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(56) References cited:
EP-A1- 1 669 434 EP-A2- 0 794 243
WO-A2-2008/073186 US-A- 4 769 082
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Description**BACKGROUND**

[0001] Biomass, particularly biomass waste, is abundantly available. It would be useful to derive materials and fuel, such as ethanol, from biomass.

WO 2008/073186 discloses the processing of biomass to produce useful products, such as fuels. EP 1 669 434 describes a method and installation for conversion of organic material originating from domestic waste into fuel.

US 4,769,082 discloses that the efficiency of enzymatic saccharification and fermentation of cellulose in a waste cellulose resource can be increased by a preliminary treatment with ionizing radiation.

EP 0 794 243 describes a petroleum derived oil which is subject to propane deasphalting to yield a solid asphaltene residue and specified processing of this to form suspensions. US 4,797,135 discloses a method for the production of highly comminuted flour of wood and other types of vegetable biomass, suitable for use as fuel.

SUMMARY

[0002] Materials, such as biomass, can be processed to alter their structures at one or more levels by cooling and processing. The processed materials can then be used, e.g., as sources of further materials and fuel.

[0003] Many embodiments of this application use Natural Force™ chemistry. Natural Force™ chemistry methods use the controlled application and manipulation of physical forces, such as particle beams, gravity, light, temperature, etc., to create intended structural and chemical molecular change.

[0004] Lignin present in many different types of biomass, including cellulosic and lignocellulosic biomass, can complicate efforts to alter the biomass to form intermediate feedstock for conversion to simpler sugars and, ultimately, products such as alcohols. As a result, yields of products, such as ethanol obtained from biomass, can be less (and in some cases, considerably less) than maximum theoretical yields of such products.

[0005] The methods disclosed herein utilize cooling and processing of materials, e.g., cryogenic cooling, in combination with one or more other processing techniques that include one or more radiation processing steps (e.g., exposure to charged particles such as electrons and/or ions). These other processing techniques are performed after cooling.

[0006] By cooling the biomass or other material, the brittleness of various components of the biomass or other material (e.g., hemicellulose and/or lignin and/or proteins and/or pectin and/or minerals) can be increased, thereby significantly improving the effectiveness of the processing techniques that are used to alter the material. By increasing the brittleness of the materials, the materials can be fractured (e.g., the edges of fibers can be fractured) or cracked as a result of various processing steps. Fracturing can be, e.g., microfracturing.

[0007] In addition, cooling the material can have other effects that arise from differential rates of expansion and/or contraction of various components of the material. For example, certain components (e.g., lignin with water present) can contract or expand at faster rates than, or in different amounts than other components (e.g., hemicellulose, cellulose) with which they are associated. As a result, the subject material can be weakened, promoting separation (e.g., phase separation, delamination, interfacial cleavage, cracking, or fracturing, e.g., microfracturing) of its various components. These processes - which can occur independently of other processing techniques or in conjunction with other processing techniques - can also improve yields of products, e.g., ethanol obtained from hemicellulose or cellulose that has been separated from lignin. Separation of the lignin from the material reduces the recalcitrance of the material, facilitating conversion of the cellulosic components of the material into a sugar solution (saccharification of the cellulose by an enzyme). Without wishing to be bound by theory, it is believed that the fracturing of the material can allow the enzyme to penetrate the material at the fracture sites, thereby accelerating saccharification. The saccharified material can then be converted to a product, e.g., fermented to ethanol.

[0008] As cooling is combined with other processing techniques, i.e. radiation and oxidation, the other techniques can be used to a lesser extent to obtain equivalent results. For example, when cooling is used with radiation the radiation can be used at a lower dose to provide the same degree of reduction in recalcitrance.

[0009] During the various processing techniques that are used to alter and/or convert materials into other materials, a significant amount of heat can be generated in the materials. To avoid combusting or otherwise initiating unwanted thermal alteration of the materials, the cooling methods disclosed herein can be used to dissipate or offset the excess heat. The extent of cooling (e.g., the amount of heat removed from the material) can be varied according to the amount of heat generated during processing of the material. The extent of cooling can also be adjusted to adjust certain properties of the biomass material, such as its brittleness, to improve the efficiency of certain subsequent processing steps. For example, comminution of the hemicellulose, cellulose, and lignin, and separation of these components can be enhanced by the methods disclosed herein.

[0010] As used herein, a "cryogenic" material is a material at a temperature of 200 K or less (e.g., 170 K or less, 150 K or less, 130 K or less, 120 K or less, 110 K or less, 100 K or less, 90 K or less, 80 K or less, 70 K or less, 60 K or less,

50 K or less, 40 K or less, 30 K or less). Thus, for example, a "cryogenic liquid" is a liquid having a temperature of 200 K or less.

[0011] As will be discussed in further detail below, various materials can be used for cooling, including for example liquid nitrogen, carbon dioxide, and ice.

[0012] The methods disclosed herein can produce material particles (e.g., fibers) having a length-to-diameter ratio of 5:1 or more (e.g., 6:1 or more, 8:1 or more, 10:1 or more, 12:1 or more, 15:1 or more, 20:1 or more).

[0013] The methods disclosed herein can also produce particles having a largest dimension, e.g., diameter, of less than, e.g., 2000 nm, 1000, 750, 500, 250, 100, 50, 25, 20, 10, 5, or even 1 nm.

[0014] The methods disclosed herein can produce materials having a reduced bulk density. For example, the bulk density of the materials produced using the methods disclosed herein can be 0.8 g/cm³ or less (e.g., 0.6, 0.5, 0.4, 0.3, 0.2 or less, e.g., 0.1 g/cm³).

[0015] The methods disclosed herein can produce materials having relatively thin cross-sections, due to the combined effects of cooling the material to increase its brittleness, and processing the material using any one or more of the techniques disclosed herein. In general, materials having thin cross-sections can be cooled more efficiently than materials having thicker cross-sections; as a result, the costs (e.g., energy consumption) for material processing (e.g., particularly the costs for energy consumption in processing techniques) can be reduced.

[0016] In one aspect, the invention features a method that includes cooling a material having more than one component and an interface between the components to a temperature at which the components separate at the interface. The cooled material can then be processed to produce a product that is different, e.g., chemically different, from the material itself. For example, biomass can be cooled and then processed to produce ethanol.

[0017] Some implementations include one or more of the following features. The material can be or include biomass, e.g., in some cases the material comprises a lignocellulosic material. The components can include lignin and cellulose. The temperature can be less than or equal to the brittle point of the material. The method further includes irradiating the material, e.g., with electron beam radiation. The method can further include mechanically treating the material, e.g., by grinding, milling, or comminution. For example, mechanically treating the material can include freeze grinding or freeze milling the material. Cooling can include pre-cooling the material prior to freeze grinding or freeze milling. The components can have different coefficients of thermal expansion. The method may include temperature cycling the material. The material can be or include a hydrocarbon-containing material.

[0018] In another aspect, the invention features a method comprising processing a material to make a product, the material having been produced by treating a starting material to embrittle the starting material and processing the embrittled material to produce a product different from the embrittled material. In some implementations, the method further includes grinding or comminuting the embrittled material.

[0019] Some implementations include one or more of the following features. Treating includes cooling the starting material. In addition, treating includes irradiating the material. The starting material includes biomass. Treating and grinding or comminuting can be performed simultaneously, e.g., in a freeze grinding or freeze milling device. Processing the material can include contacting the material with an enzyme and/or a microorganism. Treating can include temperature cycling the starting material. The biomass can include lignocellulosic material, and the method can further include separating lignin from cellulose. The invention features a method that includes cooling a biomass material to reduce the recalcitrance of the material, and, after cooling, processing the cooled material to produce a product that is different, e.g., chemically different, from the biomass material. In some implementations processing comprises contacting the material with an enzyme and/or a microorganism, e.g., saccharifying the material with an enzyme or fermenting the material with a microorganism. The material includes cellulose, and contacting the material can include utilizing an enzyme to saccharify the cellulose. The method further includes irradiating the biomass material. Cooling can be performed in a freeze grinding or freeze milling device. Contacting the material can include utilizing a microorganism to produce an alcohol. Cooling can include cooling the material to a temperature below the brittle point of the material.

[0020] In other aspects, the invention features a method that includes processing, such as by mechanical processing, a biomass material to reduce a dimension such as a particle size of the biomass material; and either cooling the material to a temperature of 273 K or less prior to processing, or maintaining the material at a temperature of 273 K or less during the processing. The method further includes contacting the processed material with an enzyme and/or a microorganism. In some cases, the method includes sonicating the material, and/or treating the material with charged particles. Cooling may embrittle the material, which may cause separation of components of the material at an interface.

[0021] Unless otherwise defined, all technical and scientific terms used herein have the same meaning as commonly understood by one of ordinary skill in the art to which this invention belongs. In case of conflict, the present specification, including definitions, will control. In addition, the materials, methods, and examples are illustrative only.

[0022] Other features and advantages will be apparent from the description, drawings, and claims.

DESCRIPTION OF DRAWINGS

[0023]

FIG. 1 is a schematic diagram showing a biomass processing system.
 FIG. 2 is a schematic diagram showing a biomass processing system.
 FIG. 3 is a schematic diagram showing a milling unit.

DETAILED DESCRIPTION

[0024] Certain types of materials, including cellulosic and/or lignocellulosic materials, can include significant fractions of lignin bound to cellulose and/or hemicellulose in a complex polymeric framework structure. Without wishing to be bound by theory, some evidence suggests that lignin may be bound covalently to both cellulose and hemicellulose in materials (see, e.g., Karlsson et al., Journal of Pulp and Paper Science 27: 196-201 (2001)). Further, it has generally been observed that separating lignin from cellulose and/or hemicellulose increases yields of sugars, alcohols, and other products derived from further processing of cellulose and/or hemicellulose. Further, the separating of the lignin from cellulose and hemicellulose creates a valuable co-product - the lignin itself.

[0025] Examples of biomass materials can include any biomass material that is or includes carbohydrates composed entirely of one or more saccharide units or that include one or more saccharide units can be processed by any of the methods described herein. For example, the biomass material can be cellulosic or lignocellulosic materials, starchy materials, such as kernels of corn, grains of rice or other foods, or materials that are or that include one or more low molecular weight sugars, such as sucrose or cellobiose.

[0026] For example, such biomass materials can include paper, paper products, wood, wood-related materials, particle board, grasses, rice hulls, bagasse, cotton, jute, hemp, flax, bamboo, sisal, abaca, straw, corn cobs, rice hulls, coconut hair, algae, seaweed, cotton, synthetic celluloses, or mixtures of any of these.

[0027] Biomass also includes cellulosic fiber sources, including paper and paper products (e.g., polycoated paper and Kraft paper), and lignocellulosic fiber sources, including wood, and wood-related materials, e.g., particle board. Still other biomass includes natural fiber sources, e.g., grasses, rice hulls, bagasse, cotton, jute, hemp, flax, bamboo, sisal, abaca, straw, corn cobs, rice hulls, coconut hair; fiber sources high in α -cellulose content, e.g., cotton; and synthetic fiber sources, e.g., extruded yarn (oriented yarn or un-oriented yarn). Natural or synthetic sources can be obtained from virgin scrap textile materials, e.g., remnants, or they can be post consumer waste, e.g., rags. When paper products are used, they can be virgin materials, e.g., scrap virgin materials, or they can be post-consumer waste. Aside from virgin raw materials, post-consumer, industrial (e.g., offal), and processing waste (e.g., effluent from paper processing) can also be used. Also, the fiber source can be obtained or derived from human (e.g., sewage), animal or plant wastes. Additional biomass sources have been described in U.S. Patent Nos. 6,448,307, 6,258,876, 6,207,729, 5,973,035 and 5,952,105.

[0028] Separating lignin from cellulose and/or hemicellulose can be both time-consuming and costly. Processing techniques, including methods such as grinding and milling, can be limited in their efficiency by the strong bonds that bind the lignin to cellulose and hemicellulose.

[0029] Many processing methods - including mechanical methods, exposure to radiation, sonication, and even some chemical processing steps - generate heat in the material. While additional process heat can be advantageous in some embodiments, large quantities of heat generated by certain processing steps can also lead to thermal alteration of cellulose and/or hemicellulose, reducing yields of sugars, alcohols, and other products produced from the cellulose and/or hemicellulose.

[0030] Moreover, by example, when lignin is heated (e.g., by process heat generated during processing steps) above its glass transition temperature, the lignin can become softer and more deformable (e.g., less brittle), and therefore more difficult to process.

[0031] The methods disclosed herein use cooling techniques, e.g., cryogenic cooling techniques, for example to ensure that undesired thermal decomposition, e.g., of cellulose and/or hemicellulose, does not occur during material processing. Cooling can also be used to adjust properties of the material to improve the efficiency of separation, for example of lignin from cellulose and/or hemicellulose.

[0032] In particular, the cooling methods disclosed herein can be used alone or in combination to increase the brittleness of materials, making the cooled materials more amenable to separation via one or more processing methods, specifically one or more radiation processing steps (e.g., exposure to charged particles such as electrons and/or ions. By increasing the brittleness of the material by cooling and improving the efficiency with which the material by cooling can be processed, e.g., by comminution or separation, processing costs (e.g., energy-related processing costs) can be reduced and intended product yields can be increased.

[0033] Moreover, when a multi-component material is cooled, different components thereof will contract and/or expand at different rates and/or in different amounts. In certain embodiments, this process can lead to breakage of chemical

bonds in the material. For example, this cooling behavior can introduce stresses between bound components, leading to processes such as delamination, fracturing, peeling, disassociation, and separation of the bound components. As a result, the efficiency with which the components can be separated - and the yields of various intended products derived from the material - can be increased or decreased or kept in balance.

[0034] Cooling in combination with other treatments such as irradiation and oxidation can be used to control the functionalization of the fibrous material, i.e., the functional groups that are present on or within the material. The functionalization of the material can increase solubility and/or dispersibility and can make the material more susceptible to conversion by enzymes and/or microorganisms.

[0035] In some embodiments, after the material is treated from about 1 out of every 2 to about 1 out of every 250 saccharide units includes a carboxylic acid group, or an ester or salt thereof; whereas the native or unprocessed base material can have less than 1 carboxylic acid group per 300 saccharide units. In other embodiments, from about 1 out of every 5 to about 1 out of every 250 saccharide units, e.g., 1 out of every 8 to about 1 out of every 100 units or from 1 out of 10 to about 1 out of 50 units includes a carboxylic acid group, or an ester or salt thereof.

[0036] In some embodiments, in the irradiated material from about 1 out of every 5 to about 1 out of every 1500 saccharide units includes a nitrile group, a nitroso groups or a nitro group. In other embodiments, from about 1 out of every 10 to about 1 out of every 1000 saccharide units, e.g., 1 out of every 25 to about 1 out of every 1000 units or from 1 out of 35 to about 1 out of 750 units includes a nitrile group, a nitroso groups or a nitro group.

[0037] In some embodiments, the saccharide units include mixtures of carboxylic acid groups, nitrile groups, nitroso groups and nitro groups. Mixed groups can enhance the solubility of a cellulosic or lignocellulosic material. The treated material can also include functional groups selected from the group consisting of aldehyde groups, ketone groups, amino groups, alkyl amino groups, alkyl groups, chloroalkyl groups, chlorofluoroalkyl groups, and enol groups.

[0038] FIG. 1 shows a schematic diagram of a biomass processing system 100. System 100 includes a material storage unit 102, a first material processing sub-system 104, a cooling conduit 106, a second material processing sub-system 108, a processed material reservoir 110, and a cooling fluid supply unit 112. During operation, material stored in storage unit 102 is transported via conduit 114 to first material processing sub-system 104.

[0039] Sub-system 104 can include a variety of different processing units. For example, in some embodiments, sub-system 104 can include one or more mechanical processing units (e.g., grinding units, agitation units, milling units, abrasion units, chopping units, shearing units). In certain embodiments, sub-system 104 can include one or more radiation processing units. The radiation processing units can include charged particle sources (e.g., electron beam sources and/or ion sources), in which the material is exposed to charged particles to cause alteration of the material. In some embodiments, sub-system 104 can include one or more sonication units, in which material is exposed to ultrasonic waves to alter the material. In certain embodiments, sub-system 104 can include one or more pyrolysis units and/or one or more chemical processing units. In some embodiments, sub-system 104 can include one or more steam explosion processing units. In some embodiments, sub-system 104 can include one or more combinations of these processing units.

[0040] In general, sub-system 104 can include any one or more of the above processing units, in any combination. Sub-system 104 is generally configured to provide an initial stage of alteration of the material, in preparation for further processing steps. In some embodiments, sub-system 104 may not be present at all, and material may be transferred directly from storage unit 102 to cooling conduit 106. FIG. 2 shows an embodiment of a material processing system that does not include a processing sub-system 104. The various components in FIG. 2 have been discussed above in connection with FIG. 1, and their descriptions are not repeated at this point.

[0041] Referring again to FIG. 1, after the material has been processed in sub-system 104, e.g., by cutting, chopping, shearing, or shredding, the material is transferred via conduit 116 to cooling conduit 106. Cooling fluid supply unit 112 supplies cooling fluid (e.g., liquid nitrogen and/or cooled nitrogen gas, and/or liquid helium and/or cooled helium gas, and/or liquid argon and/or cooled argon gas, and/or solid CO₂ and/or liquid CO₂, and/or liquid air and/or cooled gaseous air) to cooling conduit 106 via conduit 120. The material is transported through cooling conduit 106 in the direction shown by arrow 128. As the material moves through conduit 106 (e.g., on a transport device such as a conveyor belt and/or an auger), the material is cooled via heat exchange with cooling fluid supplied by cooling fluid supply unit 112.

[0042] When the material reaches the end of cooling conduit 106, the material is transported through conduit 118 to second material processing sub-system 108. In some embodiments, cooling fluid supply unit 112 supplies cooling fluid via conduit 122 to second sub-system 108, as shown in FIG. 1. In general, second processing sub-system 108 can include one or more of any of the processing units disclosed herein in connection with first processing sub-system 104. Exemplary processing units include one or more processing units such as grinding, chopping, or shearing units, radiation processing units, sonication processing units, pyrolysis processing units, steam explosion processing units, and chemical processing units. Cooling fluid can be recycled for further use in cooling conduit 106 by transporting the fluid via conduit 124.

[0043] The processed material, after emerging from second processing sub-system 108, is transported to material reservoir 110 through conduit 126. Once in reservoir 110, the material can be subjected to further processing steps, including any one or more additional steps from among those disclosed in connection with processing sub-systems 104

and 108 above. Alternatively, or in addition, the processed material can be subjected to additional processing steps, including one or more processes using biological agents such as enzymes and/or microorganisms, such as bacteria and/or yeast and various chemicals and chemical formulations and solutions.

[0044] In general, the cooling methods disclosed herein can be used with a wide variety of different biomass and other material processing techniques. Exemplary techniques that can be used with the cooling methods discussed herein are disclosed, for example, in the following patent applications: WO 2008/073186; and U.S. Serial Numbers 12/417,699, 12/417,707, 12/417,720, 12/417,723, 12/417,731, 12/417,786, 12/417,840, 12/417,880, 12/417,900, 12/417,904, 12/429,045, and 12/486,436.

[0045] Any of the processes disclosed herein, e.g., such as comminution, can in some embodiments be particularly advantageous when used in combination with one or more cooling methods, e.g., cryogenic cooling methods. Without wishing to be bound by theory, it is believed that the increased brittleness of the lignocellulosic material that results from cooling the material assists in at least partially separating components, e.g., at an interface. Further, by increasing the brittleness of a material, it is believed that techniques may be more effective at breaking up a material - in effect, the material (and, by way of example, the lignin fraction of a material) can be transformed from a deformable, flexible polymer to a glass-like, rigid material that can be "shattered."

[0046] FIG. 3 shows an exemplary embodiment of a milling unit 200 that can form a portion of either or both of processing sub-systems 104 and 108. Milling unit 200 includes a conduit 202 through which material is transported. Fixed blades 204 are positioned within the conduit. Rotating blades 206 are attached to a centrally positioned shaft 208. During operation, the material is milled through the cutting action of blades 204 and 206.

[0047] Commercially available freeze milling, freeze grinding, cryomilling and cryogrinding equipment may be used. Such equipment combines cooling of the material with comminution of the material. Examples of a commercially available cryogrinding devices include the Freezer/Mill 6870, available from SPEX CertiPrep, Metuchen, New Jersey, and the cryogenic grinding devices available from Pulva Corporation, Saxonburg, PA. Other suppliers include Air Products, Praxair, and Air Liquide. In some embodiments, the equipment may include a pre-cooling area, e.g., a cooling conveyor such as a cooled screw extruder. In some cases liquid nitrogen is sprayed onto the material to be cooled in the pre-cooling area. The grinding may be provided, for example, by a reciprocating pin or other element. For example, the grinding device may be a pin mill. It is generally preferred that the temperature of the material be monitored and controlled throughout feeding and grinding.

[0048] Freeze grinding is combined with irradiation, in which case irradiation is performed after freeze grinding. In some cases, freeze grinding can reduce the amount of radiation that is needed to reduce the recalcitrance of a biomass material or process a hydrocarbon-containing material.

[0049] Sonication processing techniques can, in certain embodiments, be particularly advantageous when used in combination with, e.g., before, immediately after, or during, the cooling methods disclosed herein. In general, sonication processing of material is effective at altering the material due to heat supplied to the material via mechanical waves (e.g., sound waves). When cooling methods are used to reduce the temperature of the material, the material becomes more brittle, and is less able to deform in response to incident mechanical waves and/or undergo rapid expansion due to local heating. As a result, the efficiency with which sonication effectively changes the material is increased. The material will first be cooled, and then irradiated (e.g., in sub-system 108). The radiation dose may be, for example, from about 0.1 MRad to 200 Mrad, e.g., from about 10 MRad to 100 Mrad or about 30 MRad to 90 MRad. The radiation may be delivered in a single irradiation step or multiple irradiation steps, and the material can be cooled between irradiation steps if desired. Such cooling is described in U.S. Serial No. 12/417,880.

[0050] Exposure of the material to certain types and dosages of radiation may increase the brittleness of the material. The material can be cooled to decrease its temperature and further increase its brittleness. During and/or after the cooling of the material, the material can be processed (e.g., via milling, grinding, shearing, and other such techniques) to alter the material in preparation for further processing steps that produce useful products. In addition, radiation exposure (e.g., electron beam exposure and/or ion beam exposure) of the material after cooling the material is used to further alter the material and/or make the material more brittle. As both radiation exposure and cooling are used to make the material more brittle, product yields (e.g., ethanol and/or other alcohols) can be significantly increased, and the amount of energy required to process the material can be reduced.

[0051] In certain embodiments, multiple cooling and mechanical processing stages, or alternating cooling and heating stages, e.g., with or without additional mechanical or other physical processing, can be used to process a material, e.g., biomass. For example, each successive stage can further reduce the average size of the biomass particles, until a desired particle size is reached. Each cooling stage can be similar or different (e.g., the system can include a plurality of similar cooling sub-systems). In some embodiments, the system can include a single cooling sub-system through which the material passes multiple times. Alternatively, in certain embodiments, different cooling stages (e.g., cooling stages that cool the biomass to different temperatures, such as progressively lower temperatures) can be used to process the material.

[0052] Similarly, in certain embodiments, multiple mechanical processing stages can be used to process biomass.

The materials can be recirculated through the same processing unit multiple times, and/or the system can include multiple mechanical units. The units can all be similar to one another, or some of the units can differ (e.g., in structure) from one another.

[0053] In general, a wide variety of different cooling fluids can be used to cool the material. In the embodiments discussed above, liquid and/or cold gaseous nitrogen was used as the cooling fluid. However, in some embodiments, one or more other cooling fluids can be used, including liquid helium, liquid oxygen, liquid hydrogen, liquid air, other such fluids, and combinations thereof. In certain embodiments, the fluids can be gases rather than liquids, or can include solids (e.g., ice, solid CO₂) mixed with, or instead of, the liquids. For example, a wide variety of cooled gases (including cooled noble gases, cooled nitrogen gas, cooled oxygen gas, and cooled hydrogen gas) can be used in place of, or together with, liquid cooling fluids.

[0054] In certain embodiments, solids can be added to the materials to assist in processing the materials. For example, solid CO₂ can be added to the materials to assist in altering the materials in one or more processing units. Other solids that could also be used include ice, for example. The solid may also be a solid element that is later removed or separated from the material, e.g., one or more balls, pins, or other solid milling elements.

[0055] The temperature to which the material is cooled depends upon a number of factors, including the processing techniques that are used to alter the material and the nature of the material. In some embodiments, for example, the material is cooled to a temperature less than the glass transition temperature of lignin, which is about 100° to 170° C, e.g., about 120° to 150° C, e.g., about 125° C. When the lignin is cooled below its glass transition temperature, it changes from a soft, deformable material to a brittle, glassy material. The brittle, glassy lignin can be more readily altered by various processes, including the processes disclosed above. Further, by cooling the lignin below its glass transition temperature the physical structure of the lignin can be changed. Changes to the lignin structure can lead to internal stresses within the material where the lignin is bound to cellulose and/or hemicellulose. These internal stresses can lead to delamination and thus separation of the lignin from the cellulose and/or hemicellulose. In some implementations, the material is cooled below the temperature at which the material becomes brittle (the "brittle point" of the material). This brittle point of a particular material can be measured using commercially available testing equipment, e.g., the Benz BPT2100 Brittlepoint Tester available from Benz Material Testing Instruments, Providence, Rhode Island.

[0056] In some embodiments, the material can be cooled below a glass transition temperature of one or more other elements or components in the material, such as hemicellulose. Similar considerations to those that are discussed above in connection with lignin apply to hemicellulose as well. In particular, cooling of the hemicellulose can make it more brittle, improving the efficiency of subsequent processing steps. Cooling can also introduce internal stresses within the biomass structure, which can lead to separation of the hemicellulose from other components (e.g., cellulose) in the material.

[0057] In certain embodiments, the material can be cooled to a temperature of 400 K or less (e.g., 380 K or less, 360 K or less, 340 K or less, 320 K or less, 300 K or less, 280 K or less, 260 K or less, 240 K or less, 220 K or less, 200 K or less, 150 K or less, 100 K or less, 80 K or less, 77 K or less, 70 K or less, 50 K or less). In some embodiments, the material can be cooled to a temperature less than or equal to room temperature (e.g., 293 K). In certain embodiments, the material can be cooled to about the temperature of liquid nitrogen (e.g., 77 K) or less. Cooling the material to temperatures less than the temperature of liquid nitrogen can be achieved by using cooling fluids with a lower boiling point than liquid nitrogen (e.g., liquid helium).

[0058] In some embodiments, the rate at which the material is cooled can be controlled to assist in separating components of the material. For example, by cooling the material rapidly, lowest-energy arrangements of the associated components in the biomass may not have time to form. In other words, the cooled material may be in an energy state that is not a minimum energy state, and can therefore be unstable and more readily altered using further processing steps. In certain embodiments, for example, the rate at which the material is cooled is 1 K/s or more (e.g., 2 K/s or more, 3 K/s or more, 5 K/s or more, 7.5 K/s or more, 10 K/s or more, 15 K/s or more, 20 K/s or more, 30 K/s or more, 40 K/s or more, 50 K/s or more, 75 K/s or more, 100 K/s or more, or even more).

[0059] In certain embodiments, using the processing systems disclosed herein, the material can be maintained at a selected temperature and/or within a selected temperature range during processing of the material using any one or more of the various processing techniques disclosed herein. For example, the material can be maintained at a temperature of 400 K or less (e.g., 380 K or less, 360 K or less, 340 K or less, 320 K or less, 300 K or less, 280 K or less, 260 K or less, 240 K or less, 220 K or less, 200 K or less, 150 K or less, 100 K or less, 80 K or less, 77 K or less, 70 K or less, 50 K or less). In some embodiments, the material can be maintained at or below room temperature (e.g., 293 K). In certain embodiments, the biomass can be maintained at the temperature of liquid nitrogen (e.g., 77 K) or less.

[0060] In certain embodiments, the material can be subjected to a sequence of heating and cooling stages that are selected to cause further disruption to the association (e.g., suspected covalent bonds) between lignin and cellulose and/or hemicellulose. Rapid thermal cycling of the material can introduce internal stresses within the material, which can lead to separation of biomass components (e.g., without further processing, or as a result of further processing steps).

[0061] In addition, a variety of different agents can be added to the material prior to, during, and/or following cooling

of the material. Exemplary agents that can be added include water (and, more generally, any other compounds that expand or contract when cooled), oxidizing agents, reducing agents, acids, bases, and materials that contract significantly upon cooling. In general, agents such as water can be introduced into one or more of the components of the material to cause swelling of the components when hydrated. For example, when the material, e.g., biomass, is cooled, the water expands and/or contracts, creating periodic internal stresses in the material that can lead to cleavage of bonds within the material, e.g., between lignin and cellulose and/or hemicellulose. Other agents that undergo sublimation (e.g., carbon dioxide) can also be used to produce similar results. Agents that sublime generally undergo significant changes in molar volume at a phase transition. Such agents can be introduced into the material to further promote separation of the components therein when relatively rapid expansion and/or contraction of the material occurs as a result of the added agents.

[0062] As noted above, various chemical agents such as oxidizing agents and/or reducing agents and/or acids and/or bases can be added to the material. The various agents can react with the material before, during, and/or after cooling to further assist in altering the material prior to product formation and extraction. In general, certain components of the material may be stable in the presence of one agent, but reactive in the presence of other agents. For example, cellulose is stable to bases, but is altered by acids. By introducing bases into one or more of the various processing sub-systems, one or more selected component(s) of the material, e.g., lignin, can be selectively altered and disassociated from other component(s), e.g., cellulose and/or hemicellulose, improving yields of products derived from the material. Chemical agents can be added to the various processing sub-systems as liquids, in solutions, and/or as gases. In some embodiments, the agents can be introduced in gaseous form, and can be condensed into liquids as the material is cooled.

[0063] In certain embodiments, various chemical oxidizing and/or reducing agents can be added before, during, and/or after cooling to promote separation of at least some of the material components via chemical reactions. Cooling alone, or together with one or more of the processing techniques disclosed above, can be used to promote disassociation, e.g., of lignin from cellulose and/or hemicellulose. This disassociation can be further promoted by reacting cellulose, hemicellulose, and/or lignin with agents such that the products of such reactions do not re-associate as readily. Exemplary oxidizing and reducing agents include ozone, oxygen, air, ammonia, and a wide variety of other agents.

[0064] In some embodiments, multiple different cooling stages can be used, each of which is configured to cool the material to a different temperature. For example, in an initial stage of processing, the material can be cooled to a selected temperature and can be processed (e.g., mechanically, with radiation exposure, with sonication, and/or with various other techniques). For example, in each subsequent stage of processing, as the material particles can be made increasingly smaller, the material can be cooled to successively lower temperatures and further processed, to continue to reduce the size of the particles and/or further disassociate components of the material such as biomass (e.g., disassociate lignin from cellulose and/or hemicellulose) or to change the structure.

[0065] In general, the disclosure is not limited to the specific processing system disclosed above in FIG. 1. In particular, a number of different cooling methods can be used to reduce the temperature of the material before, during, and/or after the application of various processing techniques. Further, in general, a wide variety of different cooling sub-systems can be used to cool the material.

[0066] In some embodiments, the processing systems disclosed herein can include a separation sub-system that functions to separate various components of the material after the material has been cooled and processed. For example, when material is processed to disassociate lignin from cellulose and/or hemicellulose, the processing system can include a separation sub-system configured to remove the disassociated lignin. Various methods, including physical separation methods such as decanting, centrifuging, distillation, and extraction can be used to separate the components, e.g., the lignin from the other components of a lignocellulosic material, or sand from hydrocarbons in an oil sand. Other methods which can be implemented in the separation sub-system include thermochemical processing, chemical processing, and radiation exposure processing).

[0067] In certain embodiments, the processing systems disclosed herein can include one or more wetting stations to introduce various wetting agents - particularly water and/or other liquids such as dimethyl sulfoxide - into the materials. For example, following mechanical processing units such as the milling unit shown in FIG. 3, the processing system can include a sprayer that adds water and/or other agents to the material. The sprayer can create a fine mist that settles on surfaces of the material's particles. If the material is cooled during or after the mist is applied, the mist can be frozen onto the surfaces of the particles to ensure adhesion. The temperature of the material can undergo one or more heating-cooling cycles to further swell the material with the applied mist. Further, in certain embodiments, changes, e.g., rapid changes, in the temperature of the material can further alter the material structure.

[0068] In some embodiments, multiple wetting stages can be used. Each of the multiple wetting stages can introduce the same agent into the material, or different stages can introduce different agents. The selection of which agents to introduce depends upon factors such as the intended application of the material, the physical-chemical state of the material, and the conditions in subsequent material processing stages.

[0069] Systems and methods for enhancing wetting of materials before, during, and after processing are disclosed, for example, in U.S. Serial No. 12/417,880.

[0070] In some embodiments, after the materials have been processed using the methods disclosed herein, the processed materials can be subjected to additional processing steps. In particular, the processed materials can be contacted with biological agents such as enzymes, and/or with microorganisms such as yeast (e.g., *P. Stipitis*) and/or bacteria to extract a variety of useful products from the processed materials, including products such as hydrogen, alcohols (e.g., ethanol and/or butanol), organic acids (e.g., acetic acid), hydrocarbons, co-products (e.g., proteins) or mixtures of any of these. Suitable biological agents and microorganisms for further processing of materials are disclosed, for example, in WO 2008/073186.

[0071] For example, in some embodiments the techniques described herein are used to separate and remove lignin from a lignocellulosic material, and then the remaining cellulosic components are saccharified, e.g., using an enzyme. The removal of the lignin reduces the recalcitrance of the material, allowing the conversion of the cellulose to sugars, which can then be fermented to produce alcohols.

EXAMPLE

[0072] Various samples of cellulosic materials were tested in shake flasks, using *P. stipitis* NRRL Y-7124 and a standard nutrient medium recipe at various levels. The ethanol concentration was measured over time for each of the flasks. As noted below (see Legend for Table 1), the cellulosic samples were derived from cut grass (CG). Some of the samples were freeze ground (FG), using a SPEX Certiprep® Freezer/Mill 6870. The freeze grinding conditions were as follows: 4 minutes pre-cool, followed by three cycles of 10 minutes run time and 2 minutes cooling time, with a grinder frequency of 15 Hz. Some of the samples were irradiated without freeze grinding, while others were irradiated after freeze grinding. Irradiation was performed using an electron beam. The radiation dose is indicated by the number after the "CG," with 0.2E indicating 0.2 MRads, 0.4E indicating 0.4 MRads, etc. Where the radiation dose was 10 MRad or less, it was delivered in a single pass. Where the radiation dose was greater than 10 MRad, it was delivered in multiple 10 MRad passes (e.g., 50 MRad = 5 x 10 MRad), with 1 minute intervals between passes to allow the material to cool at ambient temperature.

Reagents Used			
Media Component	Manufacturer	Reference #	Lot #
Urea	ScholAR Chemistry	9472706	AD-7284-43
Yeast Nitrogen Base	Becton Dickinson	291940	7128171
Peptone	Becton Dickinson	211677	4303198
Xylose (>98%)	Alfa Aesar	A10643	10131481
Glucose (>98.9%)	Fisher	BP-350-1, 50-99-7	030064, 030439
YM Broth	Becton Dickinson	271120	6278265
Novozyme® 188*	Novozymes	Sigma C6105	018K0735, 058K1144
Celluclast 1, 5 FG	Novozymes	Sigma C2730	077K0735, 058K1144
Optimash™ TBG enzyme**	Genencor®	N/A	1600925859
* Cellobiase from <i>Aspergillus niger</i>			
* B-glucanase EC 3.2.1.6.			

Cell Bank Preparation and Seed Flask Development

[0073] To preserve the original culture, a working cell bank of each culture was prepared. A working cell bank of *P. stipitis* NRRL Y-7124 was prepared from a rehydrated lyophilized culture obtained from ARS Culture Collection. Cryovials containing *P. stipitis* culture in 15% v/v glycerol were stored at -75 °C.

[0074] To prepare the seed flask, a portion of the thawed working cell bank material was streaked onto a Yeast Mold (YM) Broth + 20 g/L agar (pH 5.0) and incubated at 30 °C for 2 days. The plates were held for 2 days at 4 °C before use. One colony from the Yeast Mold Agar was used to inoculate a 250 mL Erlenmeyer flask containing 100 mL of sterile broth (40 g/L glucose, 1.7 g/L yeast nitrogen base, 2.27 g/L urea, 6.56 g/L peptone, 40 g/L xylose, pH 5.0) and incubated for 24 hours at 25°C and 150 rpm. After 23 hours of growth, a sample was taken and analyzed for optical density (OD 600 nm in a UV spectrophotometer), total cell count, and purity (Gram stain). Based on these results, a flask with an

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OD of between 6 and 11 and a cell count of 2 to 6 x10⁸ cells/mL was used to inoculate the test flasks. One mL of seed flask contents was added to the 100 mL test flasks (1 % v/v).

Test Flasks

[0075] The test flasks were 250 mL Erlenmeyer flasks containing 100 mL of broth. The test flasks contained the Standard Medium (1.7 g/L yeast nitrogen base, 2.27 g/L urea, 6.56 g/L peptone, pH 5.0.) There were three sets of control flasks because the testing was done over a three week span and control flasks were analyzed for each week of testing.

[0076] The timeline of activities was as follows. The lignocellulosic sample (7.77 g) was combined with 100 mL of sterile broth in a sterile 250 mL flask and allowed to soak for 14 hours at room temperature. After the soak, the pH of the flask contents was adjusted to 5.0 with 1 N NaOH. Once the pH was adjusted, 3.89 mL of Celluclast 1,5 FG, 0.77 mL Novozyme® 188, and 0.77 mL Optimash™ TBG was added and the flasks were incubated at 50 °C for 21 hours.

[0077] After the enzyme treatment, the pH of the flask contents was adjusted to 5.5, 6.0, or 6.25. After pH adjustment, flasks were inoculated with 1 mL of *P. stipitis* seed flask contents and incubated for 96 hours at 25 °C and 125 rpm.

[0078] Three control flasks (two positive, one negative) were inoculated each week, nine in total. Two positive control flasks contained sugars. One contained 80 g/L sugars (40 g/L glucose and 40 g/L xylose), the other contained 30 g of sugars (15 g/L glucose and 15 g/L xylose). There were no sugars added to the negative control flask.

[0079] One set of flasks (five in total) contained xylose-only broth (40 g/L xylose 1.7 g/L yeast nitrogen base, 2.27 g/L urea, 6.56 g/L peptone) at pH 4.5, 5.0, 5.5, 6.0, 6.5. The flasks were incubated at 125 rpm and 25 °C after inoculation with 1 mL of *P. stipitis*.

[0080] A second set of flasks (five in total) contained the xylose-only broth (40 g/L xylose 1.7 g/L yeast nitrogen base, 2.27 g/L urea, 6.56 g/L peptone) at pH 4.5, 5.0, 5.5, 6.0, 6.5. The flasks were incubated at 250 rpm and 25 °C after inoculation with 1 mL of *P. stipitis*.

[0081] During week 1, samples CG0.4E and CG0.4E-FG4102315 were tested in flasks at pH 5.5. However, the protocol indicated that they should be tested at both 5.5 and 6.0. Therefore, both samples were tested at pH 5.5 and 6.0 in week 2 of the experiment (flasks 28 through 31).

Analysis

[0082] A total of eight samples were taken from each flask at 0, 12, 24, 36, 48, 60, 72, and 96 hours post-inoculation and analyzed for glucose, ethanol, and xylose concentration using the YSI Biochem Analyzer (YSI, Interscience). Samples were centrifuged at 14,000 rpm for 20 minutes and the supernatant stored at -20 °C. A standard was analyzed daily to ensure the integrity of the membrane was maintained.

[0083] The cell count of each seed flask was analyzed in order to determine the initial cell concentration in the test flasks. One sample at 72 hours of incubation was taken from each flask analyzed for cell count. Appropriately diluted samples were mixed with 0.05% Trypan blue and loaded into a Neubauer haemocytometer. The cells were counted under 40 X magnification.

[0084] The pH of each flask was measured at 0, 12, 24, 36, 48, 60, 72, and 96 hours.

Results

[0085] The number of cells in the seed flasks was analyzed. During week 1 (Flasks 1 through 27), the seed flask cell concentration was 5.03 x 10⁸ cells/mL. Therefore, the starting cell concentration in the test flasks was 5.03 x 10⁶ cells/mL. During week 2 (Flasks 28 through 64), the number of cells in the seed flask was 6.38 x 10⁸ cells/mL. Therefore, the starting concentration of cells in the test flasks was 6.38 x 10⁶ cells/mL. During week 3 (Flasks 65 through 105), the number of cells in the seed flask was 5.93 x 10⁸ cells/mL. Therefore, the starting concentration of cells in the test flasks was 5.93 x 10⁶ cells/mL.

[0086] The ethanol concentration in each of the flasks during incubation is listed in Table 1 below:

Table 1

Legend: "CG" = Cut Grass; "FG" = Freeze Ground; 0.xE = irradiated with 0.x MRads radiation using e-beam.										
Flask No.	Sample No.	Start pH	Ethanol Concentration (g/L) at Incubation Time (h)							
			0	12	24	36	48	60	72	96
1	CG	5.5	0.10	0.14	0.16	0.05	0.03	0.04	0.05	0.07
2	CG	6.0	0.12	0.21	0.24	0.19	0.14	0.09	0.08	0.07

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(continued)

Legend: "CG" = Cut Grass; "FG" = Freeze Ground; 0.xE = irradiated with 0.x MRads radiation using e-beam.										
Flask No.	Sample No.	Start pH	Ethanol Concentration (g/L) at Incubation Time (h)							
			0	12	24	36	48	60	72	96
3	CG-FG	5.5	0.10	1.35	4.34	4.31	5.75	5.98	5.54	3.32
4	CG-FG	6.0	0.10	1.44	4.33	4.12	6.59	6.46	5.71	3.61
5	CG0.2E	5.5	0.10	0.21	0.21	0.07	0.04	0.17	1.25	0.08
6	CG0.2E-FG	5.5	0.10	1.24	4.42	3.85	5.82	6.05	5.52	3.03
7	CG0.4E	5.5	0.10	0.88	2.13	2.80	3.95	3.47	2.54	0.33
8	CG0.4E-FG	5.5	0.09	1.33	4.38	4.38	5.47	5.76	5.92	3.83
9	CG0.6E	5.5	0.11	1.06	1.98	2.67	2.94	0.91	1.13	0.11
10	CG0.6E-FG	5.5	0.10	1.33	4.53	4.65	5.94	6.22	6.33	4.09
11	CG0.8E	5.5	0.10	0.60	2.28	2.75	4.55	3.99	2.07	0.12
12	CG0.8E-FG	5.5	0.10	0.83	4.36	4.44	5.62	5.91	5.43	3.35
13	CG2E	5.5	0.10	0.61	2.23	2.72	3.79	2.33	0.06	0.08
14	CG2E-FG	5.5	0.1	1.13	4.39	4.51	5.74	6.20	6.12	3.91
15	CG4E	5.5	0.10	0.66	2.37	2.78	3.96	3.56	2.04	0.12
16	CG4E-FG	5.5	0.09	1.16	4.75	4.45	5.61	5.94	6.33	4.04
17	CG6E	5.5	0.10	0.62	2.45	2.74	4.26	4.36	3.04	0.20
18	CG6E-FG	5.5	0.00	1.17	4.66	4.38	5.77	6.06	6.27	4.26
19	CG8E	5.5	0.10	0.77	2.18	2.26	2.36	2.33	2.10	1.32
20	CG8E-FG	5.5	0.11	1.05	4.78	4.79	5.70	6.25	6.23	3.81
21	CG10E	5.5	0.12	0.70	2.28	2.62	3.88	4.04	2.82	0.14
22	CG10E	6.0	0.11	0.64	2.21	2.20	3.24	3.84	3.13	1.02
23	CG10E-FG	5.5	0.11	0.99	4.81	4.92	5.71	6.25	6.03	3.98
24	CG10E-FG	6.0	0.10	1.28	4.85	5.12	6.58	6.88	6.46	3.90
25	Control (80 g sugar)	5.0	0.04	0.89	6.95	9.57	11.10	11.90	12.40	11.90
26	Control (30 g sugar)	5.0	0.06	1.54	6.09	6.54	7.63	8.11	8.17	6.91
27	Control (No sugar)	5.0	0.06	0.01	0.00	0.00	0.00	0.16	0.00	0.04
28	CG0.4E	5.5	0.09	0.12	0.15	0.11	0.15	0.07	0.84	0.05
29	CG0.4E	6.0	0.08	0.30	1.51	1.55	1.92	3.06	2.59	1.18
30	CG0.4E-FG	5.5	0.15	0.49	4.14	4.78	5.27	5.87	5.44	3.73
31	CG0.4E-FG	6.0	0.14	0.58	4.38	5.13	6.09	5.69	5.22	3.53
32	CG20E	5.5	0.18	0.27	2.55	2.70	2.71	3.19	4.14	2.56
33	CG20E-FG	5.5	0.14	0.40	4.98	5.89	5.46	5.36	5.58	3.84
34	CG30E	5.5	0.12	0.19	2.75	3.27	3.19	2.67	3.07	2.18
35	CG30E-FG	5.5	0.15	0.30	5.24	6.33	6.08	5.83	6.12	4.91
36	CG40E	5.5	0.14	0.18	3.18	4.26	4.00	3.20	3.55	2.90
37	CG40E-FG	5.5	0.14	0.30	5.62	6.50	6.99	6.74	6.91	5.37
38	CG50E	5.5	0.17	0.22	3.06	4.33	4.27	3.97	3.60	3.38

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(continued)

Legend: "CG" = Cut Grass; "FG" = Freeze Ground; 0.xE = irradiated with 0.x MRads radiation using e-beam.										
Flask No.	Sample No.	Start pH	Ethanol Concentration (g/L) at Incubation Time (h)							
			0	12	24	36	48	60	72	96 5
39	CG50E	6.0	0.17	0.37	4.47	4.62	5.11	4.93	5.13	3.60
40	CG50E-FG	5.5	0.17	0.27	5.77	7.93	7.58	6.95	6.92	5.90
41	CG50E-FG	6.0	0.16	0.34	6.23	7.70	7.13	5.94	5.81	4.25
42	CG60E	5.5	0.14	0.18	4.24	5.76	5.99	5.58	5.56	4.33
43	CG60E-FG	5.5	0.13	0.25	6.01	8.36	8.92	8.42	8.47	7.63
44	CG70E	5.5	0.15	0.17	6.61	6.40	6.63	6.41	6.35	5.57
45	CG70E-FG	5.5	0.13	0.20	4.52	8.98	9.25	8.75	8.68	7.44
46	CG80E	5.5	0.13	0.18	5.13	7.20	6.93	6.69	7.12	5.88
47	CG80E-FG	5.5	0.14	0.20	6.96	9.58	10.20	9.54	9.03	8.52
48	CG90E	5.5	0.14	0.16	5.10	7.34	7.69	7.07	7.40	6.83
49	CG90E-FG	5.5	0.15	0.21	7.03	9.42	11.50	11.00	9.79	8.90
50	CG100E	5.5	0.18	0.20	5.84	8.05	8.99	8.52	8.32	7.14
51	CG100E	6.0	0.15	0.24	6.46	9.03	8.73	8.75	8.38	5.94
52	CG100E	6.25	0.16	0.18	6.45	9.13	8.88	8.21	7.78	6.56
53	CG100E-FG	5.5	0.13	0.14	7.30	8.87	10.90	10.20	10.40	9.28
54	CG100E-FG	6.0	0.13	0.24	7.30	10.40	10.50	10.10	9.73	8.43
55	CG100E-FG	6.25	0.13	0.19	7.33	10.50	10.70	10.60	10.00	8.94
56	CG110E	5.5	0.16	0.12	6.19	7.95	9.65	8.60	8.66	7.94
57	CG110E	6.0	0.19	0.22	6.35	8.76	9.26	8.70	8.21	7.12
58	CG110E-FG	5.5	0.15	0.14	7.06	8.80	10.40	10.10	9.74	8.88
59	CG110E-FG	6.0	0.14	0.19	7.70	10.50	11.60	10.90	10.00	8.57
60	CG120E	5.5	0.19	0.14	6.45	7.83	9.88	9.79	8.91	8.11
61	CG120E-FG	5.5	0.15	0.13	7.35	9.02	10.60	10.70	10.00	8.88
62	Control (80 g sugar)	5.0	0.10	0.54	5.22	8.46	9.85	10.90	11.90	12.50
63	Control (30 g sugar)	5.0	0.09	0.97	5.79	7.07	8.41	8.63	8.82	4.50
64	Control (No sugar)	5.0	0.07	0.04	0.00	0.00	0.00	0.00	0.00	0.00
65	CG130E	5.5	0.10	0.19	6.71	8.15	9.88	9.13	9.16	9.15
66	CG130E	6.0	0.11	0.28	6.62	9.15	9.86	9.27	9.20	8.52
67	CG130E-FG	5.5	0.11	0.20	7.42	8.72	10.50	10.50	10.10	9.45
68	CG130E-FG	6.0	0.11	0.25	7.08	9.72	10.30	10.50	9.87	8.95
69	CG140E	5.5	0.11	0.16	6.27	7.43	9.27	9.23	9.03	8.82
70	CG140E	6.0	0.09	0.22	6.34	7.90	9.44	8.94	8.88	8.17
71	CG140E-FG	5.5	0.10	0.17	7.08	8.22	9.88	10.10	9.88	8.80
72	CG140E-FG	6.0	0.10	0.30	7.21	9.50	10.30	10.20	9.64	8.72
73	CG150E	5.5	0.10	0.16	6.04	7.65	9.00	8.96	9.20	9.14
74	CG150E	6.0	0.9	0.21	6.89	8.80	9.92	9.90	9.69	8.62

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(continued)

Legend: "CG" = Cut Grass; "FG" = Freeze Ground; 0.xE = irradiated with 0.x MRads radiation using e-beam.										
Flask No.	Sample No.	Start pH	Ethanol Concentration (g/L) at Incubation Time (h)							
			0	12	24	36	48	60	72	96 5
75	CG150E	6.25	0.12	0.23	6.29	8.91	9.66	7.52	9.29	8.38
76	CG150E-FG	5.5	0.10	0.18	5.86	8.36	9.73	9.41	9.31	8.87
77	CG150E-FG	6.0	0.10	0.27	7.05	9.63	9.81	9.76	9.26	8.31
78	CG150E-FG	6.25	0.06	0.28	6.89	8.86	8.90	9.95	7.52	5.97
79	CG160E	5.5	0.10	0.12	6.02	7.55	8.99	8.70	8.62	7.92
80	CG160E-FG	6.0	0.10	0.20	6.92	9.11	9.84	10.10	9.53	8.58
81	CG170E	5.5	0.10	0.14	4.89	7.39	8.60	9.49	8.68	7.59
82	CG170E-FG	6.0	0.11	0.19	7.18	8.66	10.10	9.49	9.16	7.99
83	CG180E	5.5	0.11	0.15	6.27	7.37	8.65	9.58	8.38	7.95
84	CG180E-FG	6.0	0.11	0.22	7.00	8.69	9.22	8.98	8.84	7.85
85	CG190E	5.5	0.01	0.15	5.12	6.92	8.00	9.50	8.65	8.37
86	CG190E-FG	6.0	0.09	0.17	6.66	7.92	9.12	8.87	8.75	8.03
87	CG200E	5.5	0.10	0.15	5.75	7.12	8.68	9.05	7.99	7.55
88	CG200E	6.0	0.08	0.16	6.38	8.80	8.92	8.57	8.30	6.98
89	CG200E	6.25	0.10	0.22	6.28	8.17	8.55	8.67	8.30	7.84
90	CG200E-FG	5.5	0.01	0.16	5.54	7.47	8.69	8.50	8.32	7.67
91	CG200E-FG	6.0	0.11	0.21	5.69	7.78	8.90	8.75	8.44	7.40
92	CG200E-FG	6.25	0.11	0.19	6.29	8.30	9.37	9.08	7.93	7.31
93	Control (80 g sugar)	5.0	0.02	0.50	4.25	6.81	7.75	8.90	8.72	9.46
94	Control (30 g sugar)	5.0	0.04	0.59	4.49	5.29	6.19	8.60	5.81	5.72
95	Control (No sugar)	5.0	0.04	0.01	0.00	0.00	0.00	0.00	0.00	0.00
96	No Sample, Xylose only broth	4.5	0.03	0.28	2.07	3.82	4.37	5.44	6.41	6.72
97		5.0	0.04	0.27	2.63	4.15	7.42	8.16	8.63	9.13
98		5.5	0.04	0.34	2.94	5.00	5.96	7.96	8.77	9.39
99		6.0	0.04	0.29	2.27	5.05	6.29	7.33	8.27	8.36
100		6.5	0.04	0.28	1.59	4.40	5.72	5.61	6.93	6.21
101	No Sample, Xylose only Broth	4.5	0.02	0.18	1.50	2.13	1.91	2.37	1.99	0.23
102		5.0	0.04	0.13	1.62	2.72	2.76	2.36	2.45	1.45
103		5.5	0.04	0.12	0.99	2.31	1.62	1.52	1.41	0.06
104		6.0	0.04	0.09	0.87	1.77	1.90	2.03	1.66	0.09
105		6.5	0.04	0.13	1.17	2.54	2.66	2.69	2.08	0.89

[0087] As indicated by the data in Table 1, the yield of ethanol generally increased with increasing dose or radiation, up to 90 MRad, after which yield leveled off at increasing doses. For a given dose of radiation and pH, the yield was generally significantly higher when the grass had also been freeze ground. For grass that had not been irradiated, or had received only low dose radiation, yields were markedly higher if the grass had been freeze ground.

Claims

1. A method of processing a lignocellulosic biomass comprising:

processing an embrittled material by means of an enzyme and/or a microorganism to make a product that is chemically different from the embrittled material, the embrittled material having been produced by treating a lignocellulosic biomass material to embrittle the biomass material, wherein treating comprises irradiating the biomass material with electron beam radiation, wherein treating further comprises cooling the biomass material to a temperature of 273 K or less, wherein cooling is performed prior to irradiating, and wherein processing the material comprises contacting the material with an enzyme and/or a microorganism, or the material comprises cellulose and the method comprises utilizing an enzyme to saccharify the cellulose.

2. The method of claim 1, wherein producing the embrittled material further comprises grinding or comminuting the starting material.

3. The method of claim 2, wherein grinding or comminuting is performed before the starting material has been embrittled.

4. The method of claim 2, wherein cooling and grinding or comminuting are performed simultaneously in a freeze grinding or freeze milling device.

5. The method of claim 1, wherein the product comprises an alcohol.

6. The method of claim 5, wherein the product comprises ethanol or butanol.

7. The method of claim 1, wherein the method further comprises separating lignin from cellulose.

8. The method of any one of the above claims, wherein the biomass material has more than one component and an interface between the components, and treating comprises cooling the starting material to a temperature at which the components separate at the interface.

9. The method of claim 8, wherein the temperature is less than or equal to the brittle point of the material.

10. The method of claim 8, wherein the components have different coefficients of thermal expansion.

11. The method of any one of claims 1 to 10, wherein the dose of radiation is from 10 Mrad to 100 Mrad, or 30 Mrad to 90 Mrad.

Patentansprüche

1. Verfahren zur Verarbeitung einer Lignocellulose-Biomasse, umfassend die Verarbeitung eines versprödeten Materials mit Hilfe eines Enzyms und/oder eines Mikroorganismus zur Herstellung eines Produktes, das sich chemisch vom versprödeten Material unterscheidet, wobei dieses durch Behandlung eines Lignocellulose-Biomasse-Materials zur Versprödung des Biomassematerials hergestellt wurde, wobei die Behandlung die Bestrahlung des Biomassematerials mit Elektronenstrahlbestrahlung umfasst, wobei die Behandlung außerdem noch die Abkühlung des Biomassematerials auf eine Temperatur von 273 K oder darunter umfasst, wobei die Abkühlung vor der Bestrahlung erfolgt und wobei die Verarbeitung des Materials die Kontaktierung desselben mit einem Enzym und/oder einem Mikroorganismus umfasst, oder das Material Cellulose umfasst und das Verfahren die Verwendung eines Enzyms zur Verzuckerung der Cellulose umfasst.

2. Verfahren nach Anspruch 1, wobei die Herstellung des versprödeten Materials außerdem noch die Vermahlung bzw. Zerkleinerung des Ausgangsmaterials umfasst.

3. Verfahren nach Anspruch 2, wobei die Vermahlung bzw. Zerkleinerung vor der Versprödung des Ausgangsmaterials durchgeführt wird.

4. Verfahren nach Anspruch 2, wobei die Abkühlung und Vermahlung bzw. Zerkleinerung gleichzeitig in einer Gefrierzerkleinerungs- oder Gefriervermahlungsvorrichtung durchgeführt werden.
5. Verfahren nach Anspruch 1, wobei das Produkt einen Alkohol umfasst.
6. Verfahren nach Anspruch 5, wobei das Produkt Ethanol oder Butanol umfasst.
7. Verfahren nach Anspruch 1, wobei das Verfahren außerdem noch die Abtrennung des Lignins von der Cellulose umfasst.
8. Verfahren nach einem der vorangegangenen Ansprüche, wobei das Biomassematerial mehr als eine Komponente und eine Grenzfläche zwischen den Komponenten aufweist, und die Behandlung die Abkühlung des Ausgangsmaterials auf eine Temperatur umfasst, bei der die Komponenten sich an der Grenzfläche scheiden.
9. Verfahren nach Anspruch 8, wobei die Temperatur unterhalb des Sprödigkeitspunktes des Materials liegt oder diesem entspricht.
10. Verfahren nach Anspruch 8, wobei die Komponenten unterschiedliche Wärmeausdehnungskoeffizienten aufweisen.
11. Verfahren nach einem der Ansprüche 1 bis 10, wobei die Strahlungsdosis 10 Mrad - 100 Mrad oder 30 Mrad - 90 Mrad beträgt.

Revendications

1. Procédé de traitement d'une biomasse lignocellulosique, comprenant :

le traitement d'un matériau fragilisé au moyen d'une enzyme et/ou d'un micro-organisme pour obtenir un produit qui est chimiquement différent du matériau fragilisé, le matériau fragilisé ayant été produit en traitant un matériau à base de biomasse lignocellulosique pour fragiliser le matériau à base de biomasse, le traitement comprenant l'irradiation du matériau à base de biomasse par rayonnement d'un faisceau d'électrons, dans lequel le traitement comprend, en outre, le refroidissement du matériau à base de biomasse à une température de 273 K ou au-dessous,

dans lequel le refroidissement précède l'irradiation, et

dans lequel le traitement du matériau comprend la mise en contact du matériau avec une enzyme et/ou un micro-organisme, ou le matériau comprend de la cellulose et le procédé comprend l'utilisation d'une enzyme pour saccharifier la cellulose.

2. Procédé selon la revendication 1, la production du matériau fragilisé comprenant, en outre, le broyage ou la comminution du matériau de départ.
3. Procédé selon la revendication 2, dans lequel le broyage ou la comminution précède la fragilisation du matériau de départ.
4. Procédé selon la revendication 2, le refroidissement et le broyage ou la comminution étant réalisés simultanément dans un dispositif de broyage réfrigéré ou de mouture réfrigéré.
5. Procédé selon la revendication 1, le produit comprenant un alcool.
6. Procédé selon la revendication 5, le produit comprenant l'éthanol ou le butanol.
7. Procédé selon la revendication 1, le procédé comprenant, en outre, la séparation de la lignine de la cellulose.
8. Procédé selon l'une quelconque des revendications précédentes, le matériau à base de biomasse ayant plusieurs composants et une interface entre les composants, et le traitement comprenant le refroidissement du matériau de départ à une température à laquelle les composants se séparent au niveau de l'interface.
9. Procédé selon la revendication 8, la température étant inférieure ou égale au point de fragilité du matériau.

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10. Procédé selon la revendication 8, les composants ayant des coefficients de dilatation thermique différents.

11. Procédé selon l'une quelconque des revendications 1 à 10, la dose d'irradiation étant comprise entre 10 mrad et 100 mrad ou entre 30 mrad et 90 mrad.

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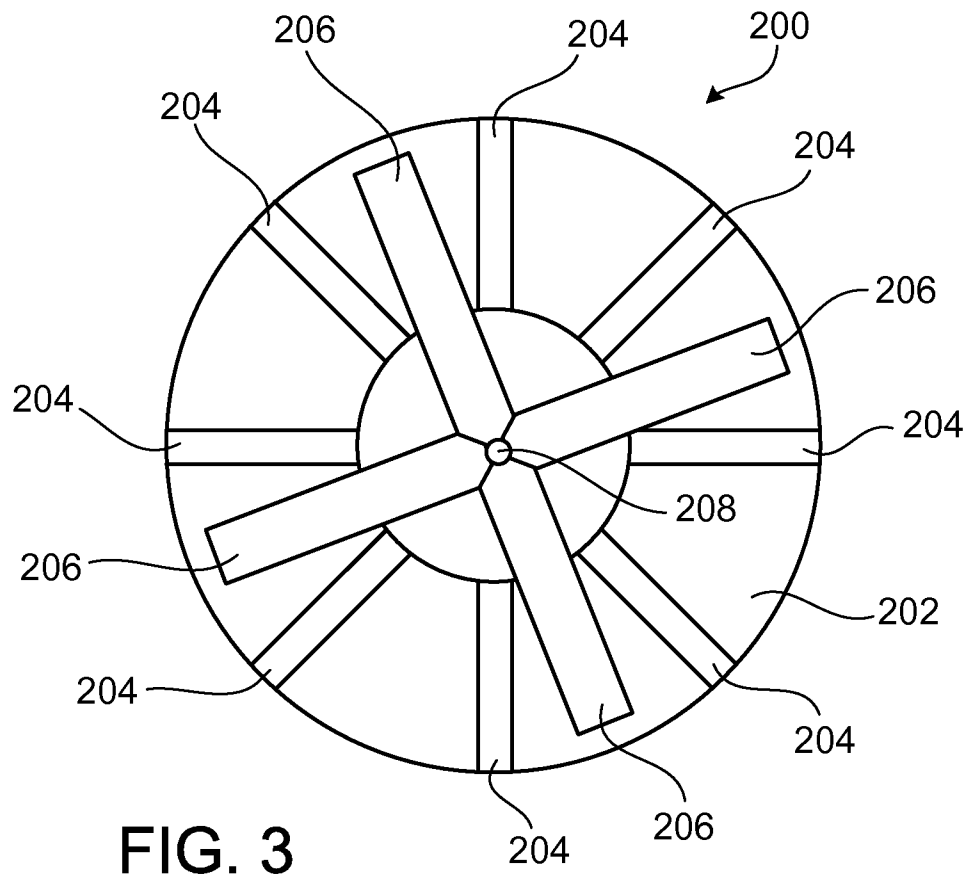
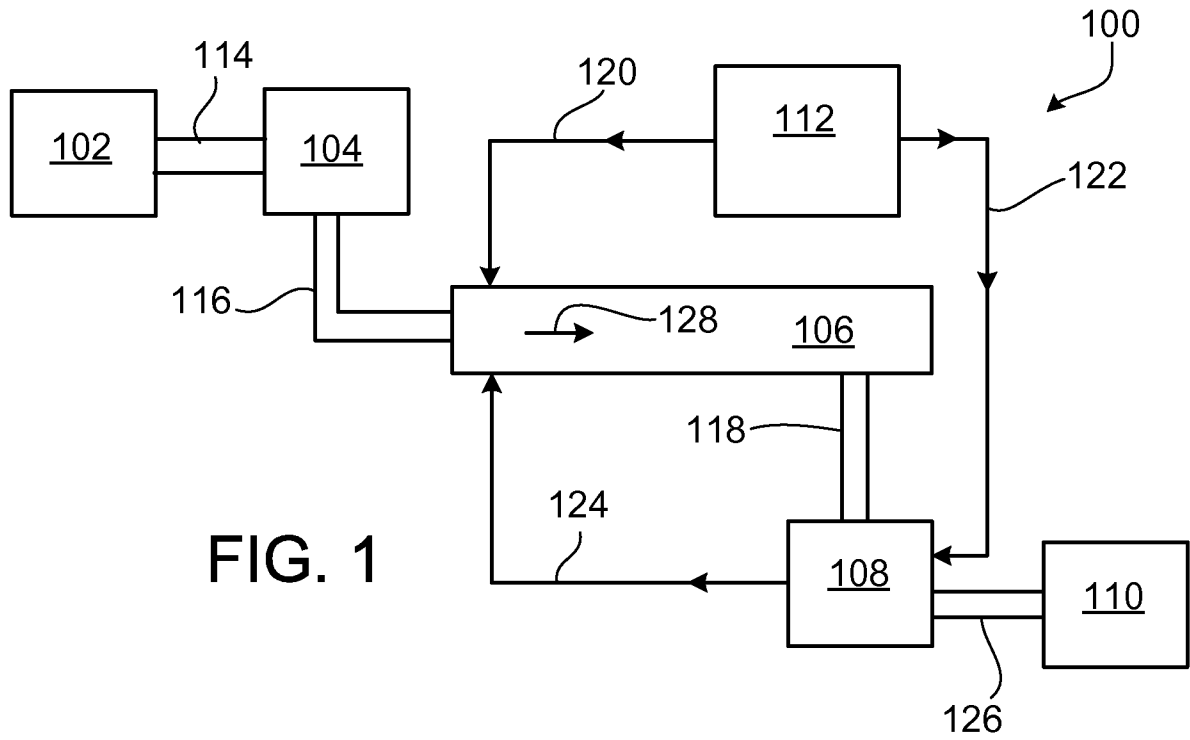
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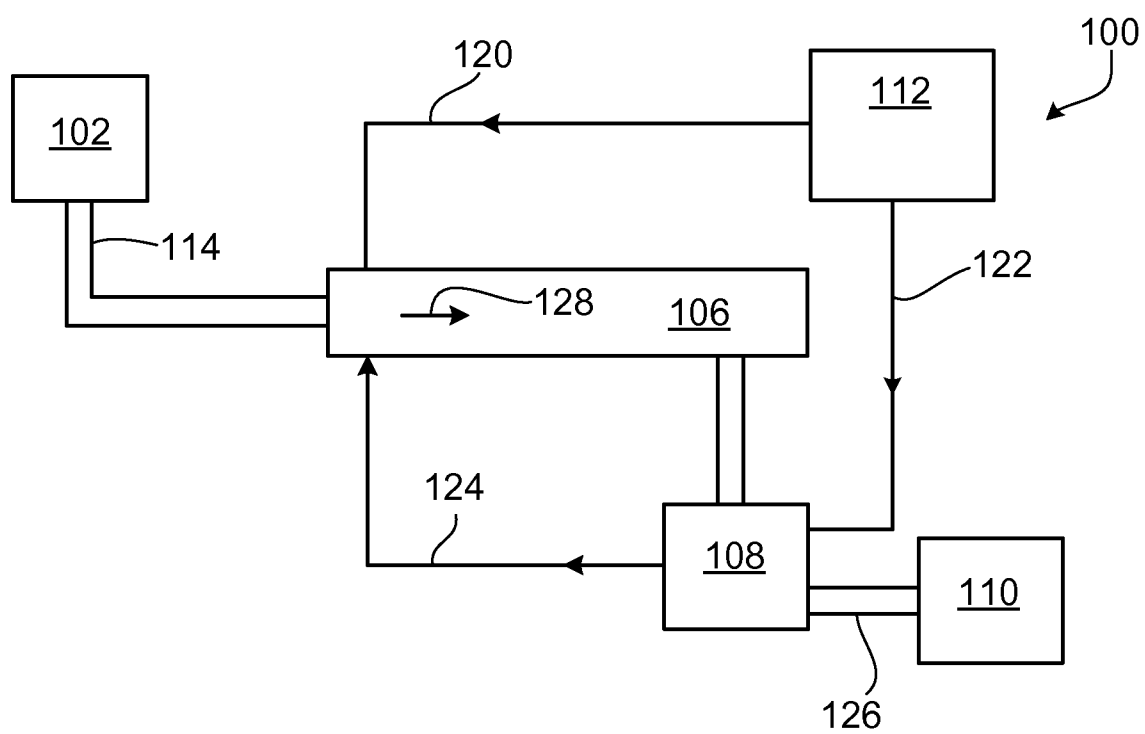


FIG. 2

REFERENCES CITED IN THE DESCRIPTION

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Patent documents cited in the description

- WO 2008073186 A [0001] [0044] [0070]
- EP 1669434 A [0001]
- US 4769082 A [0001]
- EP 0794243 A [0001]
- US 4797135 A [0001]
- US 6448307 B [0027]
- US 6258876 B [0027]
- US 6207729 B [0027]
- US 5973035 A [0027]
- US 5952105 A [0027]
- US 12417699 B [0044]
- US 12417707 B [0044]
- US 12417720 B [0044]
- US 12417723 B [0044]
- US 12417731 B [0044]
- US 12417786 B [0044]
- US 12417840 B [0044]
- US 12417880 B [0044] [0049] [0069]
- US 12417900 B [0044]
- US 12417904 B [0044]
- US 12429045 B [0044]
- US 12486436 B [0044]

Non-patent literature cited in the description

- **KARLSSON et al.** *Journal of Pulp and Paper Science*, 2001, vol. 27, 196-201 [0024]

ANYAGOK HÜTÉSE ÉS FELDOLGOZÁSA

Igénypontok

1. Lignocellulózos biomassa feldolgozására szolgáló módszer, amely a következőket foglalja magában:
 egy rideggé tett anyag feldolgozása egy enzimmel és/vagy mikroorganizmussal, olyan termék előállítására, amely kémiaiilag különbözik a rideggé tett anyagtól; a rideggé tett anyagot a lignocellulózos biomassa anyag kezelésével állították elő a biomassa anyag rideggé tételére, ahol a kezelés a biomassa anyag elektronsugárral történő besugárzását, a további kezelés a biomassa anyag 273 K vagy annál alacsonyabb hőmérsékletre való lehűtését foglalja magában, ahol a hűtésre a besugárzás előtt kerül sor; és
 ahol az anyag feldolgozása magában foglalja az anyag enzimmel és/vagy mikroorganizmussal való érintkezését, vagy az anyag cellulózt tartalmaz és a módszer magában foglalja egy enzim felhasználását a cellulóz cukrosításához.
2. Az 1. igénypont szerinti módszer, ahol a rideggé tett anyag előállítása továbbá magában foglalja a kiindulási anyag őrlését vagy aprítását.
3. A 2. igénypont szerinti módszer, ahol az őrlésre vagy aprításra a kiindulási anyag rideggé tétele előtt kerül sor.
4. A 2. igénypont szerinti módszer, ahol a hűtésre, őrlésre vagy aprításra egyidejűleg kerül sor egy fagyasztva őrlő vagy aprító berendezésben kerül sor.
5. Az 1. igénypont szerinti módszer, ahol a termék egy alkoholt tartalmaz.
6. Az 5. igénypont szerinti módszer, ahol a termék etanolt vagy butanolt tartalmaz.
7. Az 1. igénypont szerinti módszer, ahol a módszer magában foglalja a lignin és a cellulóz elválasztását is.
8. A fenti igénypontok bármelyike szerinti módszer, ahol a biomassa anyagnak egynél több komponense van és a komponensek között határfelület helyezkedik el, valamint a kezelés magában foglalja a kiindulási anyag lehűtését olyan hőmérsékletre, amelyen a komponensek a határfelületen szétválnak.
9. A 8. igénypont szerinti módszer, ahol a hőmérséklet kisebb vagy egyenlő az anyag ridegedési pontjával.
10. A 8. igénypont szerinti módszer, ahol a komponensek hőtágulási együtthatója különböző.
11. Az 1–10. igénypont bármelyike szerinti módszer, ahol a sugárzás dózisa 10 Mrad-tól 100 Mrad-ig, vagy 30 Mrad-tól 90 Mrad-ig terjed.

