

IMPROVED PROCESS FOR RECOVERING SUGARS FROM A PRETREATMENT STREAM OF LIGNOCELLULOSIC BIOMASS

Background

In the biomass field converting lignocellulosic biomass to ethanol is a common practice. If the biomass is a polysaccharide-containing biomass and it is lignocellulosic, a pre-treatment or soaking is often used to ensure that the structure of the lignocellulosic content is rendered more accessible to the enzymes, and at the same time the concentrations of harmful inhibitory by-products such as acetic acid, furfural and hydroxymethyl furfural are usually high and present problems in further processing.

In general terms the more severe the treatment, the more accessible are the cellulosic contents of the material. The severity of the steam explosion is known in the literature as R_o , and is a function of time and temperature expressed as

$$R_o = t \times e^{[(T-100)/14.75]}$$

with temperature, T , expressed in Celsius and time, t , expressed in common units. The formula is also expressed as $\ln(R_o)$, namely

$$\ln(R_o) = \ln(t) + [(T-100)/14.75].$$

It is generally considered that a high R_o value is associated with a high number of unwanted by-products which inhibit the hydrolysis and fermentation of the biomass, such as furfural.

There exists therefore, the need to have a severe process with a high overall R_o which at the same time produces a product with low furfural and high sugar yields.

Summary

Disclosed in this specification is a process for the soaking of lignocellulosic biomass, comprising the steps of: A) introducing a lignocellulosic biomass feedstock into a first soaking zone, B) soaking the lignocellulosic biomass feedstock in the presence of a liquid or vapor of the liquid for a first time and a first temperature correlating to a first severity of the soaking condi-

tions creating a first liquid comprised of at least one compound selected from the group consisting of acetic acid, glucose, xylose and soluble oligomers thereof, C) separating at least a portion of the first liquid comprised of the at least one compound selected from the group consisting of acetic acid, glucose, xylose and soluble oligomers thereof from the biomass of the first soaking, D) introducing the biomass of the first soaking zone into a second soaking zone in the presence of a liquid for a second time and a second temperature correlating to a second severity of the soaking conditions creating a second liquid comprised of at least one compound selected from the group consisting of acetic acid, glucose, xylose and soluble oligomers thereof wherein the second severity is greater than first severity, E) separating at least a portion of the second free liquid comprised of the at least one compound selected from the group consisting of acetic acid, glucose, xylose and soluble oligomers thereof from the biomass of the second soaking.

It is further disclosed to have an third soaking and washing step by introducing the biomass from the second soaking zone into a third soaking zone in the presence of a liquid for a third time and at a third temperature range correlating to a third severity of the soaking conditions creating a third liquid comprised of at least one compound selected from the group consisting of acetic acid, glucose, xylose and soluble oligomers thereof wherein the third severity is greater than second severity, separating at least a portion of the third liquid comprised of at least one compound selected from the group consisting of acetic acid, glucose, xylose and soluble oligomers thereof from the biomass of the third soaking.

It is further disclosed that the soaking and washing may be conducted in a series vessel, the same vessel or piece of equipment, and that the soaking zones may be situated on top of each other or side by side. It is also disclosed that the process may be continuous or batch.

Brief description of figures

Figure 1 is a schematic of a first embodiment of the process.

Figure 2 is a schematic of a second embodiment of the process.

Detailed description

Disclosed in this description is the discovery that when the treating of biomass, in particular lignocellulosic biomass, is conducted in a series of soaking/hydrolysis steps the resulting overall severity may be very high, indicative of the long time at temperatures during the various phases, but the amount of product recovered is substantially higher than would be expected.

The concept is demonstrated in the following working example with severity being determined by the formula:

$$Ro = t \times e^{[(T-100)/14.75]}$$

with temperature, T, expressed in Celsius and time, t, expressed in common units, in the case below minutes.

The formula is also expressed as Ln (Ro), namely

$$\text{Ln} (Ro) = \text{Ln}(t) + [(T-100)/14.75].$$

When the steps are taken in series, the total severity is the sum of the individual Ro for each soaking step.

The soaking procedure itself is known in the art, which is to place the lignocellulosic biomass having a cellulose content of at least 5% by weight of the dry matter, and preferably at least 10% by weight of the dry matter of the biomass into a soaking zone or reactor, and introduce a vapor, usually steam and maintaining the biomass at a temperature for a set amount of time. Steam is added to the soaking reactor at an exemplary rate of 0.5 kg stm/1kg biomass feedstock to 10 kg stm/1 kg biomass feedstock, depending upon the severity chosen. Instead of adding steam liquid water can be added and heated up to the those conditions. The soaking zone holds the biomass in the presence of steam and water for approximately 30 minutes to 3 hours or longer, again depending upon the severity desired. The soaking temperature can be in the range 100 °C to 210 °C, or even higher, but with diminishing returns. After soaking, the solids/liquid/steam mixture is discharged into an inclined reactor, at typically the same pressure of the soaking reactor. At this point liquid is removed via a discharge screw and into the inclined reactor. The solid biomass is carried up the inclined reactor with the cooled condensate

or even added water flowing countercurrent to the solid flow and removing free liquid with dissolved xylans and xylan derivatives.

Comparative examples CE-A and CE-C (See Table 2)

In CE-A, a lignocellulosic biomass was soaked at the indicated temperature for the time indicated in Table 1 (SOAKING CONDITIONS). The calculated severity for this step was 20. This single step recovered only 6.94% of the Xylans present in the feed stream. 87.89% remained in the solids, and 5.17% were lost, meaning they were converted to a series of unwanted by-products.

In CE-C, the same feedstock was soaked at the conditions indicated in Table 1, for a severity of 6802, dramatically more severe than the conditions of CE-A. In this single step, 65.05% of the xylans remained in the solids, and 18.92% were recovered in the liquid, but 16.03% of the xylans were lost to by-products.

Table 1 – SOAKING CONDITIONS

ID	Temperature (°C) T	time (min) t	Severity Ro $= t \times e^{[(T-100)/14.75]}$
A, and CE-A	100	20	20
B,	140	30	452
C, and CE-C	180	30	6802

TABLE 2 - COMPARATIVE EXAMPLES

ID	Severity Ro	Xylan in Solid Stream (% of Feed Stock Xylan in Solid Stream)	Xylan in Liquid Stream (% of Feed Stock Xylan in Liquid Stream)	Xylan Lost (% of Feed Stock Xylan not in Solid or Liquid Stream)
CE-A	20	87.89	6.94	5.17
CE-C	6802	65.05	18.92	16.03

In working example 2 (see Table 3), Step CE-A was performed, the liquid removed, followed by step CE-C. As can be seen by the data, the amount of xylan recovered in the liquid stream was slightly lower than expected (the amount recovered from the direct addition of CE-A and CE-C).

Unexpectedly, the amount of xylan lost to by-products was only 11.68% as opposed to the 16.03% lost in single Step CE-C. As the solids after soaking are usually passed on to a steam explosion and enzymatic hydrolysis, the xylan remaining in the solid are available for further recovery.

Working example 2 combined the conditions of soaking step A, washed, and followed by soaking step C.

In working example 3, a step having a severity in between A and C was added, named B. So working example 3, is the lignocellulosic biomass soaked at conditions A, with the liquid stream removed. The remaining solid is then processed at condition B, with the liquid removed. The remaining solid is then processed at conditions C and the liquid removed. As can be seen in Table 3 - Working Examples, less xylan were lost than compared to single step C and 36.97% of the xylan were solubilized in the liquid, with 47.91% remaining in the solid stream.

TABLE 3 - WORKING EXAMPLES

ID	Severity Ro	Xylan in Solid Stream (% of Feed Stock Xylan in Solid Stream)	Xylan in Liquid Stream (% of Feed Stock Xylan in Liquid Stream)	Xylan Lost (% of Feed Stock Xylan not in Solid or Liquid Stream)
WE-1 A+B	472	76.77	13.25	9.98
WE-2 A+C	6822	66.50	21.82	11.68
WE-3 A+B+C	7273	47.91	36.97	15.12

This evidence demonstrates the improved efficiency of conducting the soaking and washing steps in a sequential manner. This process could be done in a series of vessels as depicted in Figure 1, where the severity, in either temperature or time is progressively increased from one vessel to another.

Referring to Figure 1, the soaking zones A, B, and C are oriented in series. They are maintained at their respective temperature. In the case of Zone A, the steam entering the soaking zone A is at a Temperature T_1 and Pressure P_1 , with biomass being kept in the zone at temperature T_A and for a time, t_A . The biomass moves through a discharge screw, A_d , flowing into an inclined reactor (A_i) with liquid L_A being removed.

The biomass which has been soaked once, moves into the next soaking zone, Zone B, being characterized similarly as Zone A. In the case of Zone B, the steam entering the soaking zone B is at a Temperature T_2 and Pressure P_2 , with biomass being kept in the zone at temperature T_B and for a time, t_B . The biomass moves through a discharge screw, B_d , flowing into an inclined reactor (B_i) with liquid L_B being removed.

The biomass, now soaked and washed for the second time, is sent to a third soaking zone, Zone C, being characterized similarly as Zones A and B. In the case of Zone C, the steam entering the soaking zone C is at a Temperature T_3 and Pressure P_3 , with biomass being kept in the zone at temperature T_C and for a time, t_C . The biomass moves through a discharge screw, C_d , flowing into an inclined reactor (C_i) with liquid L_C being removed.

The biomass is then moved to a compressor to prepare it for steam explosion. The last zone is to have its severity higher than the severity of at least one of the zones before it in the process.

The process could also be done in a single vertical reactor comprised of zones, such as those described in US 2008/0295981, (See Figure 1 of US 2008/0295981).

The adaption to the vertical column is readily apparent once one of ordinary skill realizes that multiple washes in progressive temperature is beneficial. Figure 2 of this specification

demonstrates the unit operations of such a device. The biomass is fed into the top of the vessel passing into Zone A, where the biomass is treated at mild temperature conditions in the presence of steam introduced at temperature T_1 and pressure P_1 and biomass held at temperature T_A for a set period time t_A , having generally a low severity. The liquid, L_A , containing xylan can be separated from the biomass using an extraction screen indicated by the diagonal lines underneath Zone A or some other device and the solids passed into the next Zone, Zone B.

In Zone B the biomass is treated in the presence of steam introduced at temperature T_2 and pressure P_2 and biomass held at temperature T_B for a set period time t_B , and the liquid, L_B , containing xylan is separated from the biomass the using an extraction screen indicated by the diagonal lines underneath Zone B or some other device and the solids passed into the next Zone, Zone C.

In Zone C the biomass is treated in the presence of steam introduced at temperature T_3 and pressure P_3 and biomass held at temperature T_C for a set period time, t_C , and the liquid, L_C , containing xylan can be separated from the biomass using an extraction screen indicated by the diagonal lines underneath Zone C or some other device and the solids passed into the next Zone, or in this case, the compression step in preparation for steam explosion.

It is preferred to have the severity increase with each soaking.

After the washing steps are completed, the liquid streams can be collected and further treated. The solid biomass is then recovered and usually passed onto a steam explosion step, which could be mounted at the bottom of the vertical reactor.

In the above embodiment, the material flow is downward. However, the flow could also be upward with the liquid extraction device different so that the liquid, usually water, moves countercurrent to the flow of the biomass. The zones can be configured horizontal to each other and the biomass would thus move sideways.

According to a further embodiment of the invention, at least one of the wash steps has a

severity greater than or equal to the severity of a previous wash step in the process.

The process may run as a continuous process or batch process.

It should be apparent from the examples and embodiments that this invention is not limited to the embodiments as many variations of the invention exist.

CLAIMS

1. A process for the soaking of lignocellulosic biomass, comprising the steps of
 - A) introducing a lignocellulosic biomass feedstock into a first soaking zone,
 - B) soaking the lignocellulosic biomass feedstock in the presence of a liquid or vapor of the liquid for a first time and a first temperature correlating to a first severity of the soaking conditions creating a first liquid comprised of at least one compound selected from the group consisting of acetic acid, glucose, xylose and soluble oligomers thereof,
 - C) separating at least a portion of the first liquid comprised of the at least one compound selected from the group consisting of acetic acid, glucose, xylose and soluble oligomers thereof from the biomass of the first soaking,
 - D) introducing the biomass of the first soaking zone into a second soaking zone in the presence of a liquid for a second time and a second temperature correlating to a second severity of the soaking conditions creating a second liquid comprised of at least one compound selected from the group consisting of acetic acid, glucose, xylose and soluble oligomers thereof, wherein the second severity is greater than first severity,
 - E) separating at least a portion of the second liquid comprised of the at least one compound selected from the group consisting of acetic acid, glucose, xylose and soluble oligomers thereof from the biomass of the second soaking.
2. A process according to claim 1, comprising the further steps of
 - introducing the biomass from the second soaking zone into a third soaking zone in the presence of a liquid for a third time and at a third temperature range correlating to a third severity of the soaking conditions creating a third liquid comprised of at least one compound selected from the group consisting of acetic acid, glucose, xylose and soluble oligomers thereof, wherein the third severity is greater than second severity,
 - separating at least a portion of the third liquid comprised of at least one compound selected from the group consisting of acetic acid, glucose, xylose and soluble oligomers thereof from the biomass of the third soaking.
3. The process according to any of claims 1 and 2, wherein the soaking of each soaking zone is conducted in a separate vessel.

4. The process according to any of claims 1 and 2, wherein the soaking zones are in single vessel and the first soaking zone is positioned above the second soaking zone.
5. The process according to any of claims 1 and 2, wherein the soaking zones are in a single vessel and the first soaking zone and second soaking zone are horizontal to each other.
6. The process according to any of claims 1 and 2, wherein the soaking zones are in a single vessel and the first soaking zone is located beneath the second soaking zone.