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(71) Applicant: **BillerudKorsnäs AB**
169 27 Solna (SE)

(72) Inventors:
- **VIFORR, Silvia**
  164 78 Kista (SE)
- **HILDÉN, Lars**
  603 80 Norrköping (SE)
- **JUNKA, Karoliina**
  182 52 Danderyd (SE)

(74) Representative: **Kransell & Wennborg KB**
P.O. Box 27834
115 93 Stockholm (SE)

(54) **PROCESS FOR THE MANUFACTURE OF MOULDED FIBRE-BASED 3-DIMENSIONAL ARTICLES AND ARTICLES OBTAINABLE BY SAID PROCESS**

(57) A method for the production of a moulded fibre-based 3-dimensional article comprising the steps of preparing a furnish, delivering said furnish to a mould to wet-form a 3-dimensional fibre-based moulded article, and dewatering said article, wherein said furnish is foamed prior to delivery to said mould, and wherein the fibre concentration of the furnish prior to foaming is at least 1 weight-%, preferably at least 2 weight-%, most preferably at least 3 weight-%. A 3-dimensional fibre-based article, preferably a cellulose fibre-based bottle produced by said method.

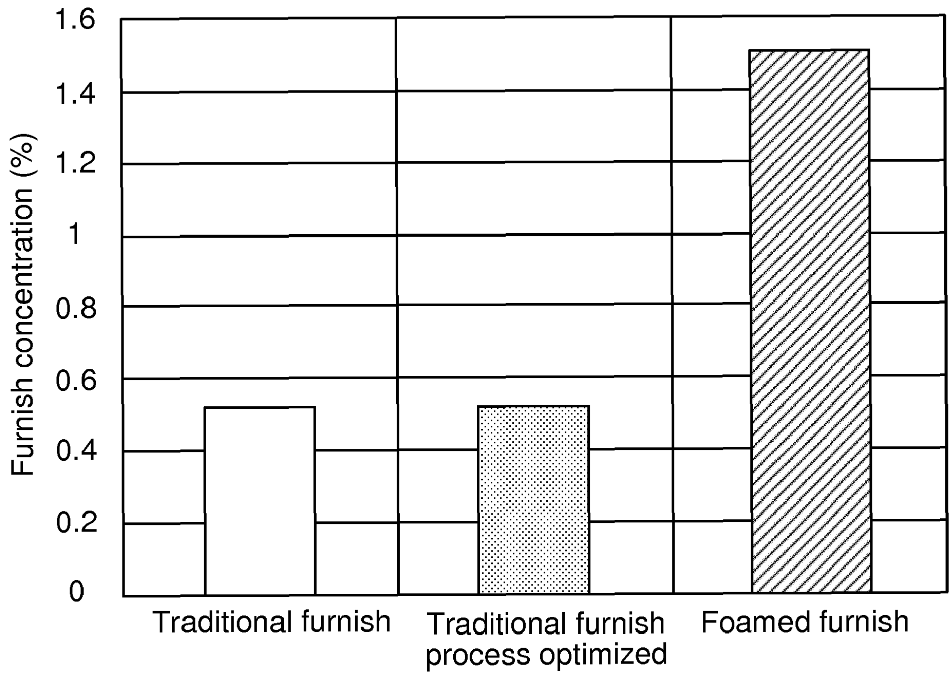

Fig. 4

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Description

Technical field

[0001] The present disclosure relates to the production of fibre-based articles having a 3-dimensional shape, such as moulded fibre-based packaging, for example bottles and other types of hollow containers. The disclosure relates in particular to a method of forming a moulded fibre-based article having a 3-dimensional and a moulded article produced by said method.

Background

[0002] The packaging industry uses enormous amounts of plastic for different packaging solutions, as plastic can be shaped and moulded into almost any desired form. In spite of a strong ambition to reduce the use of non-renewable plastic, and promising results achieved with renewable, fibre-based alternatives, most 3-dimensional packaging articles are still made of plastic. This is particularly the case when liquid packaging is concerned, where it is generally considered difficult to replace plastic bottles with bottles made from renewable materials.

[0003] It is possible to produce moulded fibre-based 3-dimensional articles, but with some exceptions, these have so far been rather unsophisticated in shape, and mainly limited to applications with lower requirements on surface finish. Such articles are generally produced using permeable moulds formed of metal mesh. A furnish comprising water, fibre and additives is applied to a mould or die, said furnish is dewatered and the still moist article is removed from the mould and dried. The construction of such moulds or dies is a lengthy and expensive procedure, so this technology is limited to items produced in very substantial numbers. Everyone is familiar with fibre-based egg cartons, egg trays, fruit trays, single-use bedpans, seedling trays, transport moulds etc.

[0004] Also the dewatering of the fibre sets its own limits to this technology. The quantity of liquid which can be expelled from the fibre deposited on a die or in a mould prior to removal / demoulding is limited by the poor level of surface smoothness obtained using such mesh moulds. More remaining liquid in the product limits the strength of the product as it is demoulded. Because of this, mainly shallow items such as egg boxes, paper trays etc. can be made this way without collapsing under their own weight prior to drying. Finally, the amount of water left in the product makes dewatering and drying the product an energy intensive procedure.

[0005] Different approaches have been tried to address these problems. For example WO 2018/020219 discloses a method of forming a moulded article comprising: preparing a fibre suspension by liquidizing fibrous material in a suspending liquid using at least one high shear mixer; feeding the fibre suspension to the moulding surface of porous mould; removing said suspending liquid via the pores of said porous mould to deposit suspended fibre on said mould surface as a moulded article, the step of removing said suspending liquid comprising pressing a bladder formed of a resilient flexible impermeable membrane against the article using pressure applied behind the membrane; removing the moulded article from the porous mould and drying the moulded article using microwave radiation.

[0006] According to WO 2018/020219, the concentration of fibrous material in the suspending liquid is in the range of 0.5 - 10 weight-% of paper fibre in water, but it is also noted that high concentrations make it difficult to transport the suspension and to achieve an even coating in the mould. In a preferred embodiment, the concentration of fibrous material in the suspending liquid is therefore about 1 %.

[0007] Further, according to WO 2018/020219, different additives may be used to modify the mechanical and other characteristics of the product. These characteristics include the mechanical strength, surface finish, the degree of waterproofing, and food barrier properties such as transmission of oxygen and other gases. The additive may for example comprise coloring or herbicide or germicide or fungicide or beeswax or decorative particles, or a combination thereof. Preferably, the additive amount is no more than 20 wt% of the solids content, and in some preferred embodiments, no additives are present.

[0008] Moulded fibre-based articles, such as bottle-shaped fibre-based articles, can be manufactured for example using a system and method as disclosed in WO 2016/055073. This system comprises a pressure device for applying a pressure to the pulp, a first compressor, a split mould having a central first cavity, said first cavity having an opening for supplying said pulp to said first cavity, one or more further cavities together surrounding said first cavity, and a wall separating said first cavity from said one or more further cavities, said wall having a structure allowing for fluid to flow between said first cavity and said one or more further cavities), said wall having a first surface facing the interior of said first cavity and supporting a layer of said pulp deposited thereon, wherein said first compressor is configured for establishing a temporary elevated fluid pressure of more than 1 bar in said one or more further cavities.

[0009] In this system and corresponding method, the dewatering of the layer of pulp deposited on the inside surface of an interior cavity of a mould is performed very rapidly, and at a temperature around 100 °C. This may make it possible to shorten or even avoid a subsequent drying step where the article must be moved to a drying station, after having been removed from the aforementioned mould.

[0010] Moulding using a traditional furnish based on cellulose fibre requires a low fibre concentration furnish and a substantial wet-forming time. This is frequently the case when producing egg boxes and other less complex shapes. Increasing the concentration may result in flocculation and uneven distribution of the furnish in the mould, reducing the quality of the product.

[0011] Moulded pulp is considered a sustainable packaging material, since it can be produced from renewable sources, or even from recycled materials, and as it can be recycled again after use. There are however still limitations associated with the production of 3-dimensional fibre-based articles, limitations which delay the reduction of the use of plastic, and complicates the transition to the use of fibre-based renewable packaging materials.

Summary

[0012] The present disclosure sets out to address the problems of the prior art, and makes available an improved method of producing a moulded fibre-based 3-dimensional article and a moulded article exhibiting improved properties, in particular hollow fibre-based articles such as containers and bottles.

[0013] According to a first aspect, the present disclosure makes available a method for the production of a moulded fibre-based 3-dimensional article comprising the steps of preparing a furnish, delivering said furnish into a mould to wet-form a 3-dimensional fibre-based moulded article, and dewatering said article, wherein said furnish is foamed prior to delivery to said mould.

[0014] In one embodiment of said first aspect, the fibre concentration of said furnish - prior to foaming - is higher than traditionally used, and preferably significantly higher such as at least 1 weight-%, more preferably at least 2 weight-%, most preferably at least 3 weight-% or higher. The fibre concentration is preferably in the interval of about 1 to about 20 weight-%, for example about 1 to about 10 weight-%, preferably more preferably about 2 to about 10 weight-%, most preferably 3 to 10 weight-%.

[0015] In one embodiment, freely combinable with the above aspect and embodiments thereof, said furnish is foamed in a mixing tank, producing a foamed furnish substantially immediately before said foamed furnish is introduced into the mould. The expression "immediately before" here means that the foamed furnish is delivered to the mould before the foam deteriorates, and preferably within about 1 minute from formation of the foam, more preferably within 1 to 30 seconds, and most preferably within 1 to 10 seconds, and most preferably within 1 to 5 seconds from formation of the foam.

[0016] In one embodiment, freely combinable with the above aspect and embodiments thereof, the foaming is performed in two steps, a first upstream pre-mixing step and a subsequent foaming step taking place in a mixing tank, producing a foamed furnish substantially immediately before the furnish is introduced into the mould. It is conceived that said furnish is prepared in a furnish tank located upstream, in which tank the ingredients are mixed. The furnish is then led, for example pumped, into a mixing tank located in close proximity to the moulding equipment. The furnish is then foamed in the mixing tank, and substantially immediately fed into the moulding equipment.

[0017] In an embodiment, freely combinable with the above aspect and embodiments thereof, the foaming is performed using vigorous mixing, pumping or by the introduction of pressurized air. The pre-mixing step, taking place upstream, can be performed using a traditional mixer, for example an impeller, whereas the foaming step that is performed in the mixing tank, in close proximity to the moulding equipment, is more vigorous.

[0018] In an embodiment, freely combinable with the above aspect and embodiments thereof, the foamed furnish has a content of air in the range of about 20 - 80 % air per volume, preferably about 30 - 70 %, more preferably 40 - 60 %.

[0019] In an embodiment, freely combinable with the above aspect and embodiments thereof, said furnish comprises an additive chosen from a polyvinyl alcohol, a sodium dodecyl sulphate, a carboxymethyl cellulose, a surfactant, or combinations thereof.

[0020] In an embodiment, freely combinable with the above aspect and embodiments thereof, the 3-dimensional article is a container for liquids, preferably a fibre-based bottle.

[0021] In an embodiment, freely combinable with the above aspect and embodiments thereof, the foamed furnish comprises fibers of different origin, such as cellulose fibers and synthetic fibers.

[0022] In another embodiment, freely combinable with the above aspect and embodiments thereof, the foamed furnish comprises fibers of different length.

[0023] In an embodiment, freely combinable with the above aspect and embodiments thereof, the foamed furnish comprises a functional additive chosen from natural and synthetic polymers, pigments, fillers and combinations thereof.

[0024] In an embodiment, freely combinable with the above aspect and embodiments thereof, the wet-formed 3-dimensional article is dewatered by applying vacuum to the outside of the mould, or by applying pressure to the inside of the mould, or a combination of the two, and subsequently removed from the mould.

[0025] Using foamed furnish, the distribution of the furnish is improved, and according to an embodiment, freely combinable with the previous embodiments, the wet-forming of said 3-dimensional article takes place during a time period in the interval of 1 - 20 seconds.

[0026] In an embodiment, freely combinable with the above aspect and embodiments thereof, the 3-dimensional article has lower water content after dewatering, but before demoulding and drying, than traditionally produced articles, preferably a water content of about 50 to about 75 % after dewatering.

[0027] A second aspect of the present disclosure relates to a 3-dimensional moulded fibre-based article, obtainable by a method according to any one of the above first aspect and embodiments thereof.

[0028] In an embodiment, freely combinable with the above second aspect and embodiments thereof, the article is a hollow article, such as a container for liquids, preferably a fibre-based bottle.

[0029] In an embodiment, freely combinable with the above second aspect and embodiments thereof, wherein the article is a fibre-based bottle for carbonated drinks.

Short description of the drawing

[0030] The aspects and embodiments will be presented in closer detail in the following description and examples and with reference to the attached drawing, in which:

Fig. 1 is a schematic illustration of the process flow used in the experiments, comprising the steps of pre-mixing, mixing tank foaming, wet-forming and dewatering/drying.

Fig. 2 shows the effect of Poval 23-88 on the stability of the foam when added in different concentrations.

Figure 3 is a bar diagram showing an example of the reduction of wet-forming time achieved with a foamed furnish, compared to a traditional furnish and a traditional furnish in an optimized process.

Figure 4 is a bar diagram showing an example of how the foaming disclosed herein makes it possible to use a significantly more concentrated furnish.

Figure 5 is a bar diagram showing the Pressure Resistance Index, PRI for a number of moulded articles (fibre-based bottles), i.e. a reference (at 0.5 % furnish concentration) and four different foaming agents used with seven different settings (at 1.5 % furnish concentration).

Description

[0031] Before the present invention is described, it is to be understood that the terminology employed herein is used for the purpose of describing particular embodiments only and is not intended to be limiting, since the scope of the present invention will be limited only by the appended claims and equivalents thereof.

[0032] It must be noted that, as used in this specification and the appended claims, the singular forms "a," "an," and "the" include plural referents unless the context clearly dictates otherwise.

[0033] The term "furnish" is used to describe a mixture of fibre and additives, chosen for a specific product. Typically, a furnish comprises water, cellulose fibre and additives, for example sizing, fillers, optical brighteners etc.

[0034] The term "fibre" encompasses cellulose fibre, such as virgin fibre, for example bleached and/or unbleached kraft pulp, or chemithermomechanical pulp (CTMP), but also includes recirculated fibre, pulped recycled paper, such as pulped newsprint, de-inked pulp (DIP) etc. The term "fibre" also encompasses other natural fibres, as well as synthetic fibres of different composition, length and width.

[0035] The term "foaming agent" is used to describe an additive capable of aiding and/or sustaining foaming when air is mixed into the furnish.

[0036] Pressure Resistance (PR) denotes a measure of the strength of the bottles used in this disclosure. A method was designed specifically for the purpose of exploding bottles, and for accurately measuring the burst pressure.

[0037] Pressure Resistance Index (PRI) denotes a normalized value, obtained by dividing the measured pressure resistance with the weight of oven dry fibre (in gram) for each measured bottle.

[0038] According to a first aspect, the present disclosure makes available a method for the production of a moulded fibre-based 3-dimensional article comprising the steps of preparing a furnish, delivering said furnish to a mould to wet-form a 3-dimensional fibre-based moulded article, and dewatering said article, wherein said furnish is foamed prior to delivery to said mould.

[0039] Foaming the furnish offers many advantages, such as a more even distribution of the fibre, and a lower water content, reducing the dewatering time of the article in the mould. A shortened dewatering time reduces the cycle time and increases throughput. A more even distribution of fibre reduces flocculation and results in more uniform and smoother surfaces in the 3-dimensional article. These advantages are even more pronounced when a 3-dimensional article having a complicated shape, such as a hollow shape, is produced.

[0040] In one embodiment of said first aspect, the fibre concentration of the furnish is higher than traditionally used, and preferably significantly higher such as at least 1 weight-%, more preferably at least 2 weight-%, most preferably at least 3 weight-% or higher. The fibre concentration is preferably in the interval of about 1 to 20 weight-%, for example about 1 to 10 weight-%, preferably more preferably 2 to 10 weight-%, most preferably 3 to 10 weight-%.

[0041] A higher fibre concentration in the furnish is very advantageous also because it reduces the water consumption and thus the environmental impact of the process. Possibly also the energy requirement is reduced, both as less water needs to be pumped in the process flows, and as less energy is required for dewatering and drying the 3-dimensional article.

[0042] In one embodiment, freely combinable with the above aspect and embodiments thereof, said furnish is foamed in a mixing tank, producing a foamed furnish substantially immediately before said foamed furnish is introduced into the mould. The expression "immediately before" means that the foamed pulp is delivered to the mould before the foam deteriorates, and preferably within about 1 minute from formation of the foam, more preferably within 1 to 30 seconds, and most preferably within 1 to 10 seconds, and most preferably within 1 to 5 seconds from formation of the foam.

[0043] In an embodiment, freely combinable with the above aspect and embodiments thereof, the foaming is performed in two steps, a first upstream pre-foaming step and a second subsequent foaming step taking place in a mixing tank, producing a foamed furnish substantially immediately before the furnish is introduced into the mould. It is conceived that the furnish is prepared in a furnish tank located upstream, in which tank the ingredients are mixed and the furnish optionally is prefoamed. The furnish is then led, for example pumped, into a mixing tank located in close proximity to the moulding equipment. The furnish is then foamed in the mixing tank, and substantially immediately fed into the moulding equipment.

[0044] A pre-mixing step, taking place upstream, can be performed using a traditional mixer, for example an impeller, whereas the foaming step that is performed in the mixing tank, in close proximity to the moulding equipment, is more vigorous, and performed for example using an injector mixer. Also other types of mixing equipment are contemplated, such as but not limited to impeller-based mixers, a pump or re-circulation based mixers, and mixing based on the injection of compressed air.

[0045] In an embodiment, freely combinable with the above aspect and embodiments thereof, the foamed furnish has a content of air in the range of about 20 - 80 % air per volume, such as about 30 - 70 %, and preferably about 40 - 60 %. The inclusion of such a high proportion of air has many advantages, among others that the tiny bubbles in the foam encase individual fibre and particles included in the furnish, resulting in a homogenous distribution and stabilizing the mixture. When foaming the furnish in the production of hollow 3-dimensional articles, such as bottles, it becomes possible to include functional additives, such as natural and synthetic polymers, fibre of varying length, fillers, etc.

[0046] In one embodiment, freely combinable with the above aspect and embodiments thereof, the furnish comprises an additive chosen from a polyvinyl alcohol (PVOH), sodium dodecyl sulphate (SDS), carboxymethyl cellulose (CMC), a surfactant, such as a non-ionic surfactant, or combinations thereof. The additive is added in a concentration sufficient to produce stable foam, i.e. foam which retains at least about 60 % of its volume at 60 seconds from formation. When said additive is a polyvinyl alcohol, the concentration of additive is in the interval of 0.05 - 0.15 g/g fibre. The exact amount of additive is dependent on the type of additive chosen, and the character of other additives and components used in the furnish. It is contemplated that more than one additive is used, in which case the amounts of each additive can be reduced.

[0047] In another embodiment, freely combinable with the above aspect and embodiments thereof, the 3-dimensional fibre-based article is a container for liquids, preferably a fibre-based bottle. The inventors have shown that the method where a foamed furnish is used to produce paper bottles results in strong and smooth bottles, with good handling properties immediately after dewatering, and with a good finish and high strength after drying.

[0048] In an embodiment, freely combinable with the above aspect and embodiments thereof, the foamed furnish comprises fibers of different origin, such as cellulose fibers and synthetic fibers. Alternatively, or in combination therewith, synthetic polymer fibre could be added, and the type of polymer chosen such, that it melts at least partially at the drying temperature of the 3-dimensional article, thus reinforcing said 3-dimensional article. It is also conceivable that other functional additives are used, for example additives increasing the dry strength of the finished product. Synthetic fillers which melt at the drying temperatures used can also be added, providing added strength and possibly barrier properties or improved printability to the finished article.

[0049] In another embodiment, freely combinable with the above aspect and embodiments thereof, the foamed furnish comprises fibers of different length, different width, or with other desired properties. Advantageously, longer fibre can be added to function as reinforcement in the resulting 3-dimensional article. Here, a fibre is considered to be "long" if the average fibre length is more than 100 times the average outer diameter of the fibre.

[0050] In an embodiment, freely combinable with the above aspect and embodiments thereof, the foamed furnish comprises a functional additive chosen from natural and synthetic polymers, pigments, fillers and combinations thereof.

[0051] In one embodiment, freely combinable with the above aspect and embodiments thereof, the wet-formed 3-dimensional article is dewatered by applying vacuum to the outside of the mould, or by applying pressure to the inside of the mould, or a combination of the two, and subsequently removed from the mould. When using foamed furnish, as disclosed herein, the amount of water introduced into the mould is significantly reduced, and hence the dewatering time is reduced. In the experiments performed by the present inventors, the wet-forming time could be reduced to less than 20 seconds, compared to about 140 seconds using traditional furnish, and 60 seconds, using traditional furnish in an optimized process.

[0052] In one embodiment, freely combinable with the above aspect and embodiments thereof, the 3-dimensional article has lower water content after dewatering but before drying of the article than traditionally produced articles, preferably a water content of about 50 to about 75 % after dewatering, before demoulding. As a result, the demoulded article retains its form and can be handled safely without collapsing, for example transferred to a drying section of the equipment, or subjected to optional subsequent process steps.

[0053] Another aspect of the present disclosure relates to a 3-dimensional moulded fibre-based article, obtainable by a method according to any one of the above first aspect and embodiments thereof.

[0054] In an embodiment, freely combinable with the above second aspect and embodiments thereof, the article is a container for liquids, preferably a fibre-based bottle. In such a bottle, a barrier layer is applied to the inside of the fibre-based bottle, and the smooth finish achieved using foamed furnish constitutes a good basis onto which the barrier layer is applied.

[0055] In an embodiment, freely combinable with the above second aspect and embodiments thereof, wherein the article is a fibre-based bottle for carbonated drinks. Bottles for carbonated drinks must withstand a significant pressure, and the even fibre distribution and increased strength of the disclosed articles constitute advantageous properties.

Examples

[0056] The inventors have performed extensive experimental work investigating the effect of different foaming agents and the feasibility of foaming in a mixing tank. The inventors have also produced paper fibre-based bottles in a series of comparative examples, using traditional furnish and foamed furnish, and demonstrated the shortened wet-forming time and improved properties achieved with the inventive method.

Materials

[0057] Pre-mixer: A pre-foaming mixer was constructed using a steel tank and a mixer mounted on a power drill. The tank volume was approximately 4 litres.

[0058] Mixing tank: A mixing tank was constructed from a closed tank with the possibility to adjust degree of mixing, residence time and pressure (for transport of foam to a wet-forming unit as described below)

[0059] Moulding equipment: A modified pilot equipment for the production of paper bottles constructed basically as disclosed in WO 2016/055073 was used. However, no expandable pressure tool was used in the modified pilot equipment, thus the pulp was dewatered using only pressure inside the unit and vacuum outside the unit. Further, the drying was not performed in the wet-forming device itself but in a subsequent unit where an expandable pressing tool was used.

[0060] Pulp: Bleached and refined softwood market pulp was used in the experiments. The pulp was refined in a conical low-consistency (LC) refiner using either a laboratory refiner or a slightly larger conventional refiner (Valmet JC-00 Conflo®). In both cases, the resulting pulp was identical with respect to Shopper-Riegler value, fibre properties and behavior in bottle production. 75% of the pulp was refined at 50 kWh/ton and 25% was refined at 300 kWh/ton. Tap water was used as process water.

[0061] Foaming agents of commercial grade: Different types of PVOH (polyvinyl alcohol) in the form of dry power, CMC (carboxymethyl cellulose), and different types of surfactants, e.g. SDS (sodium dodecyl sulphate) and non-ionic surfactants.

Example 1. Effect of foaming agent

[0062] Before the actual bottle production described in Example 3 was performed, an investigation of the effect of different foaming agents was conducted by the inventors. A furnish with a concentration of 0.5% was foamed using different concentrations of foaming agents and the stability of the foam over time was recorded. The foaming agent was added to 4 liter of 0.5 % furnish, and then mixed for 60 s using a mixer attached to a power drill. A sample of about 2 liter of the foamed pulp was collected in a transparent and graded jar. The top level of the foam layer and the top level of the water phase were recorded at 30, 60 and 120 seconds after collection. The remaining foam volume was used as a measure of the stability of the foam.

[0063] The trials were performed with polyvinyl alcohol and three different surfactants. Two different grades of polyvinyl alcohol were tested; Poval 25-88KL and Poval 23-88, both from Kuraray Europe GmbH, Hattersheim, Germany. The following surfactants were tested: Nalco 74407, Nalco 2634 and Nalco 2642m, all from Nalco Water / Nalco AB Sweden, Älvsjö, Sverige.

[0064] Part of the results are shown in Figure 2, illustrating the effect of Poval 23-88 when added at concentrations ranging from 0.025 to 0.15 g/g fibre. At the highest concentration, 70 % of the foam was still left after 120 seconds.

Example 2. Foam production in a mixing tank

[0065] The results from the investigation of different foaming agents were used when scaling up the process. Foam production tests were performed directly in the mixing tank, normally filled with 4 l furnish. The mixing tank was placed immediately at the inlet to a paper bottle moulding machine, serving as the equivalent to a headbox to the same. The inventors found that the amount of foaming agent (for example PVOH or surfactant) could be reduced when the foaming was performed in the mixing tank, immediately prior to feeding the foamed pulp into the paper bottle moulding machine.

[0066] For a stable production of paper bottles with the equipment used in the current experiments, it was found that the minimal starting volume of furnish was 1.5 liter. A framework of process parameters was established. It was found that actual bottle production required slightly less foaming agent than the pre-trials indicated.

Example 3. Pilot-scale production of bottles based on traditional furnish and foamed furnish

3.1 Method

[0067] Paper bottles were produced in a batch-wise manner. The bottles were shaped similar to traditional bottles, i.e. they consisted of a bottle neck followed by a shoulder with increasing diameter, followed by a bottle body (with significantly large volume and diameter than the neck part), and a bottom part. All bottles produced had the same shape and volume, here 0.5 l.

[0068] Two types of furnish were prepared, a traditional furnish containing 0.5 % fibre without foaming agents, and a 1.5 % furnish which comprised a foaming agent, and which was mixed into a foam before it was injected into the mould. The moulding equipment comprised an experimental bottle production unit as disclosed in the "Materials" section above, operated as detailed in the following:

The furnish was injected in the wet-forming section of the bottle production unit at a pressure of 0.2 bar above atmospheric pressure for 18 s. Then the dewatering unit was sealed and water allowed to exit through the porous walls of the mould during 30 s. Next, vacuum was applied on the outside of the mould for 45 s, further increasing the removal of water. Finally, the overpressure was replaced by atmospheric pressure by connecting the inside of the form to the ambient while vacuum was still applied to the outside during 55 s. Following this, the mould was opened, the bottles were removed and inspected.

[0069] The wet-formed bottles generally contained about 72 $\pm$ 2 % water. They were sufficiently form-stable to allow manual handling without deformation of the bottles. The outer surface of the bottles was smooth and uniform. Surprisingly, the bottles produced with 1.5 % foamed furnish had the same tactile and visual appearance as the bottles produced with un-foamed traditional 0.5 % furnish. The bottles were also comparable in terms of formation and floc distribution.

[0070] After this inspection, the wet bottles were transferred to the drying section. The drying section consisted of two mould halves of porous, heated metal. The temperature of the drying section was set to 200°C and the drying time was 120 seconds. An impermeable, flexible balloon was inserted through the bottle neck. After insertion, the balloon was expanded and exerted a pressure on the inside of the bottle. This presses the wet-formed bottle against the hot porous metal, a step referred to as restrained drying. Water escapes as vapour. After completion of the 120 s drying, the mould is opened and the bottle removed from the drying section.

3.2 Comparative examples

[0071] Reference bottles: Traditional pulp without foaming agent was used as reference. This pulp had a concentration of 0.5 % (5 g dry pulp per kg solution). This is a typical concentration when using pulp to make paper bottles with the equipment described in this text, and with similar equipment. Higher concentrations will generally not render whole bottles.

[0072] The pulp was mixed in a mixing unit for 20 seconds and thereafter injected into the wet-forming section of the bottle production unit and treated as described in the method section above. The wet bottles were further treated in a drying section as described above.

[0073] Bottles made with foamed pulp using SDS: A high-concentration pulp was prepared, having a concentration of 1.5 % (15 g dry pulp per kg solution). SDS - solution was added to the pulp at two different concentrations. In one batch, 1.2 ml of a 40 g/l SDS-solution was added to 1.5 l of 1.5 % pulp and mixed for 60 seconds with a stirrer mounted on a power drill, forming stable foam. In another batch, termed "high SDS" 12 ml of a 40 g/l SDS-solution was added to 1.5 l of 1.5 % pulp and mixed for 60 seconds, forming stable foam.

[0074] The pulp was then transferred into a mixing tank connected to the bottle forming machine, and further mixed for 60 seconds. The foamed pulp was thereafter immediately injected into the wet-forming section of the bottle production unit and treated as described in the method section above (18 s, 0.2 bar overpressure). The mixing tank was located in close proximity to the bottle forming unit, and it is estimated that the foamed furnish reached the mould within less than 3 seconds from formation of the foam. The resulting wet bottles were further treated in a drying section as described above.

[0075] Bottles made with foamed pulp using PVOH: A high concentration pulp containing 1.5 % fibre was used. Different concentrations of polyvinyl alcohol were evaluated:

10 ml of 25 g/l Poval 23-88/ 1.5 l of 1.5 % pulp

7.5 ml of 50 g/l Poval 23-88 (high) / 1.5 l of 1.5 % pulp

10 ml 25 g/l Poval 28-99 / 1.5 l of 1.5 % pulp

7.5 ml of 50 g/l Poval 23-88 in combination with traditional furnish additives /1.5 l of 1.5 % pulp

[0076] The combination of Poval 23-88 and traditional furnish additives was tested in order to find out if there would be any unwanted interactions between the traditional furnish additives and the polyvinyl alcohol.

[0077] Each sample was mixed for 60 s with a stirrer mounted on a power drill, forming a foam. The foamed pulp was then transferred into a mixing tank and further mixed for 60s. The foamed pulp was thereafter injected into the wet-forming section of the bottle production unit and treated as described in the method section above. The mixing tank was located in close proximity to the bottle forming unit, and it is estimated that the foamed furnish reached the mould within less than 3 s from formation of the foam. The produced wet bottles were further treated in a drying section as described above.

[0078] Bottles made with foamed pulp using CMC: 8 ml of a 20 g/l CMC-solution was added to 1.5 l of 1.5 % pulp and mixed for 60 s with a beater mounted on a power drill. The pulp was then transferred into a mixing tank and further mixed for 60s. The pulp was thereafter injected to the wet-forming section of the bottle production unit and treated as described in the methods section above. The mixing tank was located in close proximity to the bottle forming unit, and it is estimated that the foamed furnish reached the mould within less than 3 seconds from formation of the foam. The produced wet bottles were further treated in a drying section as described above. Also here, a combination of CMC and traditional furnish additives was tested in order to find out if there would be any unwanted interactions between the traditional furnish additives and the CMC.

[0079] All the bottles were visually inspected when they were removed from the production unit. To remove any residual water after the machine drying step, all bottles were dried in an oven set to 120°C. Their dry weights were noted. They were thereafter allowed to reach constant moisture content in ambient room conditions or in a room tempered, 100% RH moisture chamber consisting of a sealed box with a large open tank of water below a storage space holding 20 bottles.

3.3 Evaluation of Pressure Resistance (PR)

[0080] The conditioned bottles were tightly connected to a pressure nozzle to record their ability to resist pressure. Gradually increasing pressure was then applied to the nozzle and the burst pressure (i.e. when the bottle exploded) was registered using a digital manometer. The Pressure Resistance Index, PRI, was calculated by dividing the burst pressure (in bar) with the dry fibre weight of the bottles.

[0081] It is known that the tensile properties (such as elongation and strain at break) of fibre-based material determine the pressure resistance of the final product. Flat paper samples are tested for tensile properties according to ISO 1924-3. Data from the testing is used to calculate tensile index (kNm/kg) and tensile energy absorption index (J/kg) according to equations given in the standard.

[0082] The present inventors also cut samples from the paper bottles, both longitudinal- and circumferential stripes, and tested them according to ISO 1924-3. The theoretical pressure resistance at break was calculated. These values were compared to the PR values obtained in the explosion test. It was shown that the PR values were of the same magnitude as the theoretical values, which confirms the relevance of the explosion test developed by the inventors.

[0083] When evaluating moist bottles, great care was taken to avoid any drying out of the bottle before the test. The bottles were taken out one by one from the conditioning chamber, mounted on the nozzle and blown immediately. An average PRI-value of minimum 8 (typically 10) bottles was used for each measurement point.

Results and discussion

[0084] A paper bottle must meet many requirements in order to be considered a realistic alternative to plastic bottles. One of the most important properties of a paper bottle is its ability to resist pressure, thus the importance of evaluating it. In this work the evaluation was done by measuring the Pressure Resistance Index (PRI) of the produced bottles.

[0085] The results are presented in Fig. 5 for all the bottles tested. Both SDS and PVOH made it possible to produce bottles at 1.5% furnish concentration while maintaining a good PRI. This is valid both for room conditioned (RC) bottles as well as for bottles conditioned in moisturized environment (Moist). In Fig. 5, the bars represent the following samples:

Table. 1. Pressure Resistance Index, PRI

Number	Type	Fibre concentration (%)	Comment
1	Reference (no foaming agent)	0.5	RC
2	SDS	1.5	RC
3	SDS "high"	1.5	RC
4	Poval 23-88	1.5	RC
5	Poval 23-88 "high"	1.5	RC
6	Poval 28-99	1.5	RC
7	Poval 23-88 + furnish chemicals	1.5	RC
8	CMC + furnish chemicals	1.5	???
9	Reference	0.5	Moist
10	SDS	1.5	Moist
11	Poval 23-88 "high"	1.5	Moist
12	Poval 23-88 "high"	1.5	Moist
13	Poval 23-88 "high"	1.5	Moist

[0086] Generally, the strength properties of lignocellulose fibre-based products are deteriorated by moist conditions. Lignocellulose fibre is hydrophilic and therefore moisture has a negative effect on dimensional stability and strength. In the present study, it was expected that the pressure resistance index of bottles exposed to moisture would decrease. However, as can be seen in Figure 5, deterioration caused by moisture could be reduced or even avoided depending on the type of foaming agent used.

[0087] The experiments indicated that foaming of the furnish results in significantly improved fibre distribution, and thus improved formation. This is an important advantage, as it improves the conditions for applying barrier layers on the inner and/or outer surface of the article, and printing on the outer surface of the article.

[0088] Another advantage is that the efficiency of the wet-forming process can be significantly improved since part of the foamed pulp consists of air instead of water. Due to this, a higher pulp consistency can be used without increasing flocculation. It was surprisingly shown that for similar bottles, a furnish having three times higher pulp concentration than traditionally used could now be used without increasing the dewatering time or impairing bottle properties. It was also demonstrated that the wet-forming time could be significantly reduced (from 60 to 15 s) while still producing bottles of good quality. See Figure 3.

[0089] The results indicate that the fibre concentration of the furnish can be increased from about 0.5 % which is normally used, to above 1 %, preferably to about 1.5 % or more preferably to about 3 % or even higher while still maintaining desired formation and a high quality of the end product, or even improving the same. Without foaming, a fibre concentration above 1% is difficult to use without compromising the quality of the paper bottles.

[0090] As a result of the method disclosed herein, the amount of water used in the moulding process can be significantly reduced. This will improve process economy and reduce environmental impact. It will be possible to use a higher fibre concentration, thus reducing the water consumption. Another advantage of using foamed furnishes is improved dryness profile due to improved uniformity or evenness of the bottle. It also makes it possible to use various lignocellulose and/or synthetic fibre types difficult or impossible to use without foam, such as long reinforcement fibre.

[0091] It can be assumed that also the consumption of energy, or at least the energy required for drying the products, will be reduced thanks to the improved control of bottle porosity and reduced water content. It is also expected that a more even bottle will exhibit a more uniform dryness profile.

[0092] Without further elaboration, it is believed that a person skilled in the art can, using the present description, including the examples, utilize the present invention to its fullest extent. Also, although the invention has been described herein with regard to its preferred embodiments, which constitute the best mode presently known to the inventors, it should be understood that various changes and modifications as would be obvious to one having the ordinary skill in this art may be made without departing from the scope of the invention which is set forth in the claims appended hereto.

[0093] Thus, while various aspects and embodiments have been disclosed herein, other aspects and embodiments will be apparent to those skilled in the art. The various aspects and embodiments disclosed herein are for purposes of illustration and are not intended to be limiting, with the true scope and spirit being indicated by the following claims.

Claims

1. Method for the production of a moulded fibre-based 3-dimensional article comprising the steps of preparing a furnish, delivering said furnish into a mould to wet-form a 3-dimensional fibre-based moulded article, and dewatering said article, **characterized in that** said furnish is foamed prior to delivery into said mould.

2. The method according to claim 1, wherein the fibre concentration of said furnish is in an interval of about 1 to about 20 weight-% prior to foaming.

3. The method according to claim 2, wherein the fibre concentration of said furnish is in an interval of about 1 to about 10 weight-%, preferably about 2 to about 10 weight-%, most preferably 3 to 10 weight-%.

4. The method according to any one of claims 1 - 3, wherein said furnish is foamed in a mixing tank, producing a foamed furnish substantially immediately before said foamed furnish is introduced into the mould.

5. The method according to any one of claims 1 - 4, wherein said foamed furnish has a content of air in the range of 20 to 80 % air per volume, such as 30 to 70 %, and preferably 40 to 60 %.

6. The method according to any one of claims 1 - 5, wherein said furnish comprises a foaming agent chosen from a polyvinyl alcohol, a carboxymethyl cellulose, a surfactant, or combinations thereof.

7. The method according to any one of claims 1 - 6, wherein said 3-dimensional article is a container for liquids, preferably a fibre-based bottle.

8. The method according to any one of claims 1 - 7, wherein said foamed furnish comprises fibers of different origin, such as cellulose fibers and synthetic fibers.

9. The method according to any one of claims 1 - 8, wherein said foamed furnish comprises fibers of different length.

10. The method according to any one of claims 1 - 9, wherein said foamed furnish comprises a functional additive chosen from natural and synthetic polymers, pigments, fillers and combinations thereof.

11. The method according to any one of claims 1 - 10, wherein the wet-formed 3-dimensional article is dewatered by applying vacuum to the outside of the mould, or by applying pressure to the inside of the mould, or a combination of the two, and subsequently removed from the mould.

12. The method according to any one of claims 1 - 11, wherein wet-forming of said article takes place during a time in the interval of 1 - 20 seconds.

13. The method according to any one of claims 1 - 12, wherein the 3-dimensional article has a water content of about 50 to about 75 % after dewatering, but before drying of the article.

14. A 3-dimensional moulded fibre-based article, obtainable by a method according to any one of claims 1 - 13.

15. The 3-dimensional article according to claim 16, wherein the article is a container for liquids, preferably a fibre-based bottle, most preferably a fibre-based bottle for carbonated drinks.

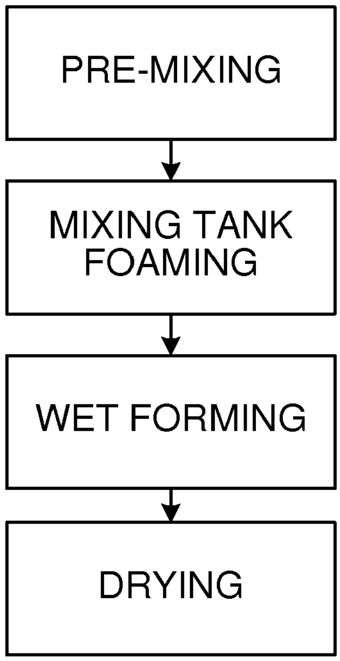
PRE-MIXING
MIXING TANK FOAMING
WET FORMING
DRYING

Fig. 1

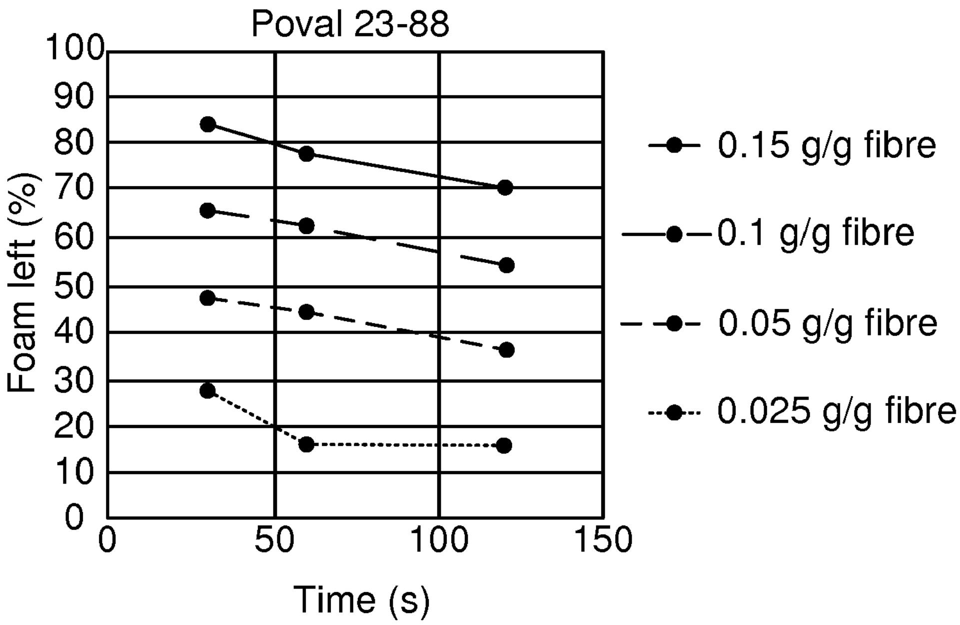
Poval 23-88
Foam left (%)
100
90
80
70
60
50
40
30
20
10
0
0
50
100
150
Time (s)
0.15 g/g fibre
0.1 g/g fibre
0.05 g/g fibre
0.025 g/g fibre

Fig. 2

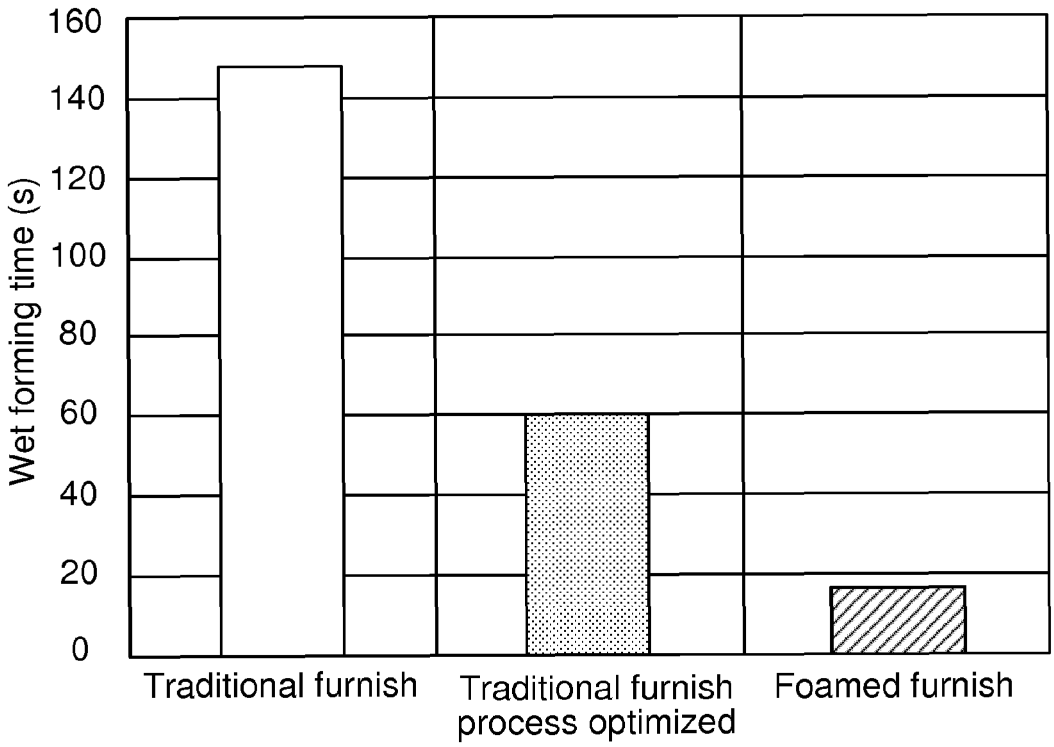
Wet forming time (s)
160
140
120
100
80
60
40
20
0
Traditional furnish
Traditional furnish process optimized
Foamed furnish

Fig. 3

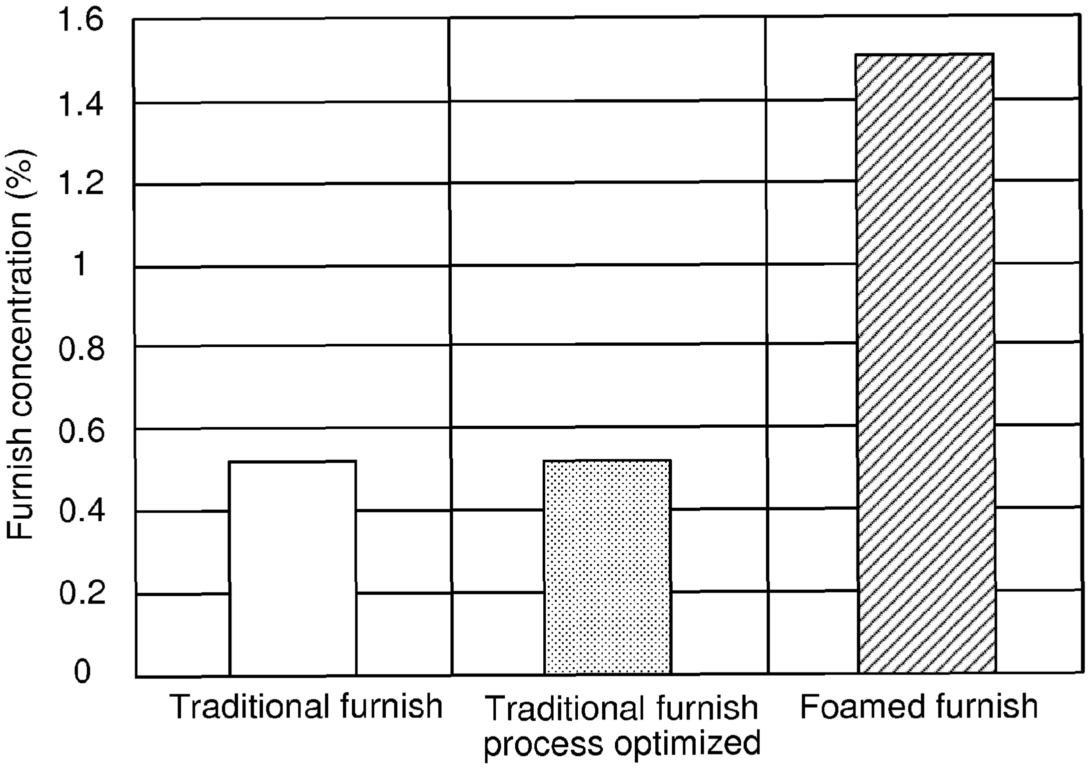
Furnish concentration (%)
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
Traditional furnish
Traditional furnish process optimized
Foamed furnish

Fig. 4

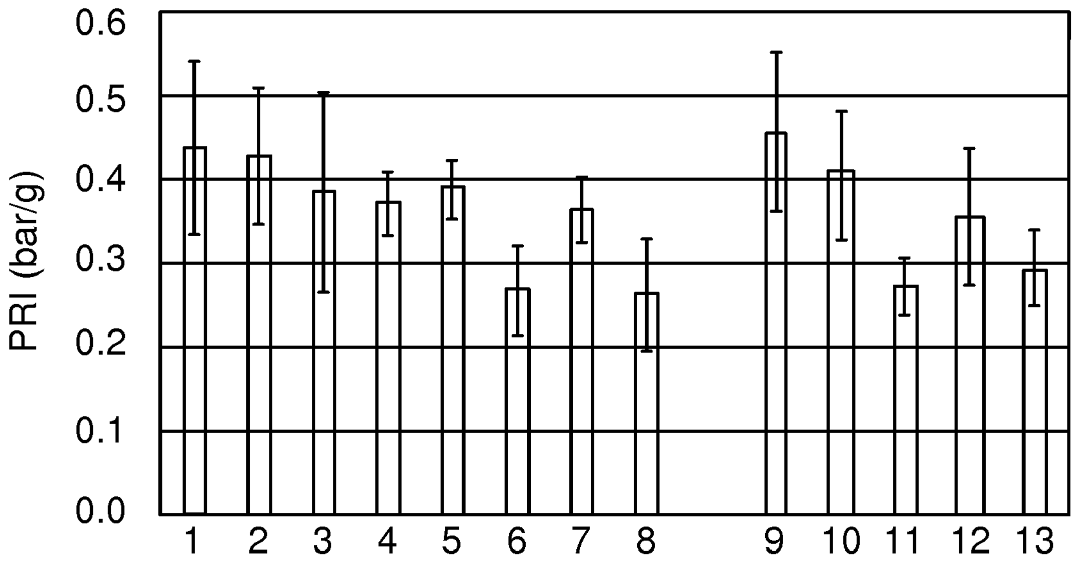

Fig. 5

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EUROPEAN SEARCH REPORT

Application Number
EP 18 19 8384

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
X	WO 2018/021907 A1 (HUHTAMAKI MOLDED FIBER TECH BV [NL]) 1 February 2018 (2018-02-01) * page 1, line 15 - page 8, line 2; figures *	1-15	INV. D21J3/10 D21J7/00
X	WO 2015/036659 A1 (TEKNOLOGIAN TUTKIMUSKESKUS VTT [FI]) 19 March 2015 (2015-03-19) * page 4, line 30 - page 12, line 18; figures *	1-6,8-14	
X	WO 2013/192260 A1 (PEPSICO INC [US]) 27 December 2013 (2013-12-27) * paragraph [0057]; figures *	14,15	

TECHNICAL FIELDS SEARCHED (IPC)
D21J

The present search report has been drawn up for all claims

1

Place of search	Date of completion of the search	Examiner
Munich	25 October 2018	Maisonnier, Claire

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
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25-10-2018

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WO 2015036659 A1	19-03-2015	CN 105829414 A	03-08-2016
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		FI 126194 B	15-08-2016
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WO 2013192260 A1	27-12-2013	NONE	

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

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- WO 2018020219 A **[0005] [0006] [0007]**
- WO 2016055073 A **[0008] [0059]**