissolved and/or dispersed non-fibrous biomass present in aqueous liquor withdrawn from the biomass bio-digestive step(s), e.g. the fresh biomass bio-digestive step, in a separate anaerobic degradation step. In the separate anaerobic degradation step dissolved and/or dispersed non-fibrous biomass is degraded to methane gas and carbon dioxide gas, and possibly also some minor amounts of, e.g., nitrogen gas, ammonia gas and hydrogen sulfide gas, which in the form of a biogas is withdrawn separately, to provide an aqueous liquor with decreased content of non-fibrous biomass. The dissolved and/or dispersed non-fibrous biomass typically comprises fatty acids among other constituents. In the initial steps of bio-digestion, releasing the cellulosic fibers present, the pH will decrease. The pH drop is, without being bound to any theory, believed to result from fatty acids being formed in these steps. The pH of aqueous liquor withdrawn from the fresh biomass bio-digestive step may thus be less than 7.0, such as 6.0 to 6.9, or 6.5 to 6.9.

The anaerobic degradation step may be performed in an anaerobic biogas producing digestion reactor, such as an up flow anaerobic sludge bed (UASB). By anaerobically degrading dissolved and/or dispersed digested non-fibrous biomass present in aqueous liquor withdrawn from the fresh biomass bio-digestive step, the aqueous liquor withdrawn from the fresh biomass bio-digestive step may subsequently be re-used in the bio-digestive steps to form part of the retting aqueous liquor, e.g. the first retting aqueous liquor.

According to an embodiment, the process comprises the step of anaerobically degrading dissolved and/or dispersed digested non-fibrous biomass present in aqueous liquor withdrawn from the bio-digestive step, e.g. the fresh biomass bio-digestive step, to biogas in a separate anaerobic degradation step to provide an aqueous liquor with decreased content of non-fibrous biomass and utilizing at least part of the aqueous liquor with decreased content of non-fibrous biomass to form part of the retting aqueous liquor, e.g. the first retting aqueous liquor.

In order to avoid inorganic compounds, e.g. various salts, accumulating in the re-circulated retting aqueous liquor, part of the aqueous liquor with decreased content of non-fibrous biomass may be taken out from the circulation of retting aqueous liquor. As

already explained, the circulation of retting aqueous liquor may be continuous as well as intermittent. Further, the fresh water may be introduced into the circulation of retting aqueous liquor to compensate for the liquor taken out. Thus, the part of the aqueous liquor with decreased content of non-fibrous biomass being utilized to form part of the retting aqueous liquor, e.g. the first retting aqueous liquor, may be diluted with water.

Further, as elaborated herein below, part of the aqueous liquor withdrawn from the bio-digestive step, e.g. the fresh biomass bio-digestive step, may be directly re-circulated to form part of the retting aqueous liquor, e.g. the first retting aqueous liquor, and thus not undergoing the anaerobic degradation step.

According to an embodiment, the ammonia content in the aqueous liquor with decreased content of non-fibrous biomass withdrawn from the anaerobic degradation step is decreased in a separate nitrification/de-nitrification step. By decreasing the ammonia content, the aqueous liquor withdrawn from the biomass bio-digestive(s) step is further adopted for re-use in the bio-digestive step(s). A too high content of ammonia may be negative for the performance of the bio-digestive step(s), as ammonia is toxic to the anaerobic digestive bacteria releasing the cellulosic fibers in the bio-digestive step. The ammonia content may thus be decreased in a separate nitrification/de-nitrification step. As recognized by the skilled person, bacterial nitrification/de-nitrification, preferably aerobic bacterial nitrification/de-nitrification, may be employed to convert ammonia to nitrogen gas (N_2). By decreasing the ammonia content, an aqueous liquor with decreased content of ammonia and decreased content of non-fibrous biomass is provided. The aqueous liquor with decreased content of non-fibrous biomass withdrawn from the anaerobic degradation step may be aerated in decreasing the ammonia content, as the bacterial nitrification/de-nitrification preferably is aerobic. The ammonia content in the aqueous liquor with decreased content of non-fibrous biomass may be decreased in a moving bed biofilm reactor (MBBR). The aqueous liquor with decreased content of ammonia and non-fibrous biomass withdrawn from the separate nitrification/de-nitrification step typically has a pH of 7.0 or higher, such as a pH of 7.0 to 8.5, or 7.0 to 8.0. The aqueous liquor with decreased content of ammonia and non-fibrous biomass withdrawn from the separate nitrification/de-nitrification step typically has a pH which is at least 0.2 pH units higher than the pH of aqueous liquor withdrawn from the bio-digestive step, e.g. the fresh biomass bio-digestive step.

As already explained, anaerobically degrading dissolved and/or dispersed digested non-fibrous biomass present in aqueous liquor withdrawn from the biomass bio-digestive step(s) and subsequently decreasing the ammonia content provides an

aqueous liquor that may be re-used in the bio-digestive step(s). According to a further embodiment, at least part of the aqueous liquor with decreased content of ammonia and non-fibrous biomass withdrawn from the separate nitrification/de-nitrification step is utilized to form part of the retting aqueous liquor, e.g. the first retting aqueous liquor. Thus, at least a part of the aqueous liquor with decreased content of ammonia and non-fibrous biomass withdrawn from the separate nitrification/de-nitrification step may be mixed with at least a part of the aqueous liquor withdrawn from the bio-digestive step, e.g. the fresh biomass bio-digestive step, to form the retting aqueous liquor, e.g. the first retting aqueous liquor. The aqueous liquor with decreased content of ammonia and non-fibrous biomass withdrawn from the separate nitrification/de-nitrification step and the aqueous liquor withdrawn from the bio-digestive step, e.g. the fresh biomass bio-digestive step, may be mixed in a buffer vessel.

As already mention, part of the process liquor, e.g. the aqueous liquor with decreased content of ammonia and non-fibrous biomass withdrawn from the separate nitrification/de-nitrification step may be taken out from the circulation of retting aqueous liquor, in order to avoid inorganic compounds, e.g. various salts, accumulating in the re-circulated retting aqueous liquor. Further, fresh water may be introduced into the circulation of retting aqueous liquor to compensate for the liquor taken out. Thus, the aqueous liquor with decreased content of ammonia and non-fibrous biomass withdrawn from the separate nitrification/de-nitrification step being at least partly utilized to form part of the retting aqueous liquor may be diluted with water. Further, as elaborated herein below, part of the aqueous liquor withdrawn from the bio-digestive step, e.g. the fresh biomass bio-digestive step, may be directly, i.e. without undergoing the separate anaerobic degradation step, re-circulated to form part of the retting aqueous liquor, e.g. the first retting aqueous liquor, and thus not undergoing the anaerobic degradation step.

The pH of the aqueous liquor withdrawn from the bio-digestive step, e.g. the fresh biomass bio-digestive step, will typically be acidic, i.e. having a pH of less than 7. The pH may even be lower than 6.5. On the other hand, the pH of the aqueous liquor withdrawn from the separate nitrification/de-nitrification step may be at least 7.0, such as 7.0 to 8.5, or 7.0 to 8.0. Further, the concentration of anaerobic digestive bacteria will be lower in aqueous liquor withdrawn from the separate nitrification/de-nitrification step compared to aqueous liquor withdrawn from the bio-digestive step, e.g. the fresh biomass bio-digestive step. Accordingly, mixing the aqueous liquor withdrawn from the separate nitrification/de-nitrification step with the aqueous liquor withdrawn from the

bio-digestive step, e.g. the fresh biomass bio-digestive step, may provide an aqueous liquor suitable for use as retting aqueous liquor, e.g. first retting aqueous liquor. If process liquor is taken out from the circulation of retting aqueous liquor, the mixed liquors, i.e. the aqueous liquor withdrawn from the separate nitrification/de-nitrification step and the aqueous liquor withdrawn from the biomass bio-digestive step, e.g. the fresh biomass bio-digestive step, respectively, may be diluted with water. The pH of the retting aqueous liquor, e.g. the first retting aqueous liquor, may be at least 7.0, such as 7.0 to 7.5. As an acidic pH will lower the efficiency of the steps of bio-digestion releasing cellulosic fibers from fibrous biomass and as the pH will decrease in the bio-digestion releasing cellulosic fibers, a neutral, to very slightly basic pH is preferred in the retting aqueous liquor, e.g. the first retting aqueous liquor.

Further, the pH of the aqueous liquor withdrawn from the bio-digestive step, e.g. the fresh biomass bio-digestive step, and/or the pH of the retting aqueous liquor, e.g. the first retting aqueous liquor, may be used to control flow rates in the process. The relative flow rates will affect the pH of the various aqueous liquors used in the process. Thus, the pH of the aqueous liquor withdrawn from the bio-digestive step, e.g. the fresh biomass bio-digestive step, may be measured by a first pH-meter. The pH of the aqueous liquor withdrawn from the bio-digestive step, e.g. the fresh biomass bio-digestive step, may be used to control the flow rate of the retting aqueous liquor, e.g. the first retting aqueous liquor, supplied to a batch of fibrous biomass, e.g. partly digested fibrous biomass. Similarly, the pH of the retting aqueous liquor, e.g. the first retting aqueous liquor, may be measured by a second pH-meter. Thus, the second pH-meter may measure pH in the buffer vessel. The pH of the retting aqueous liquor, e.g. the first retting aqueous liquor, may be used to control the flow rate of aqueous liquor comprising dissolved and/or dispersed digested non-fibrous biomass being supplied to the anaerobic degradation step.

The second retting aqueous liquor may have a lower pH than the first retting aqueous liquor. The pH of the second retting aqueous liquor may be less than 7.0, such as 6.5 to 6.95.

According to a further embodiment, the process may comprise more than two bio-digestive steps. Thus, at least one, such as 1, 2, 3, 4, 5, or 6, intermediate bio-digestive step(s) may be included between the fresh biomass bio-digestive step and the final fiber releasing bio-digestive step. Such intermediate bio-digestive step(s) are adapted to digest fibrous biomass having undergone the fresh biomass bio-digestive step to provide partly digested fibrous biomass for digestion in the final fiber releasing bio-

digestive step. Further, aqueous liquor comprising anaerobic digestive bacteria withdrawn from the final fiber releasing bio-digestive step may be supplied to the intermediate bio-digestive step(s) and used as retting aqueous liquor(s) in the intermediate bio-digestive step(s). If more than one intermediate bio-digestive step is present, aqueous liquor comprising anaerobic digestive bacteria may be withdrawn from a first intermediate bio-digestive step, downstream of the final fiber releasing bio-digestive step, and supplied to a subsequent intermediate bio-digestive step to be used as retting aqueous liquor in the subsequent intermediate bio-digestive step. Further, aqueous liquor comprising anaerobic digestive bacteria withdrawn from a last intermediate bio-digestive step may be supplied to the fresh biomass bio-digestive step for use as the second retting aqueous liquor. In a process employing only one intermediate bio-digestive step, the first and the last intermediate bio-digestive step will be the same step.

According to a further embodiment, at least three different batches of fibrous biomass are processed simultaneously. The different batches are at different stages of bio-digestion, i.e. at different bio-digestive cycles. A batch of partly digested fibrous biomass is subjected to the final fiber releasing bio-digestive step in a first vessel to provide released cellulosic fibers. Simultaneously, a subsequent batch of fresh fibrous biomass is subjected to the fresh biomass bio-digestive step in a second vessel, which is separate from the first vessel. Also simultaneously therewith, at least one intermediate batch is subjected to an intermediate bio-digestive step in an intermediate vessel, which is separate from the first and second vessels. Whereas the different batches of fibrous biomass present in the vessels are digested in a batch wise manner, retting aqueous liquor is preferably continuously supplied to the vessels and passed through the batches of fibrous biomass to digest the biomass. According to some embodiment, the retting aqueous liquor is however supplied to the fibrous biomass in a batch wise manner. Especially, if the fibrous biomass is packed, it may be preferred to supply the retting aqueous liquor in a batch wise manner. Thus, retting aqueous liquor withdrawn from the first vessel may be transferred to a first downstream intermediate vessel. Further, retting aqueous liquor generated in a last downstream intermediate vessel may be transferred, as the second retting aqueous liquor, to the second vessel. If more than one intermediate vessel is present, the aqueous liquor may be transferred from an upstream intermediate vessel to a downstream intermediate vessel. As retting aqueous liquor preferably is continuously supplied to the vessels and passed through the batches of fibrous biomass to digest the biomass, there is preferably a continuous flow of retting aqueous liquor

from the first vessel to one or more intermediate vessels and thereafter to the second vessel. According to some embodiments, the retting aqueous liquor is however transferred from one vessel to the other intermittently.

Each of the first, second and intermediate vessel(s) is capable of first being used for conducting the fresh biomass bio-digestive step, then for conducting one or more intermediate bio-digestive step(s), and then for conducting the final fiber releasing bio-digestive step. The vessels may thus be provided with a pipe system controlled to supply retting aqueous liquor to and between the various vessels. In processing fibrous biomass in this manner, the biomass remains in the same vessel throughout the process. A given vessel is firstly operated to perform the fresh biomass bio-digestive step. The flow of retting aqueous liquors is then changed such that the vessel is operated to perform intermediate bio-digestive step(s). Thereafter, the flow of retting aqueous liquors is once more changed such that the vessel is operated to perform the fiber releasing bio-digestive step.

According to a further aspect of the invention, there is provided a system for retting fibrous biomass to release cellulosic fibers present therein. The system comprises a vessel and a pipe system. The vessel is adapted for holding and digesting fibrous biomass by use of anaerobic digestive bacteria in a bio-digestive step to provide released cellulosic fibers. In order to provide and withdraw retting aqueous liquors to and from the vessel, the system comprises a pipe system. The pipe system is arranged for supplying a retting aqueous liquor comprising anaerobic digestive bacteria to the vessel. Further, the pipe system is arranged for withdrawing a retting aqueous liquor with increased concentration of anaerobic digestive bacteria from the vessel. According to an embodiment, the pipe system comprises a pump for supplying and withdrawing aqueous liquor from the vessel. The pipe system may also comprise a pump for re-circulating aqueous liquor within the vessel.

According to an embodiment, the vessel in the system comprises a fluid permeable net basket for holding packed fibrous biomass. Optionally the net basket is removable. The vessel may be provided with a perforated distribution pipe, either for supplying the aqueous retting liquor to the fibrous biomass or for receiving the aqueous retting liquor from the fibrous biomass. Preferably, the perforated distribution pipe is arranged along the center axis of the vessel. The vessel as well as the net basket may be of a generally cylindrical shape. The perforated distribution pipe may be arranged for supplying the aqueous retting liquor radially through the packed fibrous biomass, or for receiving the aqueous retting liquor radially around its periphery from the fibrous

biomass. In order to keep the fibrous biomass in place and to prevent packed biomass from expanding, the fluid permeable net basket may further be provided with a lid.

According to an embodiment, the system further comprises a separate fiber refining tank, such as an autoclave. The refining tank is arranged for performing a post retting, fiber refining step in which the cellulosic fibers released in the bio-digestive step are further treated. The fibers are to be treated with an aqueous composition, such as aqueous composition comprising a cleansing agent, e.g. an alkaline agent or a detergent. In embodiments, wherein the refining tank is an autoclave, the autoclave is arranged for treating the cellulosic fibers released in the final fiber releasing bio-digestive step at a temperature higher than 100°C, such as at a temperature of more than 100 to 160°C, preferably at temperature of 110 to 130°C, and at a pressure higher than 101 kPa, such as at a pressure of more than 101 to 600 kPa, preferably at a pressure of 140 to 270 kPa.

According to an embodiment, the system comprises at least two vessels - a first vessel and a second vessel. The first vessel is adapted for holding and digesting partly digested fibrous biomass by use of anaerobic digestive bacteria in a final fiber releasing bio-digestive step to provide released cellulosic fibers. As already outlined, partly digested fibrous biomass may be provided in a preceding bio-digestive step, e.g. a fresh biomass bio-digestive step. The second vessel is adapted for holding and digesting fresh fibrous biomass by use of anaerobic digestive bacteria in a fresh biomass bio-digestive step to provide a partly digested fibrous biomass. In order to provide and withdraw retting aqueous liquors to and from the vessels, the system comprises a pipe system. The pipe system is arranged for supplying a first retting aqueous liquor comprising anaerobic digestive bacteria to the first vessel and to withdraw a retting aqueous liquor with increased concentration of anaerobic digestive bacteria there from. Further, the pipe system is arranged for supplying the retting aqueous liquor withdrawn from the first vessel as a second retting aqueous liquor comprising anaerobic digestive bacteria to the second vessel. Furthermore, the pipe system is arranged for withdrawing aqueous liquor comprising dissolved and/or dispersed digested non-fibrous biomass from the second vessel. Optionally, the pipe system may be arranged for supplying part of the aqueous liquor withdrawn from the second vessel as part of the first retting aqueous liquor. By such an arrangement, the concentration of anaerobic digestive bacteria in the second retting aqueous liquor supplied to the second vessel will be higher than in the first retting aqueous liquor supplied to the first vessel, which is advantageous.

According to an embodiment, the pipe system comprises pumps for supplying and

withdrawing aqueous liquor from the various vessels. The pipe system may also comprise pumps for re-circulating aqueous liquor within each vessel.

Further, the pipe system may be adapted for changing which of the first and second vessels that is utilized for the final fiber releasing bio-digestive step and which of the first and second vessels that is utilized for the fresh biomass bio-digestive step. Thus, the first vessel may be utilized for the final fiber releasing bio-digestive step in a first bio-digestive cycle and for the fresh biomass bio-digestive step in a second bio-digestive cycle. Similarly, the second vessel may be utilized for the fresh biomass bio-digestive step in a first bio-digestive cycle and for the final fiber releasing bio-digestive step in a second bio-digestive cycle.

According to an embodiment, the system further comprises an intermediate vessel. Similar to the first and second vessel, the intermediate vessel is adapted for holding and digesting fibrous biomass by use of anaerobic digestive bacteria in an intermediate bio-digestive step. The fibrous biomass digested in the intermediate bio-digestive step is obtained from the step of digesting fresh fibrous biomass. In the intermediate bio-digestive step partly digested fibrous biomass for digestion in the final fiber releasing bio-digestive step is provided. The pipe system according to such an embodiment is further arranged for withdrawing the retting aqueous liquor comprising anaerobic digestive bacteria from the first vessel and to supply it as an intermediate retting aqueous liquor comprising anaerobic digestive bacteria to the intermediate vessel. Furthermore, the pipe system according to such an embodiment is arranged for withdrawing a retting aqueous liquor comprising anaerobic digestive bacteria from the intermediate vessel and to supply it as the second retting aqueous liquor comprising anaerobic digestive bacteria to the second vessel.

According to a further embodiment, the system also comprises an anaerobic biogas producing digestion reactor, such as an up flow anaerobic sludge bed (UASB). The anaerobic biogas producing digestion reactor is adapted for anaerobically degrading dissolved and/or dispersed digested non-fibrous biomass, such as fatty acids, present in the aqueous liquor withdrawn from the vessel, e.g. the second vessel to produce biogas. By anaerobically degrading dissolved and/or dispersed digested non-fibrous biomass an aqueous liquor with decreased content of non-fibrous biomass is provided. By anaerobically degrading dissolved and/or dispersed digested non-fibrous biomass present in aqueous liquor withdrawn from the second vessel, the aqueous liquor withdrawn may subsequently be re-used in the bio-digestive steps to form part of the first retting aqueous liquor. The pipe system may thus further be arranged to supply part

of the aqueous liquor with decreased content of non-fibrous biomass withdrawn from the anaerobic biogas producing digestion reactor, be it directly or indirectly, to the vessel, e.g. the first vessel, as part of the retting aqueous liquor, e.g. the first retting aqueous liquor.

The system may further comprise a nitrification/de-nitrification reactor. The nitrification/de-nitrification reactor, which may, according to one preferred embodiment, be a moving bed biofilm reactor (MBBR), is arranged downstream the anaerobic biogas producing digestion reactor and serves to decrease the ammonia content in the aqueous liquor with decreased content of non-fibrous biomass withdrawn from the anaerobic biogas producing digestion reactor. In the nitrification/de-nitrification reactor, such as the MBBR, the ammonia content is decreased by bacterial nitrification/de-nitrification converting ammonia to nitrogen gas (N_2). By the bacterial nitrification/de-nitrification, an aqueous liquor with decreased content of ammonia and decreased content of non-fibrous biomass is provided.

In a system provided with a nitrification/de-nitrification reactor, such as an MBBR, the pipe system may further be arranged to supply, either directly or via another vessel, such as a buffer vessel, at least a part of the aqueous liquor with decreased content of ammonia and non-fibrous biomass withdrawn from the nitrification/de-nitrification reactor to the vessel, e.g. the first vessel, as part of the retting aqueous liquor, e.g. the first retting aqueous liquor. This allows for dilution of the retting aqueous liquor withdrawn from the biodigestive vessel before being re-supplied thereto. Thus, the retting aqueous liquor withdrawn from the second vessel may be diluted before being supplied to the first vessel once more.

According to an embodiment, the system further comprises a buffer vessel for holding the retting aqueous liquor, e.g. the first retting aqueous liquor. The pipe system may according to such a embodiment further being arranged for supplying the aqueous liquor with decreased content of non-fibrous biomass withdrawn from the anaerobic biogas producing digestion reactor, or the aqueous liquor with decreased content of ammonia and non-fibrous biomass withdrawn from the nitrification/de-nitrification reactor, to the buffer vessel and for supplying aqueous liquor comprising dissolved and/or dispersed digested non-fibrous biomass withdrawn from the vessel, e.g. the second vessel, to the to the buffer vessel. By such an arrangement, the retting aqueous liquor withdrawn from the vessel, e.g. second vessel, may be diluted by aqueous liquor with decreased content of non-fibrous biomass withdrawn from the anaerobic biogas producing digestion reactor, or by the aqueous liquor with decreased content of

ammonia and non-fibrous biomass withdrawn from the nitrification/de-nitrification reactor to provide the retting aqueous liquor, e.g. the first retting aqueous liquor. Further, the retting aqueous liquor, e.g. the first retting aqueous liquor, in the buffer vessel may be further diluted by supplying fresh water to the buffer vessel. The pipe system may thus further be arranged for supplying fresh water to the buffer vessel. Furthermore, the pipe system may according to such an embodiment be arranged for supplying the retting aqueous liquor from the buffer vessel to the vessel, e.g. the first vessel, for bio-digestion of fibrous biomass.

According to an embodiment, each of the vessels in the system comprises a fluid permeable net basket for holding packed fibrous biomass. The net baskets may be provided with perforated distribution pipes for supplying the aqueous retting liquor to the fibrous biomass. Preferably, the perforated distribution pipe is arranged along the center axis of the net basket. The net basket may be cylindrical.Further advantageous features of the invention are elaborated in embodiments disclosed herein. In addition, advantageous features of the invention are defined in the claims.

Brief description of the drawings

These and other aspects, features and advantages of which the invention is capable of will be apparent and elucidated from the following description of embodiments of the present invention, reference being made to the accompanying drawings, in which:

Fig. 1 depicts a process scheme for retting fibrous biomass to release cellulosic fibers present therein according to the process described herein;

Fig. 2a depicts a net basket 80 positioned in a digestion vessel 110';

Fig. 2b depicts a net basket 80 according to an embodiment;

Fig. 2c depicts a net basket 80 with a lid 85 according to an embodiment

Fig. 3 depicts a process scheme for retting fibrous biomass to release cellulosic fibers present therein according to an embodiment;

Fig. 4a depicts the operation of the first circuit 40 of the process scheme in Fig.3 during a first bio-digestive cycle;

Fig. 4b depicts the operation of the first circuit 40 of the process scheme in Fig.4 during a second bio-digestive cycle;

Fig. 4c depicts the operation of the first circuit 40 of the process scheme in Fig.4 during a third bio-digestive cycle; and

Fig. 5 depicts a schematic flow diagram illustrating steps included in one embodiment of the process.

Detailed description

The following description focuses on embodiments of the present invention applicable to a process for retting fibrous biomass to release cellulosic fibers present therein, the process comprising digesting the fibrous biomass in at least two bio-digestive steps. However, it will be appreciated that the invention is not limited to specific exemplary embodiments described.

In Fig. 1, a process scheme for retting fibrous biomass to release cellulosic fibers present therein in accordance with an exemplary embodiment of the present invention is provided. The process scheme comprises one bio-digestive step. Further, the process scheme comprises a post retting, fiber refining step performed in the separate autoclave 90.

In the bio-digestive step, anaerobic digestive bacteria present in a retting aqueous liquor releases the cellulosic fibers by digesting biomass. The retting aqueous liquor is pumped through vessel 110 in which a batch of biomass is present. Preferably, the retting aqueous liquor is continuously pumped through the vessel 110.

A pipe system 100 is used to supply a retting aqueous liquor to the vessel 110. Further, the pipe system 100 is used to withdraw retting aqueous liquor from the first vessel 110. Via the pipe system 100, the vessel 110 is connected to a buffer vessel 13. The thereby connected vessel 110 and 13 together with part of the pipe system 100 forms a first circuit 40. Aqueous liquor comprising anaerobic digestive bacteria and dissolved and/or dispersed digested non-fibrous biomass is withdrawn from the 110 and supplied to the buffer vessel 13. Further, aqueous liquor comprising anaerobic digestive bacteria is withdrawn from the buffer vessel 13 and supplied as the retting aqueous liquor to the vessel 110. Further, the pipe system 100 comprises a pipe 60 for supplying fresh water to the buffer vessel 13. Thus, the retting aqueous liquor in the buffer vessel 13 may be diluted. In addition, out-take of liquor may be compensated for.

In order to degrade dissolved and/or dispersed digested non-fibrous biomass present in the aqueous liquor withdrawn from the vessel 110 also a second circuit 41 is connected to the buffer vessel 13 via the pipe system 100. By degrading dissolved and/or dispersed digested non-fibrous biomass and decreasing the ammonia content, the resulting aqueous liquor may re-used in the bio-digestive step. Thus, an almost closed system may be provided for releasing cellulosic fibers present in biomass by retting.

Further, the second circuit 41 also serves to decrease the concentration of anaerobic digestive bacteria in aqueous liquor present in the buffer vessel 13 by diluting the aqueous liquor withdrawn from the vessel 110 and supplied to the buffer vessel 13.

Accordingly, in a second circuit 41 aqueous liquor comprising dissolved and/or dispersed digested non-fibrous biomass is withdrawn from the buffer vessel 13 to an anaerobic biogas producing digestion reactor, which may, for example, have the form of an up flow anaerobic sludge bed (UASB) 16. In the up flow anaerobic sludge bed 16, dissolved and/or dispersed digested non-fibrous biomass present in the aqueous liquor withdrawn from the buffer vessel 13 is anaerobically degraded to form biogas, thereby decreasing the content of non-fibrous biomass. The biogas formed is vented off and taken care of. The up flow anaerobic sludge bed 16 may further be provided with an internal circulation via a third circuit 42 comprising a heat-exchanger 20, to regulate the temperature within the up flow anaerobic sludge bed 16.

Downstream to the up flow anaerobic sludge bed 16, a filter 17, such as a filter based on sedimentation principle or on vortex principle, may be provided. The filter 17 serves to remove possible solid material present in the aqueous liquor withdrawn from the up flow anaerobic sludge bed 16 before decreasing the ammonia content therein.

Downstream the up flow anaerobic sludge bed 16 and the filter 17, if present, a nitrification/de-nitrification reactor, such as a moving bed biofilm reactor (MBBR) 18 is provided. In the nitrification/de-nitrification reactor, the ammonia content in the aqueous liquor withdrawn from the up flow anaerobic sludge bed 16, having decreased content of non-fibrous biomass, is decreased. The ammonia content is decreased by bacterial nitrification/de-nitrification to convert ammonia to nitrogen gas, N_2. For example, the MBBR 18 may contain plastic carriers, e.g. beads, that are inoculated with a sewage sludge aerobic microbiological culture. In order to avoid inorganic compounds accumulating in the process liquor, part of the liquor from the MBBR 18 may be taken out via the pipe 70. Process liquor may also be taken out at other positions in the process.

Via the pipe system 100, the up flow anaerobic sludge bed 16 and the MBBR 18 are connected to the buffer vessel 13 forming a second circuit 41. The first circuit 40 is provided with a pump 120 to circulate, continuously or intermittently, aqueous liquor in the first circuit 40. Similarly, the second circuit 41 is provided with a pump 121 to circulate, continuously or intermittently, aqueous liquor in the second circuit 41.

Due to the presence of the two circuits 40, 41 the aqueous liquor withdrawn from the vessel 110 in Fig. 1, is diluted by the aqueous liquor withdrawn from the

MBBR 18, having higher pH and lower concentration of anaerobic digestive bacteria. The pH and the concentration of anaerobic digestive bacteria in the aqueous liquor present in the buffer vessel 13 may thus be controlled by the relative flow ratio between the first circuit 40 and the second circuit 41, respectively. This is important as the aqueous liquor present in the buffer vessel 13 is used as retting aqueous liquor in the bio-digestive step. Further, the amount of dissolved and/or dispersed digested non-fibrous biomass obtained in the bio-digestive step is reduced in the second circuit 41. As the aqueous liquor present in the buffer vessel 13 is used as the retting aqueous liquor in the bio-digestive step, it is beneficial to reduce, or completely remove, dissolved and/or dispersed non-fibrous biomass. Dissolved and/or dispersed non-fibrous biomass present in the retting aqueous liquor may reduce the efficiency of the bio-digestion of the fibrous biomass.

Further, as known to the skilled person, anaerobic bio-digestion includes 5 major steps. The two first steps being hydrolysis and acidogenesis are involved in releasing the fibers, whereas the subsequent three steps, i.e. acetogenesis, degradation of volatile fatty acids and methanogenesis, are involved in degrading dissolved and/or dispersed digested non-fibrous biomass to form biogas. By providing two circuits 40, 41 and controlling the pH and concentration of anaerobic digestive bacteria in the first retting aqueous liquor, the two first steps will be promoted in the bio-digestive step conducted in the vessel 110.

In accordance with one embodiment a pH control arrangement may be provided. The pH control arrangement is suitably provided with a first pH-meter 50 that measures the pH in the liquor withdrawn from the vessel 110 and supplied to the buffer vessel 13, the first pH-meter 50 preferably also comprising control capabilities. A second pH-meter 52, preferably also comprising control capabilities, measures the pH in buffer vessel 13 and this second pH-meter 52 measures the pH of the mixture obtained by mixing the liquid from the vessel 110, of first circuit 40, with the liquid from the MBBR 18, of second circuit 41.

The first pH-meter 50 measures the pH of the liquid withdrawn from the vessel 110 and compares the measured pH to a set-point, such set point could, for example, be a pH of 6.7. If the pH measured by the pH-meter 50 is lower than the set-point then the pH-meter 50 may send a signal to the pump 120 and order the same to increase the flow in the first circuit 40. If, on the other hand, the pH measured by the pH-meter 50 is higher than the set-point then the pH-meter 50 may send a signal to the pump 120 and order the same to reduce the flow in the first circuit 40.

Furthermore, the second pH-meter 52 measures the pH of the liquid of the buffer vessel 13 and compares the measured pH to a set-point, such set point could, for example, be a pH of 6.8. If the pH measured by the pH-meter 52 is lower than the set-point then the pH-meter 52 may send a signal to the pump 121 and order the same to increase the flow in the second circuit 41. Thereby, more liquid is treated in the UASB 16 and in the MBBR 18 and is returned, at a higher pH than the liquid in the buffer vessel 13, to the buffer vessel 13. Similarly, if the pH measured by the pH-meter 52 is higher than the set-point then the pH-meter 52 may send a signal to the pump 121 and order the same to reduce the flow in the second circuit 41. Thereby, less liquid is treated in the UASB 16 and in the MBBR 18.

The system may further comprise an autoclave 90. In the autoclave 90, cellulosic fibers released in the bio-digestive step, is treated with an alkaline aqueous composition, optionally comprising a detergent, in post retting, fiber refining. By using an autoclave, the cellulosic fibers may be treated at a temperature higher than 100°C and at a pressure higher than 101 kPa.

According to an embodiment, the vessel 110 is provided with a fluid permeable net basket 80 for holding packed fibrous biomass. A cylindrical vessel 110' with the fluid permeable net basket 80 positioned therein is depicted in Fig. 2a. The fluid permeable net basket 80 is cylindrical with a perforated, fluid permeable shell 83. Further, the net basket is provided with a perforated distribution pipe 81 arranged along the center axis of the net basket 80. The distribution pipe 81 has a fluid receiving end 82 for receiving the first retting aqueous liquor, e.g. from a pump (not shown). The fluid receiving end 82 is connected to the pipe system 100 via a first connection pipe 131 being part of the first vessel 110'. Similarly the vessel 110' is connected to the pipe system 100 via a second connection pipe 132.

As the vessel 110' is closed, it may be pressurized. By pumping the retting aqueous liquor into the distribution pipe 81, it will be distributed into the fibrous biomass hold in the net basket 80 and radially pushed there through. Operated in this mode, the second connection pipe 132 serves as outlet. Alternatively, but less preferred, the vessel 110' may be operated in a mode wherein the first connection pipe 131 serves as outlet and the second connection pipe 132 serves as inlet.

In order to keep the fibrous biomass in place, the fluid permeable net basket 80 is further provided with a lid 85. The lid 85 may be perforated to facilitate overflow.

In Fig. 3, a process scheme for retting fibrous biomass to release cellulosic fibers present therein in accordance with another exemplary embodiment of the present

invention is provided. The process scheme comprises three bio-digestive steps, i.e. a fresh biomass bio-digestive step, an intermediate bio-digestive step, and a final fiber releasing bio-digestive step, performed batch wise in bio-digestive cycles.

In the bio-digestive steps, anaerobic digestive bacteria present in a retting aqueous liquor releases the cellulosic fibers by digesting biomass. The retting aqueous liquor is pumped through vessels 10, 11, 12 in which batches of biomass at various states, i.e. having undergone a different number of bio-digestive cycles, of digestion is present. Preferably, the retting aqueous liquor is continuously pumped through the vessels 10, 11, 12. In the first bio-digestive cycle depicted in Fig. 3 and 4a, a batch of fresh biomass is present in the second vessel 12, a batch of fibrous biomass having already undergone the fresh biomass bio-digestive step in a preceding bio-digestive cycle is present in the intermediate vessel 11, and a batch of partly digested fibrous biomass having undergone fresh biomass bio-digestive step and intermediate bio-digestive step in two previous bio-digestive cycles is present in the first vessel 10.

A pipe system 100 is used to supply a first retting aqueous liquor to the first vessel 10. Further, the pipe system 100 is used to withdraw retting aqueous liquor from the first vessel 10 and supply it to the intermediate vessel 11. The retting aqueous liquor supplied to the intermediate vessel 11 will have a higher concentration of anaerobic digestive bacteria than the first retting aqueous liquor supplied to the first vessel 10. Furthermore, the pipe system 100 is used to withdraw retting aqueous liquor from the intermediate vessel 11 and to supply it as a second retting aqueous liquor to the second vessel 12. The second retting aqueous liquor supplied to the second vessel 12 will have a higher concentration of anaerobic digestive bacteria than the first retting aqueous liquor supplied to the first vessel 10.

Via the pipe system 100, the first vessel 10 and the second vessel 12 are connected to a buffer vessel 13. The thereby connected vessels 10, 11, 12, and 13 together with part of the pipe system 100 forms a first circuit 40. Aqueous liquor comprising anaerobic digestive bacteria and dissolved and/or dispersed digested non-fibrous biomass is withdrawn from the second vessel 12 and supplied to the buffer vessel 13. Further, aqueous liquor comprising anaerobic digestive bacteria is withdrawn from the buffer vessel 13 and supplied as the first retting aqueous liquor to the first vessel 10. Further, the pipe system 100 comprises a pipe 60 for supplying fresh water to the buffer vessel 13. Thus, the retting aqueous liquor in the buffer vessel 13 may be diluted. In addition, out-take of liquor may be compensated for.

In order to degrade dissolved and/or dispersed digested non-fibrous biomass present in the aqueous liquor withdrawn from the second vessel 12 also a second circuit 41 is connected to the buffer vessel 13 via the pipe system 100. By degrading dissolved and/or dispersed digested non-fibrous biomass and decreasing the ammonia content, the resulting aqueous liquor may re-used in the bio-digestive steps. Thus, an almost closed system may be provided for releasing cellulosic fibers present in biomass by retting. Further, the second circuit 41 also serves to decrease the concentration of anaerobic digestive bacteria in aqueous liquor present in the buffer vessel 13 by diluting the aqueous liquor withdrawn from the second vessel 12 and supplied to the buffer vessel 13. By decreasing the concentration of anaerobic digestive bacteria before the final fiber releasing bio-digestive step, efficient fiber release with reduced risk for over-retting is provided.

Accordingly, in a second circuit 41 aqueous liquor comprising dissolved and/or dispersed digested non-fibrous biomass is withdrawn from the buffer vessel 13 to an anaerobic biogas producing digestion reactor, which may, for example, have the form of an up flow anaerobic sludge bed (UASB) 16. In the up flow anaerobic sludge bed 16, dissolved and/or dispersed digested non-fibrous biomass present in the aqueous liquor withdrawn from the buffer vessel 13 is anaerobically degraded to form biogas, thereby decreasing the content of non-fibrous biomass. The biogas formed is vented off and taken care of. The up flow anaerobic sludge bed 16 may further be provided with an internal circulation via a third circuit 42 comprising a heat-exchanger 20, to regulate the temperature within the up flow anaerobic sludge bed 16.

Downstream to the up flow anaerobic sludge bed 16, a filter 17, such as a filter based on sedimentation principle or on vortex principle, may be provided. The filter 17 serves to remove possible solid material present in the aqueous liquor withdrawn from the up flow anaerobic sludge bed 16 before decreasing the ammonia content therein.

Downstream the up flow anaerobic sludge bed 16 and the filter 17, if present, a nitrification/de-nitrification reactor, such as a moving bed biofilm reactor (MBBR) 18 is provided. In the nitrification/de-nitrification reactor, the ammonia content in the aqueous liquor withdrawn from the up flow anaerobic sludge bed 16, having decreased content of non-fibrous biomass, is decreased. The ammonia content is decreased by bacterial nitrification/de-nitrification to convert ammonia to nitrogen gas, N_2.For example, the MBBR 18 may contain plastic carriers, e.g. beads, that are inoculated with a sewage sludge aerobic microbiological culture. In order to avoid inorganic compounds accumulating in the process liquor, part of the liquor from the MBBR 18 may be taken

out via the pipe 70. Process liquor may also be taken out at other positions in the process.

Via the pipe system 100, the up flow anaerobic sludge bed 16 and the MBBR 18 are connected to the buffer vessel 13 forming a second circuit 41. The first circuit 40 is provided with a pump 120 to circulate aqueous liquor in the first circuit 40. Similarly, the second circuit 41 is provided with a pump 121 to circulate aqueous liquor in the second circuit 41.

Due to the presence of the two circuits 40, 41 the aqueous liquor withdrawn from the fresh biomass bio-digestive step, e.g. from second vessel 12 in Fig. 3, is diluted by the aqueous liquor withdrawn from the MBBR 18, having higher pH and lower concentration of anaerobic digestive bacteria. The pH and the concentration of anaerobic digestive bacteria in the aqueous liquor present in the buffer vessel 13 may thus be controlled by the relative flow ratio between the first circuit 40 and the second circuit 41, respectively. This is important as the aqueous liquor present in the buffer vessel 13 is used as first retting aqueous liquor in the final fiber releasing bio-digestive step. Further, the amount of dissolved and/or dispersed digested non-fibrous biomass obtained in the bio-digestive steps is reduced in the second circuit 41. As the aqueous liquor present in the buffer vessel 13 is used as the first retting aqueous liquor in the final fiber releasing bio-digestive step, it is beneficial to reduce, or completely remove, dissolved and/or dispersed digested non-fibrous biomass. Dissolved and/or dispersed digested non-fibrous biomass present in the first retting aqueous liquor may reduce the efficiency of the bio-digestion of the fibrous biomass.

Further, as known to the skilled person, anaerobic bio-digestion includes 5 major steps. The two first steps being hydrolysis and acidogenesis are involved in releasing the fibers, whereas the subsequent three steps, i.e. acetogenesis, degradation of volatile fatty acids and methanogenesis, are involved in degrading dissolved and/or dispersed digested non-fibrous biomass to form biogas. By providing two circuits 40, 41 and controlling the pH and concentration of anaerobic digestive bacteria in the first retting aqueous liquor, the two first steps will be promoted in the bio-digestive steps conducted in the first, intermediate and second vessels 10, 11, 12.

In accordance with one embodiment a pH control arrangement may be provided. The pH control arrangement is suitably provided with a first pH-meter 50 that measures the pH in the liquor withdrawn from the second vessel 12 and supplied to the buffer vessel 13, the first pH-meter 50 preferably also comprising control capabilities. As noted above, and as will be elaborated more hereinafter, that vessel from which

liquor is withdrawn to the buffer vessel 13 is altered during operation, however the pH meter 50 is arranged just upstream of the buffer vessel 13 and thereby measures the pH of liquid withdrawn from vessels 10 and 11 when the latter vessels are utilized for the fresh biomass bio-digestive step (cf. Figs. 2b and 2c, respectively). However, the description of the function of the pH control as provided hereinafter is focused, for the purpose of maintaining clarity of description, on second vessel 12 in position for fresh biomass bio-digestive step (cf. Fig. 4a). A second pH-meter 52, preferably also comprising control capabilities, measures the pH in buffer vessel 13 and this second pH-meter 52 measures the pH of the mixture obtained by mixing the liquid from the vessel 12, of first circuit 40, with the liquid from the MBBR 18, of second circuit 41.

The first pH-meter 50 measures the pH of the liquid withdrawn from the second vessel 12 and compares the measured pH to a set-point, such set point could, for example, be a pH of 6.7. If the pH measured by the pH-meter 50 is lower than the set-point then the pH-meter 50 may send a signal to the pump 120 and order the same to increase the flow in the first circuit 40. If, on the other hand, the pH measured by the pH-meter 50 is higher than the set-point then the pH-meter 50 may send a signal to the pump 120 and order the same to reduce the flow in the first circuit 40.

Furthermore, the second pH-meter 52 measures the pH of the liquid of the buffer vessel 13 and compares the measured pH to a set-point, such set point could, for example, be a pH of 6.8. If the pH measured by the pH-meter 52 is lower than the set-point then the pH-meter 52 may send a signal to the pump 121 and order the same to increase the flow in the second circuit 41. Thereby, more liquid is treated in the UASB 16 and in the MBBR 18 and is returned, at a higher pH than the liquid in the buffer vessel 13, to the buffer vessel 13. Similarly, if the pH measured by the pH-meter 52 is higher than the set-point then the pH-meter 52 may send a signal to the pump 121 and order the same to reduce the flow in the second circuit 41. Thereby, less liquid is treated in the UASB 16 and in the MBBR 18.

Furthermore, the first circuit 40 of the pipe system 100 is provided with a number of valves 101-109. The valves 101-109 are used to control the pipe system 100 in order to be able to supply the aqueous liquor to the vessels 10, 11, 12 in different order. The valves 101-109 and the pipe system 100 thus allows for performing a sequence of bio-digestive steps, e.g. firstly a fresh biomass bio-digestive step, subsequently an intermediate bio-digestive step, and lastly a final fiber releasing bio-digestive step, in each of the vessels 10, 11, 12.

In operating the pipe system in accordance with Fig. 4a, valves 103, 104, 105, and 107 will be open, whereas valves 101, 102, 106, 108, and 109 will be closed. In this mode, the fresh biomass bio-digestive step is performed in the second vessel 12, the intermediate bio-digestive step is performed in the intermediate vessel 11, and the final fiber releasing bio-digestive step is performed in the first vessel 10.

After having completed a first bio-digestive cycle, released fibers are removed from the first vessel 10. Thereafter fresh biomass is added to the first vessel 10 and the pipe system is operated in accordance with Fig. 4b in a second bi-digestive cycle.

In operating the pipe system in accordance with Fig. 4b, valves 101, 105, 106, and 108 will be open, whereas valves 102, 103, 104, 107, and 109 will be closed. In this mode, the fresh biomass bio-digestive step is performed in the first vessel 10, the intermediate bio-digestive step is performed in the second vessel 12, and the final fiber releasing bio-digestive step is performed in the intermediate vessel 11. A batch of fresh bio-mass having undergone the fresh biomass bio-digestive step in the second vessel 12 during the first bio-digestive cycle will undergo the intermediate bio-digestive step in the same vessel, i.e. the second vessel 12, during the second bio-digestive cycle. An intermediate batch having undergone the intermediate bio-digestive step in the intermediate vessel 11 during the first bio-digestive cycle, will undergo the final fiber releasing bio-digestive step in the intermediate vessel 11 during the second bio-digestive cycle.

After having completed the second bio-digestive cycle, released fibers are removed from the intermediate vessel 11. Thereafter fresh biomass is added to the intermediate vessel 11 and the pipe system is operated in accordance with Fig. 4c for a third bio-digestive cycle.

In operating the pipe system in accordance with Fig. 4c, valves 102, 104, 106, and 109 will be open, whereas valves 101, 103, 105, 107, and 108 will be closed. In this mode, the fresh biomass bio-digestive step is performed in the intermediate vessel 11, the intermediate bio-digestive step is performed in the first vessel 10, and the final fiber releasing bio-digestive step is performed in the second vessel 12. A batch of fresh bio-mass having undergone the fresh biomass bio-digestive step in the first vessel 10 during the second bio-digestive cycle, will undergo the intermediate bio-digestive step in the same vessel, i.e. the first vessel 10, during the third bio-digestive cycle. An intermediate batch having undergone the intermediate bio-digestive step in the second vessel 12 during the second bio-digestive cycle, will undergo the final fiber releasing bio-digestive step in the second vessel 12 during the third bio-digestive cycle.

After having completed the third bio-digestive cycle, released fibers are removed from the second vessel 12. Thereafter fresh biomass is added to the second vessel 12 and the pipe system is once more operated in accordance with Fig. 4a for a fourth bio-digestive cycle.

According to an embodiment, each of the vessels 10, 11, and 12 are provided with net baskets 80 (cf. Fig. 2a-c) for holding packed fibrous biomass.

Fig. 5 depicts a schematic flow diagram illustrating, to the left, steps of treating fibrous biomass, and, to the right, steps of degrading dissolved and/or dispersed digested non-fibrous biomass present in the aqueous liquor. In Fig. 5, arrow FFB denotes fresh fibrous biomass that is supplied to fresh biomass bio-digestive step 70. Optionally, fibrous biomass having undergone the fresh biomass bio-digestive step 70, may, as indicated by arrow IFB, be treated in one or more intermediate bio-digestive step/-s, in Fig. 5 two consecutive intermediate bio-digestive steps 72, 74 are shown. Partly digested fibrous biomass PFB resulting after treatment in the one or more consecutive intermediate bio-digestive steps 72, 74 is thereafter treated in a final fiber releasing bio-digestive step 76. After such treatment in step 76, released fibers RF have been generated; such released fibers may optionally be subjected to washing, drying, etc. in a fiber preparation step 78.

In parallel with the fiber releasing bio-digestive steps 70, 72, 74, 76 there is also the steps of degrading dissolved and/or dispersed digested non-fibrous biomass generated in the fiber releasing bio-digestive steps. In a step 80 of anaerobically degrading dissolved and/or dispersed digested non-fibrous biomass the substances, such as fatty acids, released in the bio-digestive steps are subjected to anaerobic treatment, to produce biogas BG and a stream DFB of aqueous liquor with decreased content of non-fibrous biomass. The stream DFB of aqueous liquor with decreased content of non-fibrous biomass is thereafter treated in a step 82 of nitrification/de-nitrification by bacterial nitrification/de-nitrification to convert ammonia to nitrogen gas (N_2). This step 82 generates a stream DAF of aqueous liquor with decreased content of ammonia and non-fibrous biomass. Furthermore, the stream DAF contains little or no anaerobic digestive bacteria since the latter have been eradicated in steps 80 and 82. This stream DAF is treated in a liquor mixing step 90. The liquor mixing step 90 mixes the stream DAF of aqueous liquor with decreased content of ammonia and non-fibrous biomass, and little or no anaerobic digestive bacteria, with a liquor LWF withdrawn from the fresh biomass bio-digestive step 70, such liquor LWF containing a high amount of

anaerobic digestive bacteria. Such mixing of liquors in the mixing step 90 generates a first retting aqueous liquor FRA comprising anaerobic digestive bacteria.

The first retting aqueous liquor FRA is utilized in the final fiber releasing bio-digestive step 76 for effecting the final release of fibers. The digestion in the final fiber releasing bio-digestive step 76 results in a retting aqueous liquor comprising anaerobic digestive bacteria and having a higher concentration of anaerobic digestive bacteria than the first retting aqueous liquor FRA. In the embodiment shown in Fig. 5 the liquor resulting from the final fiber releasing bio-digestive step 76 is utilized, as first intermediate liquor IL1, for digestion in the intermediate bio-digestive step 74, and then utilized, as second intermediate liquor IL2, for digestion in the intermediate bio-digestive step 72, before being used, as second retting aqueous liquor SRA, in the fresh biomass bio-digestive step 70. The bio-digestive steps results in build-up of anaerobic digestive bacteria in the liquor, and therefore the second retting aqueous liquor SRA has a higher concentration of anaerobic digestive bacteria than the first retting aqueous liquor FRA.

Dissolved and/or dispersed digested non-fibrous biomass substances may be forwarded, as non-fibrous biomass liquor NFB, from mixing step 90 to step 80, such non-fibrous mass liquor NFB being a mixture of streams DAF and LWF. Optionally, as indicated by arrow LWF1, at portion of liquor LWF withdrawn from the fresh biomass bio-digestive step 70 could be used in step 80 without prior mixing with stream DAF.

The overall dwell time in the present process for retting a batch of fresh fibrous biomass to release cellulosic fibers present therein may be 24 to 72 hours, such as 36 to 72 hours. Typically the dwell time is the same for each process step. For a process comprising 3 bio-digestive steps, the dwell time in each step will be 24 hours if the overall dwell time is 72 hours. For a process comprising 3 bio-digestive steps, the dwell time in each step will be 16 hours if the overall dwell time is 48 hours.

While the flow of the retting aqueous liquor comprising anaerobic digestive bacteria through the vessels typically is continuous, it may be preferred to at least once during a bio-digestive cycle empty and refill the vessels. This serves to avoid parts of a batch of biomass not being effectively digested.

Within the vessels 10, 11, 12, the biomass may be present in a filter basket to remain therein when the retting aqueous liquor is withdrawn. Further, the flow of retting aqueous liquor in the vessels 10, 11, 12 is typically vertically upwards. The retting aqueous liquor may thus be supplied to the bottom of the vessels 10, 11, 12. Further, it may be withdrawn from the upper part of the vessels 10, 11, 12.

Without further elaboration, it is believed that one skilled in the art may, using the preceding description, utilize the present invention to its fullest extent. The preceding preferred specific embodiments are, therefore, to be construed as merely illustrative and not limitative of the disclosure in any way whatsoever.

Although the present invention has been described above with reference to specific embodiments, it is not intended to be limited to the specific form set forth herein. Rather, the invention is limited only by the accompanying claims and other embodiments than the specific embodiments described above are equally possible within the scope of these appended claims.

In the claims, the term "comprises/comprising" does not exclude the presence of other elements or steps. Additionally, although individual features may be included in different claims, these may possibly advantageously be combined, and the inclusion in different claims does not imply that a combination of features is not feasible and/or advantageous.

In addition, singular references do not exclude a plurality. The terms "a", "an", “first”, “second” etc. do not preclude a plurality.

CLAIMS

1. A process for retting fibrous biomass to release cellulosic fibers present therein, the process comprising digesting the fibrous biomass in at least one bio-digestive step by use of anaerobic digestive bacteria to release the cellulosic fibers, wherein packed fresh fibrous biomass is digested in the bio-digestive step to release cellulosic fibers by supplying thereto a retting aqueous liquor comprising anaerobic digestive bacteria, the packed fresh fibrous biomass to be digested in the biomass bio-digestive step having a degree of packing, when being digested in the bio-digestive step, corresponding to a density in dry state of 135 kg/m^3 to 450 kg/m^3.

2. The process according to claim 1, wherein the packed fresh biomass to be digested in the biomass bio-digestive step has a degree of packing, when being digested in the bio-digestive step, corresponding to a density in dry state of 180 kg/m^3 to 360 kg/m^3.

3. The process according to claim 1 or 2, wherein the aqueous liquor withdrawn from the biomass bio-digestive step has a pH of less than 7.0.

4. The process according to any one of the claims 1 to 3, further comprising the step of anaerobically degrading dissolved and/or dispersed non-fibrous biomass present in aqueous liquor withdrawn from the biomass bio-digestive step to biogas in a separate anaerobic degradation step to provide an aqueous liquor with decreased content of non-fibrous biomass; preferably at least part of the provided aqueous liquor with decreased content of non-fibrous biomass withdrawn is utilized to form part of the retting aqueous liquor supplied to the fibrous biomass.

5. The process according to claim 4, wherein the anaerobic degradation step is performed in an up flow anaerobic sludge bed (UASB) (16).

6. The process according to any one of the claims 4 or 5, wherein the ammonia content in the aqueous liquor with decreased content of non-fibrous biomass withdrawn from the anaerobic degradation step is decreased in a separate nitrification/de-nitrification step by bacterial nitrification/de-nitrification to convert ammonia to nitrogen gas (N_2), thereby providing an aqueous liquor with decreased

content of ammonia and non-fibrous biomass; preferably the ammonia content in the aqueous liquor with decreased content of non-fibrous biomass is decreased in a moving bed biofilm reactor (MBBR) (18).

7. The process according to claim 6, wherein the aqueous liquor with decreased content of ammonia and non-fibrous biomass provided in the separate nitrification/de-nitrification step has a pH value which is at least 0.2 pH units higher than the pH value of the aqueous liquor withdrawn from the biomass bio-digestive step.

8. The process according to claim 6 or 7, wherein the aqueous liquor with decreased content of ammonia and non-fibrous biomass withdrawn from the separate nitrification/de-nitrification step has a pH of 7.0 or higher, preferably a pH of 7.0 to 8.5, still more preferably a pH of 7.0 to 8.0.

9. The process according to any one of the claims 6 to 8, wherein at least part of the aqueous liquor with decreased content of ammonia and non-fibrous biomass withdrawn from the separate nitrification/de-nitrification step is utilized to form part of the retting aqueous liquor supplied to the fibrous biomass.

10. The process according to claim 9, wherein at least a part of the aqueous liquor with decreased content of ammonia and non-fibrous biomass withdrawn from the separate nitrification/de-nitrification step is mixed with at least part of aqueous liquor withdrawn from the biomass bio-digestive step, the aqueous liquor withdrawn from the biomass bio-digestive step having higher concentration of anaerobic digestive bacteria than the retting aqueous liquor supplied to the biomass bio-digestive step, to form the retting aqueous liquor supplied to the fibrous biomass.

11. The process according to claim 10, wherein the aqueous liquor with decreased content of ammonia and non-fibrous biomass withdrawn from the separate nitrification/de-nitrification step and the aqueous liquor withdrawn from the biomass bio-digestive step are mixed in a buffer vessel (13).

12. The process according to any one of the claims 1 to 11, wherein the pH of the aqueous liquor withdrawn from the biomass bio-digestive step is measured by a first pH-meter (50), said pH being used to control the flow rate of the retting aqueous liquor

supplied to the biomass; and/or wherein the pH of the retting aqueous liquor supplied to the fibrous biomass is measured by a second pH-meter (52), said pH of the retting aqueous liquor being used to control the flow rate of aqueous liquor comprising dissolved and/or dispersed non-fibrous biomass being supplied to an anaerobic degradation step.

13. The process according to any one of the claims 1 to 12, wherein the retting aqueous liquor has a pH of at least 7.0, preferably a pH of 7.0 to 7.5.

14. The process according to any one of the claims 1 to 13, wherein the process further comprises a post retting, fiber refining step in which the cellulosic fibers released in the final fiber releasing bio-digestive step are treated with an aqueous composition at a temperature of from 60 to 160°C, such as from 100 to 160°C, or from 110 to 130°C, and at a pressure of at least 101 kPa, such as at a pressure of 101 to 600 kPa, preferably 140 to 270 kPa.

15. The process according to claim 14, wherein the aqueous composition is an aqueous composition comprising a cleansing agent, such as an alkaline agent or a detergent.

16. The process according to any one of the claims 1 to 15, wherein the process comprises digesting the fibrous biomass in at least two bio-digestive steps including a fresh biomass bio-digestive step and a final fiber releasing bio-digestive step by use of anaerobic digestive bacteria to release the cellulosic fibers, the concentration of anaerobic digestive bacteria being higher in the fresh biomass bio-digestive step than in the final fiber releasing bio-digestive step, wherein:

packed fresh fibrous biomass is digested in the fresh biomass bio-digestive step to provide a partly digested fibrous biomass, the packed fresh fibrous biomass having a degree of packing corresponding to a density in dry state of 135 kg/m^3 to 450 kg/m^3; and

packed partly digested fibrous biomass obtained in accordance with the fresh bio-digestive step is digested in the final fiber releasing bio-digestive step to provide released cellulosic fibers;

wherein a first retting aqueous liquor comprising anaerobic digestive bacteria is supplied to a batch of packed partly digested fibrous biomass for treating the same in

the final fiber releasing bio-digestive step, said digestion in the final fiber releasing bio-digestive step resulting in a second retting aqueous liquor comprising anaerobic digestive bacteria and having a higher concentration of anaerobic digestive bacteria than the first retting aqueous liquor;

wherein the second retting aqueous liquor is supplied to a batch of packed fresh fibrous biomass for treating the same in the fresh biomass bio-digestive step, such that the packed fresh fibrous biomass digested in the fresh biomass bio-digestive step is exposed to a higher concentration of anaerobic digestive bacteria than the packed partly digested fibrous biomass digested in the final fiber releasing bio-digestive step;

furthermore, if dependent on claim 4 or a claim dependent thereon, the aqueous liquor withdrawn from a biomass bio-digestive step and comprising dissolved and/or dispersed digested non-fibrous biomass to be anaerobically degraded, is withdrawn from the fresh biomass bio-digestive step;

furthermore, if dependent on claim 9 or a claim dependent thereon, the aqueous liquor with decreased content of ammonia and non-fibrous biomass withdrawn from the separate nitrification/de-nitrification step is utilized to form part of the first retting aqueous liquor; and

furthermore, if dependent on claim 10 or a claim dependent thereon, the aqueous liquor withdrawn from the biomass bio-digestive step to be mixed with the aqueous liquor with decreased content of ammonia and non-fibrous biomass withdrawn from the separate nitrification/de-nitrification step to form part of the first retting aqueous liquor, is withdrawn from the fresh biomass bio-digestive step.

17. The process according to claim 16, wherein a batch of packed partly digested fibrous biomass is subjected to the final fiber releasing bio-digestive step in a first vessel (10) simultaneously with a subsequent batch of packed fresh fibrous biomass being subjected to the fresh biomass bio-digestive step in a second vessel (12), which is separate from the first vessel (10), wherein the second retting aqueous liquor generated in the first vessel (10) is transferred to the second vessel (12); preferably there is a continuous flow of the second retting aqueous liquor from the first vessel (10) to the second vessel (12).

18. The process according to claim 17, wherein each of the first and second vessels (10, 12) is capable of first being used for conducting the fresh biomass bio-digestive step and then for conducting the final fiber releasing bio-digestive step,

wherein a pipe system (100) is controlled to supply the second retting aqueous liquor to the respective vessel (10, 12) when in the fresh biomass bio-digestive step, and to supply the first retting aqueous liquor to the respective vessel (10, 12) when in the final fiber releasing bio-digestive step.

19. A process according to any one of the claims 15 to 18, wherein at least one intermediate bio-digestive step is included between the fresh biomass bio-digestive step and the final fiber releasing bio-digestive step, said intermediate bio-digestive step being adapted to digest packed fibrous biomass having undergone the fresh biomass bio-digestive step to provide packed partly digested fibrous biomass for being treated in the final fiber releasing bio-digestive step, aqueous liquor comprising anaerobic digestive bacteria withdrawn from the final fiber releasing bio-digestive step being supplied to the intermediate bio-digestive step/-s and used as retting aqueous liquors in the intermediate bio-digestive step/-s, if more than one intermediate bio-digestive step is present, aqueous liquor comprising anaerobic digestive bacteria is withdrawn from a first intermediate bio-digestive step, downstream of the final fiber releasing bio-digestive step, and supplied to a subsequent intermediate bio-digestive step to be used as retting aqueous liquor in the subsequent intermediate bio-digestive step, aqueous liquor comprising anaerobic digestive bacteria withdrawn from a last intermediate bio-digestive step being supplied to the fresh biomass bio-digestive step for use as the second retting aqueous liquor, preferably 1 to 6 sequential intermediate bio-digestive steps are included between the fresh biomass bio-digestive step and the final fiber releasing bio-digestive step.

20. A process according to claim 19, wherein a batch of packed partly digested fibrous biomass is subjected to the final fiber releasing bio-digestive step in a first vessel (10) simultaneously with a subsequent batch of packed fresh fibrous biomass being subjected to the fresh biomass bio-digestive step in a second vessel (12), which is separate from the first vessel (10), and simultaneously therewith at least one intermediate batch being subjected to an intermediate bio-digestive step in an intermediate vessel (11), which is separate from the first and second vessels (10, 12), wherein retting aqueous liquor withdrawn from the first vessel (10) is transferred to a first intermediate vessel, and wherein retting aqueous liquor withdrawn from a last intermediate vessel is transferred, as the second retting aqueous liquor, to the second vessel (12), if only one intermediate vessel (11) is present, the first intermediate vessel

and last intermediate vessel will be the same vessel (11), if more than one intermediate vessel is present aqueous liquor is transferred from an upstream intermediate vessel to a downstream intermediate vessel, preferably there is a continuous flow of aqueous liquor from the first vessel (10) to one or more intermediate vessels (11) and thereafter to the second vessel (12).

21. A process according to claim 20, wherein each of the first vessel (10), the second vessel (12) and the intermediate vessel/-s (11) is capable of first being used for conducting the fresh biomass bio-digestive step, then for conducting one or more intermediate bio-digestive steps, and then for conducting the final fiber releasing bio-digestive step.

22. A process according to any one of the claims 1 to 21, wherein at least 75 % by weight of the fibrous biomass is biomass originating from bast plants, such as from hemp, flax, jute, rhea, nettle, kenaf, and/or sisal.

23. A process according to any one of the claims 1 to 22, wherein at least 75 % by weight of the cellulosic fibers obtained in the final fiber releasing bio-digestive step is bast fibers.

24. A system for retting fibrous biomass to release cellulosic fibers present therein, the system comprising:

- a vessel (110) for holding and digesting fibrous biomass, by use of anaerobic digestive bacteria in a fiber releasing bio-digestive step to provide released cellulosic fibers, wherein said vessel (110) comprises a fluid permeable net basket (80) for holding packed fibrous biomass, the net basket (80) optionally being removable; and
- a pipe system (100), the pipe system (100) being arranged for supplying a retting aqueous liquor comprising anaerobic digestive bacteria to the vessel (110), and for withdrawing a retting aqueous liquor with increased concentration of anaerobic digestive bacteria from the vessel (110).

25. The system according to claim 24, wherein the vessel (110) is provided with a perforated distribution pipe (81), preferably the vessel (110) as well as the net basket (80) being of a generally cylindrical shape, the perforated distribution pipe (81) being arranged for supplying, preferably radially, the aqueous retting liquor through the

packed fibrous biomass hold in the basket (80), or for receiving, preferably radially around its periphery, the aqueous retting liquor from the fibrous biomass hold in the baskets (80).

26. The system according to claim 24 to 25, wherein the system further comprises a separate autoclave (90), the autoclave being arranged for performing a post retting, fiber refining step in which the cellulosic fibers released in the final fiber releasing bio-digestive step are treated with an aqueous composition, such as aqueous composition comprising a cleansing agent, e.g. an alkaline agent or a detergent.

27. The system according to any one of the claims 24 to 26, wherein the system further comprises an anaerobic biogas producing digestion reactor, such as an up flow anaerobic sludge bed (UASB) (16), for anaerobically degrading dissolved and/or dispersed digested non-fibrous biomass present in the aqueous liquor withdrawn from the vessel (110) to biogas, thereby providing an aqueous liquor with decreased content of non-fibrous biomass.

28. The system according to claim 27, wherein the system further comprises a nitrification/de-nitrification reactor, such as a moving bed biofilm reactor (MBBR) (18), arranged downstream the anaerobic biogas producing digestion reactor, for decreasing the ammonia content in the aqueous liquor with decreased content of non-fibrous biomass withdrawn from the anaerobic biogas producing digestion reactor by bacterial nitrification/de-nitrification to convert ammonia to nitrogen gas (N_2), thereby providing an aqueous liquor with decreased content of ammonia and non-fibrous biomass.

29. The system according to claim 28, wherein the pipe system (100) further is arranged to supply part of the aqueous liquor with decreased content of ammonia and non-fibrous biomass withdrawn from the nitrification/de-nitrification reactor to the vessel (110) as part of the retting aqueous liquor.

30. The system according to claim 29, wherein the system further comprises a buffer vessel (13) for holding the retting aqueous liquor, the pipe system (100) further being arranged:

- for supplying the aqueous liquor with decreased content of ammonia and non-fibrous biomass withdrawn from the nitrification/de-nitrification reactor to the buffer

vessel (13), and for supplying aqueous liquor comprising dissolved and/or dispersed digested non-fibrous biomass withdrawn from the vessel (110) to the buffer vessel (13) to become mixed therein; and

- for supplying the retting aqueous liquor from the buffer vessel (13) to the first vessel (110).

31. The system according to any one the claims 24 to 30, the system comprising:

- a first vessel (10) for holding and digesting partly digested fibrous biomass, obtained in digesting fresh fibrous biomass, by use of anaerobic digestive bacteria in a final fiber releasing bio-digestive step to provide released cellulosic fibers, wherein said first vessel (10) comprises a fluid permeable net basket (80) for holding packed fibrous biomass;

- a second vessel (12) for holding and digesting fresh fibrous biomass by use of anaerobic digestive bacteria in a fresh biomass bio-digestive step to provide a partly digested fibrous biomass, wherein said second vessel (12) comprises a fluid permeable net basket (80) for holding packed fibrous biomass;

- a pipe system (100), the pipe system (100) being arranged for supplying a first retting aqueous liquor comprising anaerobic digestive bacteria to the first vessel (10), for withdrawing a retting aqueous liquor with increased concentration of anaerobic digestive bacteria from the first vessel (10), for supplying the retting aqueous liquor withdrawn from the first vessel (10) as a second retting aqueous liquor comprising anaerobic digestive bacteria to the second vessel (12), for withdrawing aqueous liquor comprising dissolved and/or dispersed digested non-fibrous biomass from the second vessel (12), and optionally for supplying part of the aqueous liquor withdrawn from the second vessel (12) as part of the first retting aqueous liquor supplied to the first vessel (10), whereby the concentration of anaerobic digestive bacteria in the second retting aqueous liquor will be higher than in the first retting aqueous liquor.

32. The system according to claim 31, wherein the system further comprises an intermediate vessel (11) for holding and digesting fibrous biomass, obtained in digesting fresh fibrous biomass, by use of anaerobic digestive bacteria in an intermediate bio-digestive step to provide partly digested fibrous biomass for digestion in the final fiber releasing bio-digestive step, wherein said intermediate vessel (11) comprises a fluid permeable net basket (80) for holding packed fibrous biomass, and

wherein the pipe system (100) further is arranged for withdrawing the retting aqueous liquor comprising anaerobic digestive bacteria from the first vessel (10), for supplying the retting aqueous liquor withdrawn from the first vessel (10) as an intermediate retting aqueous liquor comprising anaerobic digestive bacteria to the intermediate vessel (11), for withdrawing a retting aqueous liquor comprising anaerobic digestive bacteria from the intermediate vessel (11), and for supplying the retting aqueous liquor withdrawn from the intermediate vessel (11) as the second retting aqueous liquor comprising anaerobic digestive bacteria to the second vessel (12).

33. The system according to claim 31 or 32, wherein the pipe system (100) is adapted for changing which of the first and second vessels (10, 12) that is utilized for the final fiber releasing bio-digestive step and which of the first and second vessels (10, 12) that is utilized for the fresh biomass bio-digestive step.

34. A process for retting fibrous biomass to release cellulosic fibers present therein, the process comprising the steps of:

- digesting the fibrous biomass in at least one bio-digestive step by use of anaerobic digestive bacteria to release the cellulosic fibers, wherein fresh fibrous biomass is digested in the bio-digestive step to release cellulosic fibers by supplying thereto a retting aqueous liquor comprising anaerobic digestive bacteria; and
- treating the cellulosic fibers released in the bio-digestive step with an aqueous composition in a post retting, fiber refining step at a temperature of at least 60°C, preferably 60 to 160°C.

35. The process according to claim 34, wherein the post retting, fiber refining step is performed at a temperature of from 100 to 160°C, such as from 110 to 130°C, and at a pressure of at least 101 kPa, such as at a pressure of 101 to 600 kPa, preferably 140 to 270 kPa.

36. The process according to claim 34 or 35, wherein the aqueous composition comprises a cleansing agent, such as a detergent or an alkaline agent; preferably the alkaline agent being selected from the group consisting of hydroxides of an alkali metal, e.g. NaOH or KOH, and hydroxides of an alkaline earth metal, e.g. $Ca(OH)_2$.

37. The process according to any of the claims 34 to 36, wherein the fresh fibrous biomass to be digested has been packed, the packed fresh biomass to be digested in the biomass bio-digestive step having a degree of packing corresponding to a density in dry state of 135 kg/m^3 to 450 kg/m^3.

38. The process according to claim 37, wherein the packed fresh biomass to be digested in the biomass bio-digestive step has a degree of packaging corresponding to a density in dry state of 180 kg/m^3 to 360 kg/m^3.

39. The process according to any one of the claims 34 to 38, wherein the aqueous liquor withdrawn from the biomass bio-digestive step has a pH of less than 7.0.

40. The process according to any one of the claims 34 to 39, further comprising the step of anaerobically degrading dissolved and/or dispersed non-fibrous biomass present in aqueous liquor withdrawn from the biomass bio-digestive step to biogas in a separate anaerobic degradation step to provide an aqueous liquor with decreased content of non-fibrous biomass.

41. The process according to claim 40, wherein the anaerobic degradation step is performed in an up flow anaerobic sludge bed (UASB) (16).

42. The process according to any one of the claims 40 or 41, wherein the ammonia content in the aqueous liquor with decreased content of non-fibrous biomass withdrawn from the anaerobic degradation step is decreased in a separate nitrification/de-nitrification step by bacterial nitrification/de-nitrification to convert ammonia to nitrogen gas (N_2), thereby providing an aqueous liquor with decreased content of ammonia and non-fibrous biomass; preferably the ammonia content in the aqueous liquor with decreased content of non-fibrous biomass is decreased in a moving bed biofilm reactor (MBBR) (18).

43. The process according to claim 42, wherein the aqueous liquor with decreased content of ammonia and non-fibrous biomass provided in the separate nitrification/de-nitrification step has a pH value which is at least 0.2 pH units higher than the pH value of the aqueous liquor withdrawn from the biomass bio-digestive step.

44. The process according to claim 42 or 43, wherein the aqueous liquor with decreased content of ammonia and non-fibrous biomass withdrawn from the separate nitrification/de-nitrification step has a pH of 7.0 or higher, preferably a pH of 7.0 to 8.5, still more preferably a pH of 7.0 to 8.0.

45. The process according to any one of the claims 42 to 44, wherein at least part of the aqueous liquor with decreased content of ammonia and non-fibrous biomass withdrawn from the separate nitrification/de-nitrification step is utilized to form part of the retting aqueous liquor to be supplied to the fresh fibrous biomass.

46. The process according to claim 45, wherein at least a part of the aqueous liquor with decreased content of ammonia and non-fibrous biomass withdrawn from the separate nitrification/de-nitrification step is mixed with at least part of aqueous liquor withdrawn from the biomass bio-digestive step, the aqueous liquor withdrawn from the biomass bio-digestive step having higher concentration of anaerobic digestive bacteria than the retting aqueous liquor supplied to the biomass bio-digestive step, to form the retting aqueous liquor supplied to the fibrous biomass.

47. The process according to claims 46, wherein the aqueous liquor with decreased content of ammonia and non-fibrous biomass withdrawn from the separate nitrification/de-nitrification step and the aqueous liquor withdrawn from the biomass bio-digestive step are mixed in a buffer vessel (13).

48. The process according to any one of the claims 34 to 47, wherein the pH of the aqueous liquor withdrawn from the biomass bio-digestive step is measured by a first pH-meter (50), said pH being used to control the flow rate of the retting aqueous liquor supplied to the biomass; and/or wherein the pH of the retting aqueous liquor supplied to the fibrous biomass is measured by a second pH-meter (52), said pH of the retting aqueous liquor being used to control the flow rate of aqueous liquor comprising dissolved and/or dispersed non-fibrous biomass being supplied to an anaerobic degradation step.

49. The process according to any one of the claims 34 to 48, wherein the retting aqueous liquor has a pH of at least 7.0, preferably a pH of 7.0 to 7.5.

50. The process according to any one of the claims 34 to 49, wherein the process comprises digesting the fibrous biomass in at least two bio-digestive steps including a fresh biomass bio-digestive step and a final fiber releasing bio-digestive step by use of anaerobic digestive bacteria to release the cellulosic fibers, the concentration of anaerobic digestive bacteria being higher in the fresh biomass bio-digestive step than in the final fiber releasing bio-digestive step, wherein:

fresh fibrous biomass is digested in the fresh biomass bio-digestive step to provide a partly digested fibrous biomass; and

partly digested fibrous biomass obtained in accordance with the fresh bio-digestive step is digested in the final fiber releasing bio-digestive step to provide released cellulosic fibers;

wherein a first retting aqueous liquor comprising anaerobic digestive bacteria is supplied to a batch of partly digested fibrous biomass for treating the same in the final fiber releasing bio-digestive step, said digestion in the final fiber releasing bio-digestive step resulting in a second retting aqueous liquor comprising anaerobic digestive bacteria and having a higher concentration of anaerobic digestive bacteria than the first retting aqueous liquor;

wherein the second retting aqueous liquor is supplied to a batch of fresh fibrous biomass for treating the same in the fresh biomass bio-digestive step, such that fresh fibrous biomass digested in the fresh biomass bio-digestive step is exposed to a higher concentration of anaerobic digestive bacteria than the partly digested fibrous biomass digested in the final fiber releasing bio-digestive step;

furthermore, if dependent on claim 40 or a claim dependent thereon, the aqueous liquor withdrawn from a biomass bio-digestive step and comprising dissolved and/or dispersed non-fibrous biomass to be anaerobically degraded, is withdrawn from the fresh biomass bio-digestive step;

furthermore, if dependent on claim 42 or a claim dependent thereon, the aqueous liquor with decreased content of ammonia and non-fibrous biomass withdrawn from the separate nitrification/de-nitrification step is utilized to form part of the first retting aqueous liquor; and

furthermore, if dependent on claim 46 or a claim dependent thereon, the aqueous liquor withdrawn from the biomass bio-digestive step mixed with the aqueous liquor with decreased content of ammonia and non-fibrous biomass withdrawn from the separate nitrification/de-nitrification step to form part of the first retting aqueous liquor, is withdrawn from the fresh biomass bio-digestive step.

51. The process according to claim 50, wherein a batch of partly digested fibrous biomass is subjected to the final fiber releasing bio-digestive step in a first vessel (10) simultaneously with a subsequent batch of fresh fibrous biomass being subjected to the fresh biomass bio-digestive step in a second vessel (12), which is separate from the first vessel (10), wherein the second retting aqueous liquor generated in the first vessel (10) is transferred to the second vessel (12); preferably there is a continuous flow of the second retting aqueous liquor from the first vessel (10) to the second vessel (12).

52. The process according to claim 51, wherein each of the first and second vessels (10, 12) is capable of first being used for conducting the fresh biomass bio-digestive step and then for conducting the final fiber releasing bio-digestive step, wherein a pipe system (100) is controlled to supply the second retting aqueous liquor to the respective vessel (10, 12) when in the fresh biomass bio-digestive step, and to supply the first retting aqueous liquor to the respective vessel (10, 12) when in the final fiber releasing bio-digestive step.

53. A process according to any one of the claims 50 to 52, wherein at least one intermediate bio-digestive step is included between the fresh biomass bio-digestive step and the final fiber releasing bio-digestive step, said intermediate bio-digestive step being adapted to digest fibrous biomass having undergone the fresh biomass bio-digestive step to provide partly digested fibrous biomass for being treated in the final fiber releasing bio-digestive step, aqueous liquor comprising anaerobic digestive bacteria withdrawn from the final fiber releasing bio-digestive step being supplied to the intermediate bio-digestive step/-s and used as retting aqueous liquors in the intermediate bio-digestive step/-s, if more than one intermediate bio-digestive step is present, aqueous liquor comprising anaerobic digestive bacteria is withdrawn from a first intermediate bio-digestive step, downstream of the final fiber releasing bio-digestive step, and supplied to a subsequent intermediate bio-digestive step to be used as retting aqueous liquor in the subsequent intermediate bio-digestive step, aqueous liquor comprising anaerobic digestive bacteria withdrawn from a last intermediate bio-digestive step being supplied to the fresh biomass bio-digestive step for use as the second retting aqueous liquor, preferably 1 to 6 sequential intermediate bio-digestive

steps are included between the fresh biomass bio-digestive step and the final fiber releasing bio-digestive step.

54. A process according to claim 53, wherein a batch of partly digested fibrous biomass is subjected to the final fiber releasing bio-digestive step in a first vessel (10) simultaneously with a subsequent batch of fresh fibrous biomass being subjected to the fresh biomass bio-digestive step in a second vessel (12), which is separate from the first vessel (10), and simultaneously therewith at least one intermediate batch being subjected to an intermediate bio-digestive step in an intermediate vessel (11), which is separate from the first and second vessels (10, 12), wherein retting aqueous liquor withdrawn from the first vessel (10) is transferred to a first intermediate vessel, and wherein retting aqueous liquor withdrawn from a last intermediate vessel is transferred, as the second retting aqueous liquor, to the second vessel (12), if only one intermediate vessel (11) is present, the first intermediate vessel and last intermediate vessel will be the same vessel (11), if more than one intermediate vessel is present aqueous liquor is transferred from an upstream intermediate vessel to a downstream intermediate vessel, preferably there is a continuous flow of aqueous liquor from the first vessel (10) to one or more intermediate vessels (11) and thereafter to the second vessel (12).

55. A process according to claim 54, wherein each of the first vessel (10), the second vessel (12) and the intermediate vessel/-s (11) is capable of first being used for conducting the fresh biomass bio-digestive step, then for conducting one or more intermediate bio-digestive steps, and then for conducting the final fiber releasing bio-digestive step.

56. A process according to any one of the claims 34 to 55, wherein at least 75 % by weight of the fibrous biomass is biomass originating from bast plants, such as from hemp, flax, jute, rhea, nettle, kenaf, and/or sisal.

57. A process according to any one of the claims 34 to 56, wherein at least 75 % by weight of the cellulosic fibers obtained in the final fiber releasing bio-digestive step are bast fibers.

58. A system for retting fibrous biomass to release cellulosic fibers present therein, the system comprising:

- a vessel (110) for holding and digesting fibrous biomass, by use of anaerobic digestive bacteria in a fiber releasing bio-digestive step to provide released cellulosic fibers;

- a pipe system (100), the pipe system (100) being arranged for supplying a retting aqueous liquor comprising anaerobic digestive bacteria to the vessel (110), and for withdrawing a retting aqueous liquor with increased concentration of anaerobic digestive bacteria from the vessel (110); and

- a separate autoclave (90), the autoclave being arranged for performing a post retting, fiber refining step in which the cellulosic fibers released in the final fiber releasing bio-digestive step are treated with an aqueous composition, such as aqueous composition comprising a cleansing agent, e.g. an alkaline agent or a detergent.

59. The system according to claim 58, wherein said vessel (110) comprises a fluid permeable net basket (80) for holding packed fibrous biomass, preferably the autoclave (90) being arranged for receiving the net basket (80), comprising cellulosic fibers released in the bio-digestive step.

60. The system according to claim 59, wherein the vessel (110) is provided with a perforated distribution pipe (81), preferably the vessel (110) as well as the net basket (80) being of a generally cylindrical shape, the perforated distribution pipe (81) being arranged for supplying, preferably radially, the aqueous retting liquor through the packed fibrous biomass hold in the basket (80), or for receiving, preferably radially around its periphery, the aqueous retting liquor from the fibrous biomass hold in the baskets (80).

61. The system according to any one of the claims 58 to 60, wherein the system further comprises an anaerobic biogas producing digestion reactor, such as an up flow anaerobic sludge bed (UASB) (16), for anaerobically degrading dissolved and/or dispersed digested non-fibrous biomass present in the aqueous liquor withdrawn from the vessel (110) to biogas, thereby providing an aqueous liquor with decreased content of non-fibrous biomass.

62. The system according to claim 61, wherein the system further comprises a nitrification/de-nitrification reactor, such as a moving bed biofilm reactor (MBBR) (18), arranged downstream the anaerobic biogas producing digestion reactor, for decreasing

the ammonia content in the aqueous liquor with decreased content of non-fibrous biomass withdrawn from the anaerobic biogas producing digestion reactor by bacterial nitrification/de-nitrification to convert ammonia to nitrogen gas (N_2), thereby providing an aqueous liquor with decreased content of ammonia and non-fibrous biomass.

63. The system according to claim 62, wherein the pipe system (100) further is arranged to supply part of the aqueous liquor with decreased content of ammonia and non-fibrous biomass withdrawn from the nitrification/de-nitrification reactor (18) to the vessel (110) as part of the retting aqueous liquor.

64. The system according to claim 63, wherein the system further comprises a buffer vessel (13) for holding the retting aqueous liquor, the pipe system (100) further being arranged:

- for supplying the aqueous liquor with decreased content of ammonia and non-fibrous biomass withdrawn from the nitrification/de-nitrification reactor to the buffer vessel (13), and for supplying aqueous liquor comprising dissolved and/or dispersed non-fibrous biomass withdrawn from the vessel (110) to the buffer vessel (13); and
- for supplying the retting aqueous liquor from the buffer vessel (13) to the first vessel (110).

65. The system according to any one of the claims 58 to 64, the system comprising:

- a first vessel (10) for holding and digesting partly digested fibrous biomass, obtained in digesting fresh fibrous biomass, by use of anaerobic digestive bacteria in a final fiber releasing bio-digestive step to provide released cellulosic fibers;
- a second vessel (12) for holding and digesting fresh fibrous biomass by use of anaerobic digestive bacteria in a fresh biomass bio-digestive step to provide a partly digested fibrous biomass;
- a pipe system (100), the pipe system (100) being arranged for supplying a first retting aqueous liquor comprising anaerobic digestive bacteria to the first vessel (10), for withdrawing a retting aqueous liquor with increased concentration of anaerobic digestive bacteria from the first vessel (10), for supplying the retting aqueous liquor withdrawn from the first vessel (10) as a second retting aqueous liquor comprising anaerobic digestive bacteria to the second vessel (12), for withdrawing aqueous liquor comprising dissolved and/or dispersed digested non-fibrous biomass from the second

vessel (12), and optionally for supplying part of the aqueous liquor withdrawn from the second vessel (12) as part of the first retting aqueous liquor supplied to the first vessel (10), whereby the concentration of anaerobic digestive bacteria in the second retting aqueous liquor will be higher than in the first retting aqueous liquor.

66. The system according to claim 65, wherein the system further comprises an intermediate vessel (11) for holding and digesting fibrous biomass, obtained in digesting fresh fibrous biomass, by use of anaerobic digestive bacteria in an intermediate bio-digestive step to provide partly digested fibrous biomass for digestion in the final fiber releasing bio-digestive step, wherein the pipe system (100) further is arranged for withdrawing the retting aqueous liquor comprising anaerobic digestive bacteria from the first vessel (10), for supplying the retting aqueous liquor withdrawn from the first vessel (10) as an intermediate retting aqueous liquor comprising anaerobic digestive bacteria to the intermediate vessel (11), for withdrawing a retting aqueous liquor comprising anaerobic digestive bacteria from the intermediate vessel (11), and for supplying the retting aqueous liquor withdrawn from the intermediate vessel (11) as the second retting aqueous liquor comprising anaerobic digestive bacteria to the second vessel (12).

67. The system according to claim 65 or 66, wherein the pipe system (100) is adapted for changing which of the first and second vessels (10, 12) that is utilized for the final fiber releasing bio-digestive step and which of the first and second vessels (10, 12) that is utilized for the fresh biomass bio-digestive step.

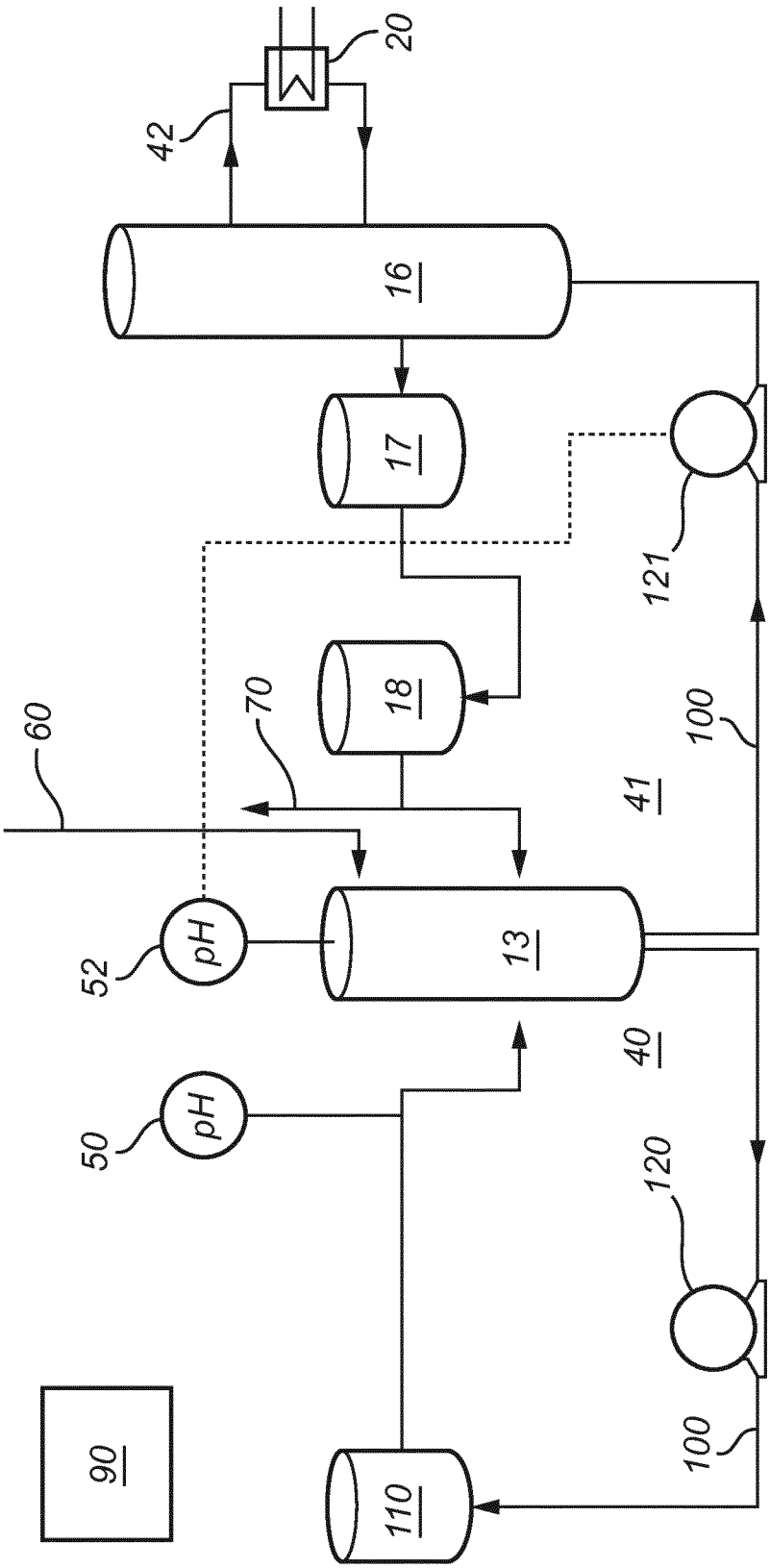


Fig. 1

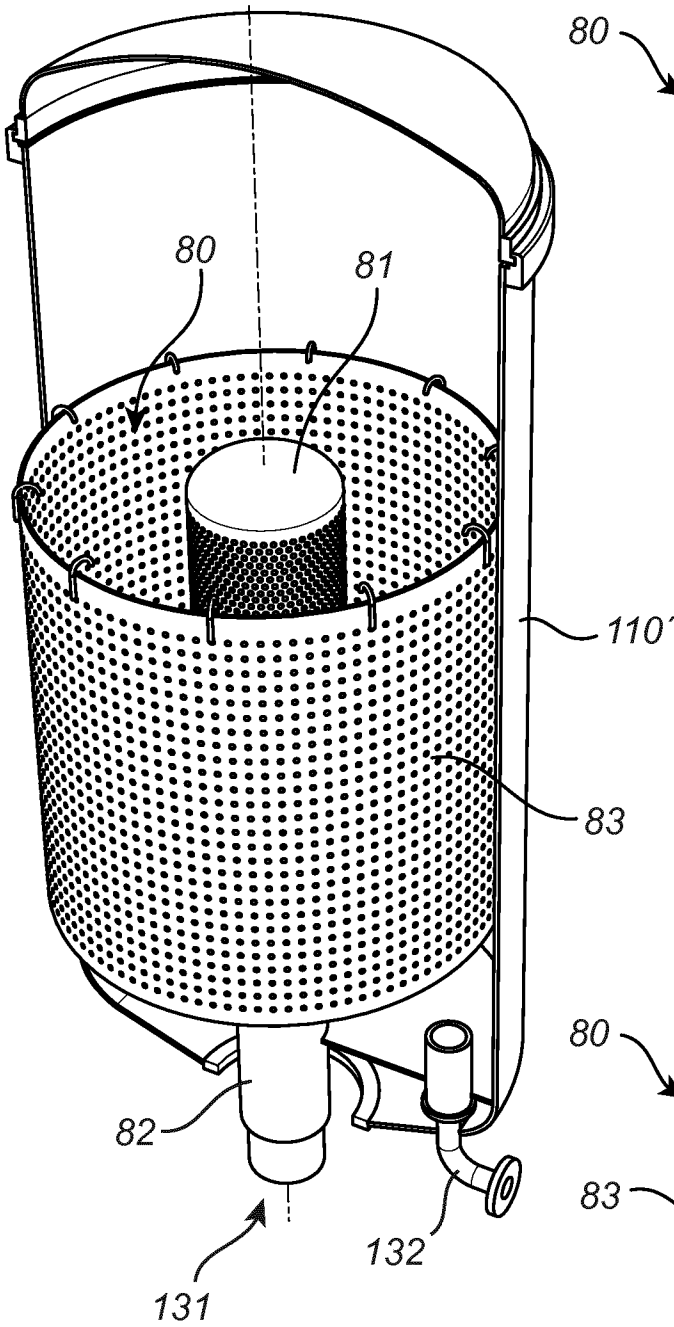


Fig. 2a

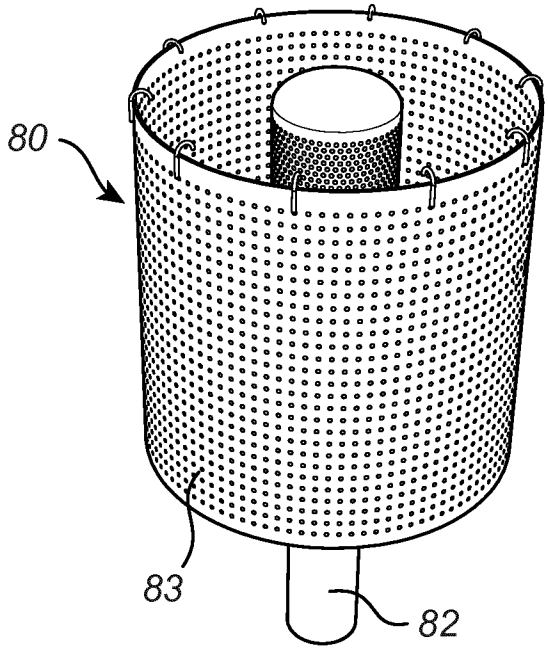


Fig. 2b

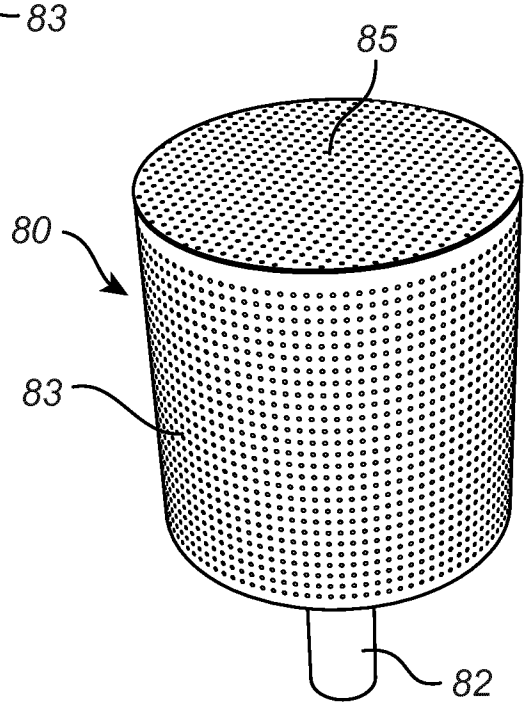


Fig. 2c

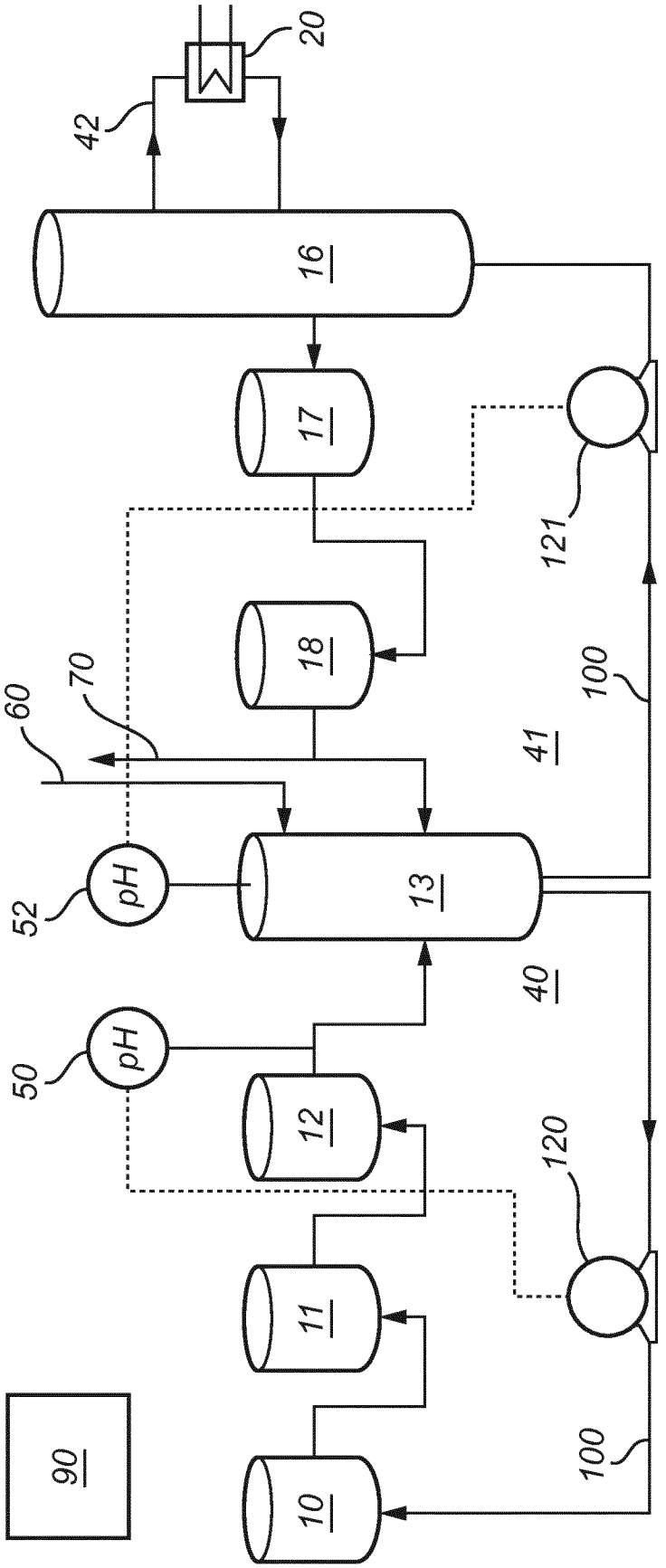


Fig. 3

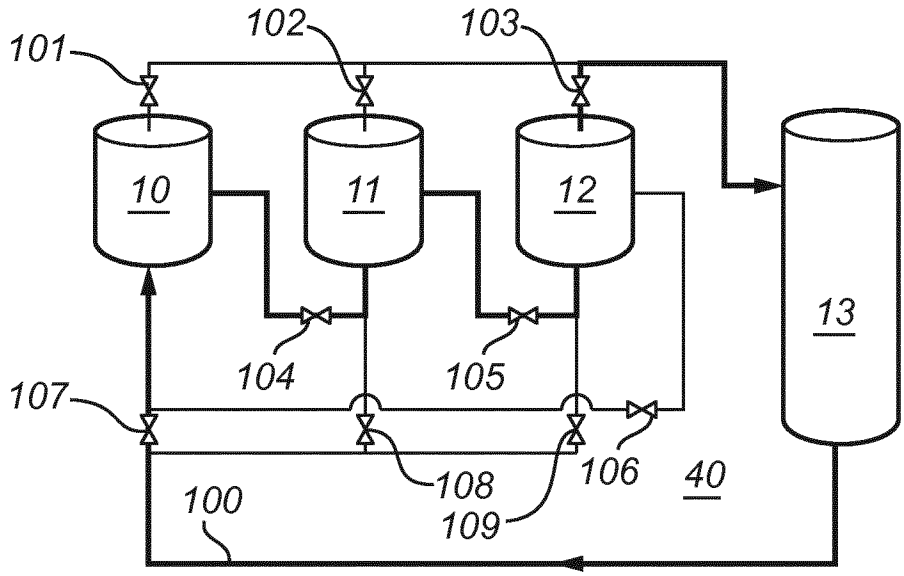

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Fig. 4a

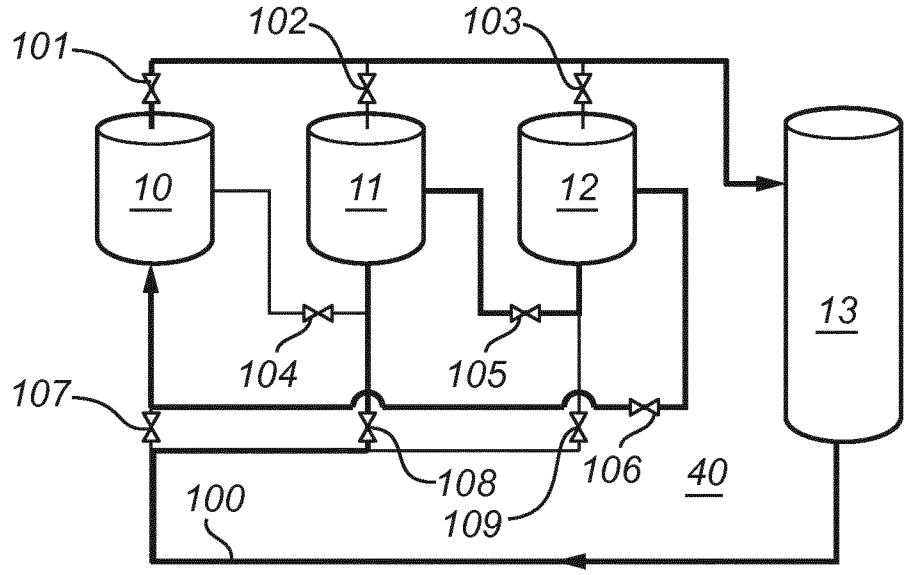

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Fig. 4b

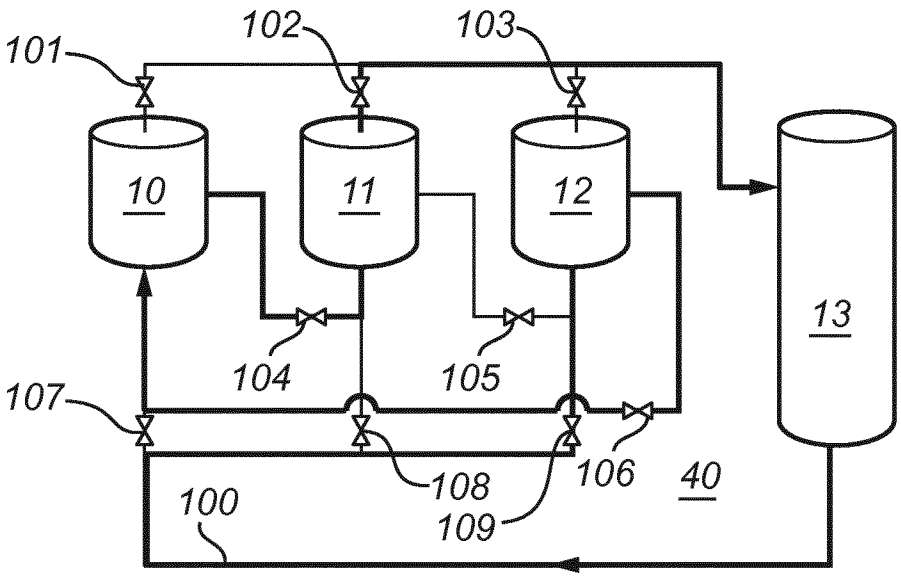

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Fig. 4c

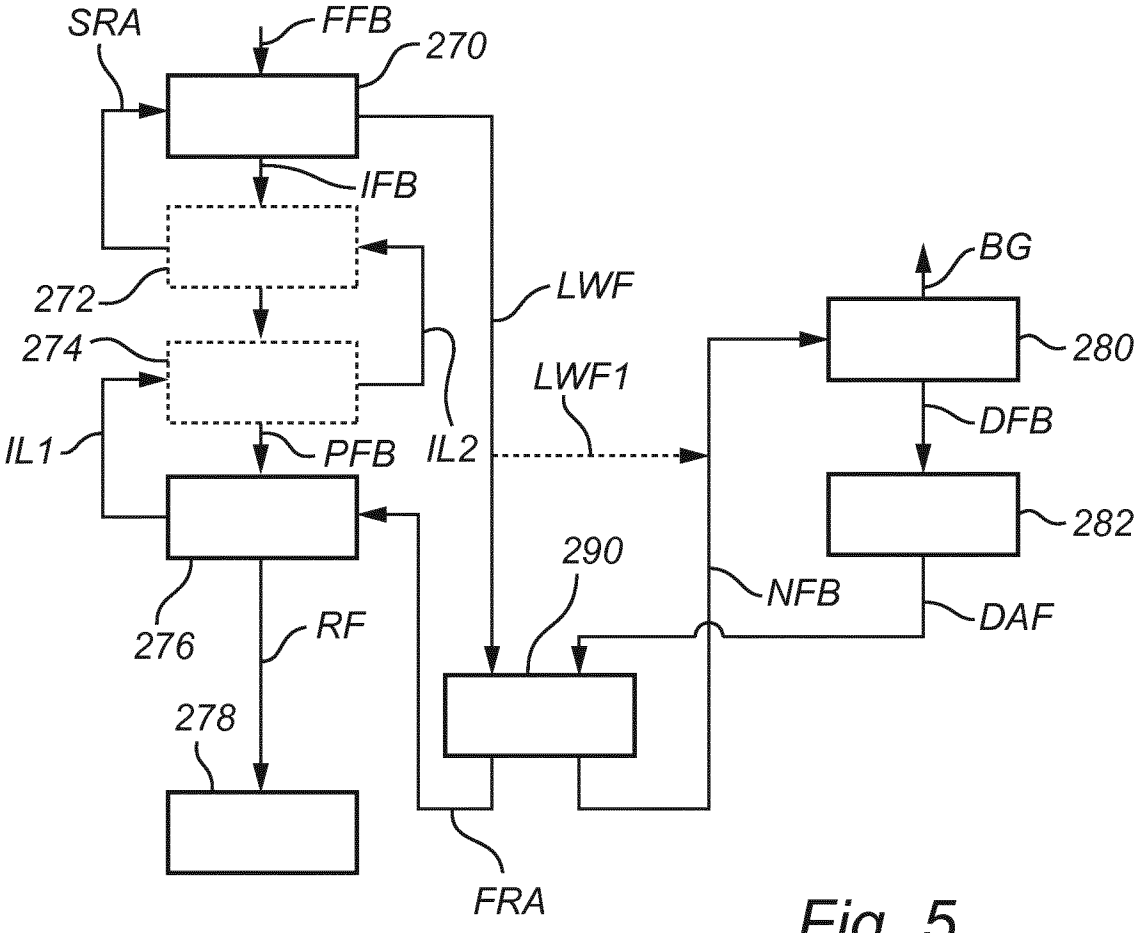

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FRA

Fig. 5