purifying a saccharified liquids utilizing an electrodialysis system, wherein the liquids includes arabinose and the purity of the arabinose after utilizing the electrodialysis system is at least about 0 to 1 wt.%.

[0016] Alternately, the saccharified biomass may be fermented and then electrodialysis steps applied. An initial electrodialysis step can remove salts especially inorganic salts, followed by a second electrodialysis step using a bipolar electrolysis step to isolate valuable ionizable organic products from the fermentation system. Subsequent purification steps as described above may be used for further purify the ionizable organic products.

[0017] Other features and advantages of the invention will be apparent from the following detailed description, and from the claims.

DESCRIPTION OF DRAWINGS

[0018] FIG. 1A is a diagram showing an electrodialysis process.

[0019] FIG. 1B is a diagrammatic view of an exemplary electrodialysis system.

[0020] FIG. 2 is a flow chart showing the steps of purifying (treating) the biomass before subjecting it to electrodialysis.

[0021] FIG. 3 is a plot showing conductivity vs time during an electrodialysis process.

~~**[0022]** FIG. 4 is flow chart showing the steps of purifying an ionizable organic product after a fermentation step; specifically D- or L-lactic acid.~~

[0023] FIG. ~~5~~ 4 is a flow chart showing steps for using two electrodialysis steps for isolating an organic acid.

DETAILED DESCRIPTION

[0024] Using the methods and systems described herein, cellulosic and lignocellulosic feedstock materials, for example that can be sourced from biomass (*e.g.*, plant biomass, animal biomass, paper, and municipal waste biomass) and that are often readily available but difficult to process, can be converted to solutions containing sugars such as xylose and glucose, which can in some cases be further processed to produce other useful products (*e.g.*, alcohols such as ethanol and butanol and organic acids such as acetic acid, propionic acid, succinic acid, tartaric acid, butyric acid and lactic acid). Methods and systems are discussed herein for removing unwanted components, such as

prior to subjecting the biomass solution to electrodialysis. In particular, it may be beneficial to remove impurities (*e.g.*, polymers, proteins, precipitants) that can coat, plug, fill or otherwise hinder the function of the electrodialysis membranes. In general, electrodialysis is subject to membrane fouling from particles and organic materials, for example, the organic impurities that can lead to color as previously discussed. Therefore, electrodialysis is preferably done after removing these materials. If fouling does occur, the membranes can be regenerated running the process in reverse by reversing the direction of constant current driving the separation and switching the dilution and concentration chambers.

[0033] A possible process for purifying biomass liquids, e. g. product liquids from saccharified feedstock or fermentation liquids before introducing it to electrodialysis, to avoid this fouling, is shown in FIG. 2. The saccharified feedstock is concentrated **210** under vacuum to remove solvents. In case of post-fermented feedstock, solvents including ethanol could be removed under vacuum or distilled away from the bulk of the solution and collected, leaving behind a solution (*e.g.*, distillate bottom) comprising sugars where at least about 80 wt.% of the sugars are xylose (*e.g.*, at least 85 wt.%, at least 90 wt.%, at least 95 wt.%, at least 96 wt.%, at least 97 wt.% or even at least 98 wt.%) and about 0.5 wt.% of the sugars are arabinose (*e.g.*, about 1 to 0 wt.%, about 1 to 0.1 wt.%, about 0.8 to 0.1 wt.%, about 0.8 to 0.2 wt.%, about 0.5 to 1.0 wt.%, about 0.1 to 0.5 wt.%).

[0034] Some impurities (*e.g.*, bi-products) are then precipitated **215** from the solution. This can be done by dilution with methanol, which induces precipitation of some impurities. The precipitates can be removed **220**, for example, by use of a centrifuged and/or filtration. The filtered solution may then be decolorized **225** with activated carbon. The decolorizing agent is removed by filtration **230**. A concentration step, **235** includes placing the solution under vacuum which removes methanol. The resulting solution can then be diluted with deionized water and subjected to electrodialysis **240** to remove the salts.

[0035] A possible process for purifying an ionizable organic product (*e.g.*, D- or L-lactic acid, succinic acid, tartaric acid) starts with saccharifying a biomass before fermentation and then introducing it to two steps of electrodialysis~~, as shown in FIG. 4~~. The saccharified feedstock is concentrated ~~(410)~~ under vacuum to remove solvents. Following saccharification the biomass is fermented ~~(415)~~ where the microorganism converts one sugar to a desired product while leaving other sugars unconverted. Prior to the electrodialysis steps the solids are removed from the fermentation product ~~(420)~~. The

first electrodialysis is done to remove salts, especially inorganic salts ~~(425)~~. Then a bipolar membrane electrodialysis ~~(430)~~ is done to isolate the ionizable organic product (in this case, D- or L-lactic acid) from the unreacted sugars such as xylose. Subsequent purification ~~(435)~~ of the ionizable organic product by simulated moving bed chromatography or similar isolation processes can lead to an isolated product of sufficient purity for its intended use.

[0036] Pertaining to FIG ~~6~~ 4 two electrodialysis steps are shown as a purification strategy. To the fermentation product liquid mixture which has had solids removed from it (**510**), is added a base if needed to convert the organic acid to its salt form (**520**) and electrodialysis processing is done to separate the nonionic sugars from the salts (including the organic acid salts). Then the salt is processed in the bipolar membrane electrodialysis unit (**530**) in which the organic acid salt is converted to its neutralized form and isolated from the salts.

[0037] Also present in the sugar solution, for example, prior to electrodialysis and/or some other purification method as described herein is applied, there can be intact or denatured enzymes utilized in the processing, or compounds derived from these enzymes (*e.g.,* proteinaceous material such as proteins and amino acids). These can be dissolved/and or precipitated and suspended solids, can subsequently be removed by filtration or centrifugation. In some cases, the enzymes can be present in a functioning state and are denatured, *e.g.,* by adding an acid, a base, heating, adding a denaturing agent. Denaturing the enzyme can facilitate its removal, *e.g.,* by the methods described herein. The sugar solutions can have, for example, up to about 10 wt.% enzymes (*e.g.,* up to 9 wt. %, up to 8 wt. %, up to 5 wt. %, up to 2 wt. %, up to 1 wt. %, between about 0.1 and 5 wt. %, between about 1 wt. % and 5 wt. %, between about 2 wt. % and 5 wt. %, between about 0.1 wt. % and 1 wt. %, between about 0.01 wt. % and 1 wt. %, between about 0.001 wt.% and 0.1 wt.%). Wherein the wt. % of enzymes is understood as the wt. % of proteinaceous material in the aqueous solution.

[0038] Some cellulolytic enzymes utilized for saccharification of a biomass operate best in the acidic region, *e.g.,* between about pH 2 and 6 (*e.g.,* between about 3 and 6, between about, 4 and 6, between about 4 and 5). The sugar solutions can be subjected to electrodialysis at these acidic pH, or optionally the pH can be adjusted up or down after saccharification and/or saccharification can be done at a higher or lower pH. Adjustment of the pH adds to the concentrations of ions in the solution. However, electrodialysis works well at pH values selected from a broad range.

CLAIMS

1. A method comprising:

pretreating a cellulosic or lignocellulosic material with ionizing radiation;

saccharifying the radiated cellulosic or lignocellulosic material to obtain saccharified biomass liquids; and

removing salts, partially ionized acids or fully ionized acids, from the saccharified biomass liquids utilizing an electrodialysis system, wherein utilizing the electrodialysis system comprises a first electrodialysis step and a second electrodialysis step, wherein the second electrodialysis step comprises the use of a bipolar membrane.

2. The method of claim 1, wherein the first electrodialysis ~~system~~ step utilizes electrodialysis or electrodialysis reversal.

~~3. The method of claim 1 or 2, wherein the saccharified biomass liquids comprises a reduced recalcitrance, cellulosic or lignocellulosic material that has been saccharified.~~

~~4. The method of claim 3, wherein the cellulosic or lignocellulosic material has had its recalcitrance reduced by treatment with ionizing radiation.~~

~~5~~3. The method of claim 4~~1~~, wherein the ionizing radiation is in the form of accelerated electrons.

~~6~~4. The method of any one of claims ~~3~~ 1 through ~~5~~3, wherein the cellulosic or lignocellulosic biomass has been saccharified utilizing one or more enzymes.

~~7~~5. The method of any one of claims ~~3~~ 1 through ~~6~~4, wherein the cellulosic or lignocellulosic biomass has been saccharified utilizing one or more acids.

~~8~~6. The method of claim ~~7~~5, wherein the acid is sulfuric acid.

~~9~~7. The method of any one of the above claims, wherein an ionic strength of the saccharified biomass liquids prior to electrodialysis is between about 500 and about 50,000 μS/cm, and wherein an ionic strength of the saccharified biomass liquids after electrodialysis is between 1 and 100 μS/cm.

~~10~~8. The method of any one of the above claims, wherein the salts, partially ionized acids or fully ionized acids removed utilizing the electrodialysis system comprise at least one element selected from the group consisting of P, K, Mg, Na, Ca, S, O, Mn, Al, Zn, Si, Cl and Fe.

~~11~~9. The method of any one of the above claims, further comprising purifying the saccharified biomass liquids by a method selected from the group consisting of chromatography, filtration, centrifugation, precipitation, distillation, complexation and combinations thereof.

~~12~~10. The method of claim ~~11~~9, wherein precipitation comprises addition of one or more solvents or non-solvents to precipitate one or more undesired components.

~~13~~11. The method of claim ~~12~~10, wherein the solvent is selected from the group consisting of methanol, ethanol, isopropanol, acetone, ethyl ether and tetrahydrofuran.

~~14~~12. The method of claim ~~12~~10, wherein the solvent is methanol.

~~15~~13. The method of any one of the above claims, wherein the saccharified biomass liquids comprise one or more fermentation products.

~~16~~14. The method of any one of the above claims, wherein the saccharified biomass liquids comprises liquids that have had a fermentation product distilled therefrom.

~~17~~15. The method of claim ~~16~~14, wherein the fermentation product is an alcohol.

~~18~~16. The method of claim ~~17~~15, wherein the alcohol is ethanol.

~~19~~17. The method of any one of the above claims, further comprising decolorizing the saccharified biomass liquids utilizing a decolorizing agent.

~~20~~18. The method of claim ~~19~~17, wherein the decolorizing agent is selected from the group consisting of powdered carbon, granular carbon, extruded carbon, bone char carbon, bead activated carbon, stryenic resins, acrylic resins, magnetic resins, decolorizing clays, bentonite, attapulgite, montmorillonite, hormite and combinations thereof.

~~21~~19. The method of claim ~~19~~17 or ~~20~~18, wherein after decolorizing the color of the solution is less than about 100 color units.

~~22~~20. The method of claim ~~19~~17 or ~~20~~18, wherein after decolorizing the color of the solution is less than about 10 color units.

~~23~~21. The method of claim ~~19~~17 or ~~20~~18, wherein after decolorizing the color of the solution is less than about 5 color units.

~~24~~22. The method of any one of the above claims, wherein utilizing the electrodialysis system comprises applying a voltage of between about 10 and 150V across ion selective membranes while flowing the saccharified biomass liquids past the membranes.

~~25~~23. The method of any one of the above claims, wherein the saccharified biomass liquids comprise one or more saccharides.

~~26~~24. The method of any one of the above claims, wherein the saccharified biomass liquids includes a sugar selected from the group consisting of xylose, glucose, arabinose, fructose and mixtures thereof.

~~27~~25. The method of claim ~~26~~24, wherein the sugar includes xylose and the purity of the xylose after utilizing the electrodialysis system is at least about 80 wt.%.

~~28~~26. The method of claim ~~27~~25, wherein the sugar includes arabinose and the purity of the arabinose after utilizing the electrodialysis system is about 0 to 1wt. %.