Lignocellulosic materials (LCM) are produced in large quantities and without clear application and their use as raw material for bioethanol production shows economic and ecologic benefits. LCM are composed mainly of three polymers: cellulose made up of glucose units, hemicellulose made up of several sugars (as xylose or arabinose), and lignin made up of phenylpropane units, interconnected in a strong structure. Pretreatment is an important step for bioethanol production from LCM, causing the solubilisation of hemicellulosic fraction (leading to the recovery of hemicellulose-derived saccharides) in order to obtain a solid phase enriched in cellulose and more susceptible to enzymatic attack. This study provides a comparative data regarding the chemical composition of various LCM used for bioethanol production, as well as different pretreatment technologies for improving the enzymatic hydrolysis of LCM.

Keywords: bioethanol, lignocellulosic material, pretreatment

Introduction
The control of European energy consumption and the increased use of energy from renewable sources are important components of measures needed to reduce greenhouse gas emission and to meet the Kyoto Protocol of the United Nation Framework Convention on Climate Change. Improving technological process, the use of energy efficiency technologies and the use of energy from renewable sources in transportation are the most effective measures to reduce dependency from fossil fuels. The European Council of March 2007 established a mandatory target of a 20% share of energy from renewable sources in energy consumption by 2020 and a mandatory 10% minimum target for the share of biofuels in transport.
petrol and diesel consumption by 2020. Member States may encourage the use of biofuels made from wastes, residues, non-food cellulosic material and lignocellulosic material (LCM) (EU-Directive 2009/28/EC).

LCM can be classified into six main groups: crop residues (corn stover, corn cobs, rice husks, barley husks, rye straw, oat straw, rice straw, wheat straw, corn stalks, cotton stalks, soya stalks, sugarcane bagasse), hardwoods (eucalyptus, acacia, poplar, black locust), softwoods (salix, spruce, pine), cellulose wastes (newspaper, waste office paper, recycled paper sludge), herbaceous biomass (alfalfa stems, switch grass), and municipal solid wastes (MSW) (Sánchez, & Cardona, 2008).

The joint U.S. Department of Energy and U.S. Department of Agriculture billion ton study (Biomass as Feedstock, 2005) found that in the United States about 368 million dry tons of sustainably removable biomass could be produced on forestlands and about 998 million dry tons could come from agricultural lands. Forestlands include 52 million dry tons of fuel wood harvested from forests, 145 million dry tons of residues from wood processing, 47 million dry tons of urban wood residues, 64 million dry tons of residues from logging, and 60 million dry tons of biomass from fuel treatment operations. Agricultural lands in the United States could produce nearly 1 billion dry tons of biomass annually, including 428 million dry tons of primary crop residues, 377 million dry tons of perennial energy crops and the rest of biomass from agricultural lands (Foust et al. 2006).

Based on the Pan-European natural resources database and Geographic Information System for European Union, land productivity potentials (Fischer et al., 2010a) and land use scenarios (Fischer et al., 2010b) were elaborated resulting in 42.7 million hectares of energy crops, such as herbaceous and woody lignocellulosic feedstock, and 166 million dry tons of agricultural residues available for biofuel production in EU27, Switzerland and Norway by 2030 (Gnansounou, 2010). In Romania and Bulgaria, the analysis suggests that almost 8 million hectares of arable land for bioenergy feedstock production could be released by 2030 without influencing the food production (Fischer et al., 2010b).

Physico-chemical and chemical processes have been used for pretreatment of lignocellulosic materials. Physico-chemical methods include: steam explosion (autohydrolysis), liquid hot water (LHW), CO₂ explosion and AFEX (Ammonia fiber/ freeze explosion). Chemical methods are based on: acid pretreatment, alkaline pretreatment, wet oxidation, ozonolysis and organosolv.

This review is focused on pretreatment methods for bioethanol production from lignocellulosic materials because they represent the largest amount of residues remaining after harvesting, with great potential, both economic and industrial, in order to produce bioethanol as an alternative fuel source.

Lignocellulosic material

LCM structure consists of three basic polymers: cellulose, hemicellulose and lignin found in stalks, stems and leaves (Demirbas, 2005; Arin & Demirbas, 2004). Cellulose is a homopolysaccharide composed of β-D-glucopyranose units linked together by (1 → 4)-glycosidic bonds. Glucose anhydride, formed by removing
water from glucose, is polymerized into long chains of cellulose containing 5000-
10000 glucose units. The basic unit of the cellulose polymer consists of two
anhydride glucose units called cellobiose units. Hemicellulose is a mixture of
various polymerized monosaccharide such as glucose, mannose, galactose, xylose,
arabinose, 4-O-methyl glucuronic acid and galacturonic acid (Mohan et al., 2006).
Lignin is a mononuclear aromatic polymer located in the cell walls of biomass and
is connected to cellulose fibers (Yaman, 2004; Balat et al., 2008).

LCM can vary in composition and moisture content according to: region,
fertilization practices, harvesting, storage and storage time (Table 1).

Table 1. Composition data of several lignocellulosic materials for bioethanol production

<table>
<thead>
<tr>
<th>Feedstock</th>
<th>Content (dry wt %)</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Cellulose</td>
<td>Hemicellulose</td>
</tr>
<tr>
<td>Hardwoods</td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Eucalyptus globulus</em></td>
<td>46.30</td>
<td>25.83</td>
</tr>
<tr>
<td><em>Acacia dealbata</em></td>
<td>50.50</td>
<td>19.30</td>
</tr>
<tr>
<td><em>Poplar</em></td>
<td>44.05</td>
<td>15.71</td>
</tr>
<tr>
<td><em>Black locust</em></td>
<td>41.61</td>
<td>17.66</td>
</tr>
<tr>
<td>Softwoods</td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Salix</em></td>
<td>42.50</td>
<td>25.00</td>
</tr>
<tr>
<td><em>Spruce</em></td>
<td>44.00</td>
<td>24.60</td>
</tr>
<tr>
<td><em>Pine</em></td>
<td>44.55</td>
<td>21.90</td>
</tr>
<tr>
<td>Agro-industrial residues</td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Corn stover</em></td>
<td>40.00</td>
<td>29.60</td>
</tr>
<tr>
<td><em>Corn cobs</em></td>
<td>34.40</td>
<td>40.75</td>
</tr>
<tr>
<td><em>Barley husks</em></td>
<td>36.70</td>
<td>20.05</td>
</tr>
<tr>
<td><em>Rye straw</em></td>
<td>21.40</td>
<td>36.62</td>
</tr>
<tr>
<td><em>Oat straw</em></td>
<td>41.10</td>
<td>30.20</td>
</tr>
<tr>
<td><em>Rice straw</em></td>
<td>39.40</td>
<td>27.10</td>
</tr>
<tr>
<td><em>Wheat straw</em></td>
<td>36.20</td>
<td>19.00</td>
</tr>
<tr>
<td><em>Corn stalks</em></td>
<td>32.90</td>
<td>24.00</td>
</tr>
<tr>
<td><em>Cotton stalks</em></td>
<td>35.00</td>
<td>16.80</td>
</tr>
<tr>
<td><em>Soya stalks</em></td>
<td>58.50</td>
<td>14.40</td>
</tr>
<tr>
<td><em>Sunflower stalks</em></td>
<td>34.50</td>
<td>24.80</td>
</tr>
<tr>
<td><em>Sugarcane bagasse</em></td>
<td>42.10</td>
<td>29.70</td>
</tr>
<tr>
<td><em>Ethiopian mustard</em></td>
<td>40.00</td>
<td>27.00</td>
</tr>
<tr>
<td><em>Flax shives</em></td>
<td>32.70</td>
<td>21.90</td>
</tr>
<tr>
<td><em>Hemp hurs</em></td>
<td>47.70</td>
<td>17.00</td>
</tr>
<tr>
<td><em>Alfalfa stems</em></td>
<td>37.40</td>
<td>27.60</td>
</tr>
<tr>
<td><em>Switch grass</em></td>
<td>27.50</td>
<td>23.00</td>
</tr>
<tr>
<td><em>Waste papers</em></td>
<td>31.98</td>
<td>25.10</td>
</tr>
<tr>
<td><em>Newspaper</em></td>
<td>61.30</td>
<td>9.80</td>
</tr>
</tbody>
</table>
A recent study of the National Renewable Energy Laboratory (NREL) together with the U.S. Department of Energy (DOE) presents the composition of corn stover from a variety of commercial hybrid varieties using a rapid compositional analysis method known as NIR/PLS (Near-Infrared Spectroscopy/Projection-to-Latent-Structures modeling) (Templeton et al., 2009). This study evaluated the compositions of 508 corn stover samples (Table 2) collected from 47 regions of 8 corn growing countries, after 2001, 2002 and 2003 harvesting. Another recent study of NREL (National Renewable Energy Laboratory) shows a comparison between the average composition of 9 corn stover samples obtained in 2012 from two lots, compared to 2011, obtained from one sample from overall distribution (Humbird et al., 2011).

Table 2. Chemical composition of corn stover
(source: Aden et al., 2002; Humbird et al., 2011)

<table>
<thead>
<tr>
<th>Component</th>
<th>whole stover</th>
<th>2002</th>
<th>2011</th>
</tr>
</thead>
<tbody>
<tr>
<td>Glucan</td>
<td>31.90</td>
<td>37.40</td>
<td>35.05</td>
</tr>
<tr>
<td>Xylan</td>
<td>18.90</td>
<td>21.07</td>
<td>19.53</td>
</tr>
<tr>
<td>Arabinan</td>
<td>2.80</td>
<td>2.92</td>
<td>2.38</td>
</tr>
<tr>
<td>Galactan</td>
<td>1.50</td>
<td>1.94</td>
<td>1.43</td>
</tr>
<tr>
<td>Mannan</td>
<td>0.30</td>
<td>1.56</td>
<td>0.60</td>
</tr>
<tr>
<td>Sucrose</td>
<td>3.60</td>
<td>-</td>
<td>0.77</td>
</tr>
<tr>
<td>Acetyl groups</td>
<td>2.20</td>
<td>2.93</td>
<td>1.81</td>
</tr>
<tr>
<td>Lignin</td>
<td>13.30</td>
<td>17.99</td>
<td>15.76</td>
</tr>
<tr>
<td>Ash</td>
<td>3.90</td>
<td>5.23</td>
<td>4.93</td>
</tr>
<tr>
<td>Protein</td>
<td>3.70</td>
<td>3.10</td>
<td>3.10</td>
</tr>
<tr>
<td>Extractives</td>
<td>8.60</td>
<td>4.68</td>
<td>14.65</td>
</tr>
</tbody>
</table>

Biochemical process

The main biochemical processes consisting in transformation of LCM into bioethanol (Figure 1) are (Wooley et al., 1999; Wooley et al., 2000; Aden et al., 2002; Aden, 2008; Humbird & Aden, 2009; Humbird et al., 2011):

- **Pretreatment.** LCM is treated at higher temperatures for a short time to release hemicellulosic sugars to enzymatic hydrolysis (Figure 2).
- **Simultaneous saccharification and fermentation (SSF).** Enzymatic hydrolysis is initiated in a continuous bioreactor using enzymes and then the biomass is inoculated with fermenting microorganisms. At this stage, most of the cellulose and xylose are converted into bioethanol.

1. **Pretreatment**

The first step in the conversion of LCM into bioethanol is reducing the size by pretreatment (Graf & Koehler, 2000). The goal of any pretreatment technology is to alter or remove structural and compositional obstacles for hydrolysis in order to improve the rate of enzymatic hydrolysis and the increasing yields of fermenting sugars from cellulose and hemicellulose (Mosier et al., 2005a). This is an
important tool for cellulose conversion processes, changing the structure of cellulosic biomass, making it more accessible for enzymes that convert polysaccharide into fermentable sugars (Patel et al., 2007; Balat et al., 2008).

Pretreatment (Figure 3) must meet the following requirements (Silverstein, 2004):

- Improving the ability to form carbohydrates by hydrolysis;
- Avoiding degradation or loss of carbohydrates;
- Avoiding the formation of byproducts that inhibit hydrolysis and fermentation process.

Pretreatment can be done in various ways, such as: steam explosion (Brownell & Saddler, 1987; Zhang et al., 2007); liquid hot water; CO₂ explosion; AFEX (Alizadeh et al., 2005; Teymouri et al., 2004; Teymouri et al., 2005; Indacoechea et al., 2006); acid pretreatment (Martín et al., 2007a); alkaline pretreatment (Silverstein et al., 2007; Champagne, 2007); wet oxidation; ozonolysis; organosolv.

1.1. Physico-chemical pretreatment

Steam explosion pretreatment

In this process which takes place at high pressure, is introduced steam at high temperature into a closed room which contains LCM. After 1-5 min, the steam is released from the matrix chains causing breakage and separation of fibers with minimal loss of material (Mabee et al., 2006; Balat et al., 2008).

Another type of steam explosion pretreatment refers to a technique in which LCM is rapidly heated with high pressure steam without adding any chemicals. Mixture of biomass/steam is kept for a period of time to promote hydrolysis of hemicellulose and the process is completed by decompression. Steam explosion involves chemical effects because acetic acid is generated by hydrolysis of the
acetyl groups associated with hemicellulose and can catalyze the hydrolysis and degradation of glucose or xylose (Mosier et al., 2005a).

**Figure 2.** Pretreatment - Fermentation Cycle
(source: NREL - National Renewable Energy Laboratory)
Figure 3. Effect of pretreatment on lignocellulosic materials

**Liquid hot water pretreatment (LHW)**

LHW is one of the hydrothermal pretreatment methods applied for pretreatment of LCM (Taherzadeh et al., 2008) that benefit from the use of no chemical agents other than water, being more environmentally friendly technologies (Garrote et al., 1999). The objective of LHW pretreatment is to solubilize mainly the hemicellulose, to make the cellulose more susceptible to enzymatic attack and to avoid the formation of inhibitors, such as hydroxymethylfurfural (HMF) and furfural (Alvira et al., 2010). The LHW pretreatment involves saturation of lignocellulosic biomass with water, followed by heat treatment of the slurry at temperatures between 120 and 200°C for 5–15 min under pressure (Kim et al., 2009). The pH is restricted to 4–7 to minimize formation of monomeric sugars and sugar decomposition products (Mosier et al., 2005a; Mosier et al., 2005b). This hydrothermal pretreatment is easy to perform: there is a low usage of energy; the process is without the difficult steps of handling and recovery of chemicals; equipment corrosion can be excluded (Cybulska et al., 2010). The process is already applied to lignocellulosic biomass such as corn stover (Mosier et al., 2005c), sugarcane bagasse (Laser et al., 2002) and wheat straw (Pérez et al., 2008).

**CO₂ explosion pretreatment**

This method is based on the use of CO₂ as a supercritical fluid. The supercritical CO₂ as well as its use in extraction as solvent is capable of enhancing the enzymatic hydrolysis of LCM. This process can remove the lignin and increase the digestibility of the substrate. Co-solvents such as ethanol, acetic acid and water improve the delignification of LCM. CO₂ forms carbonic acid in aqueous solutions, favoring hydrolysis of the polymers. CO₂ molecules are similar in size to those of water and ammonia, which allow them to penetrate in the same way the pores of
LCM. After the release of CO$_2$ under pressure, there is a change in the structure of cellulose and hemicellulose, this allows enzymes to have accessibility to the substrate surface. The main advantages of this treatment are: availability of technology at relatively low cost; it does not produce toxic degradation products; easy recovery after extraction; the process is considered environmentally friendly (Taherzadeh & Karimi, 2008).

**AFEX pretreatment (Ammonia fiber/freeze explosion)**

AFEX pretreatment involves the injection of liquid ammonia (Hamelink et al., 2005). AFEX is a process in which LCM with moisture content of 15-30 % are placed in a pressure container with liquid ammonia. This system does not release any sugars but allows hemicellulose and cellulose to be attacked by enzymes and be reduced to soluble sugars (Dale & Moehlman, 2000; Balat et al., 2008).

**2. Chemical pretreatment**

**Acid pretreatment**

The pretreatment process (Table 3) converts most of the hemicellulosic sugars from LCM into soluble sugars (glucose, xylose, arabinose, mannose) by hydrolysis reactions. Acetyl groups from hemicellulose are released as acetic acid. Sugar degradation products such as furfural and HMF can also be formed in the pretreatment (Humbird et al., 2011). The aim of this process is to obtain high yields of sugars from LCM (Lee, 2005). There are several types of acid pretreatment: the use of sulfuric acid (Parajó et al., 1993) hydrochloric acid (Kurakake et al., 2005), peracetic acid (Teixeira et al., 1999), nitric acid (Brink, 1993), or phosphoric acid (Hussein et al., 2001). Dilute acid pretreatment is one of the most studied and widely used (Karimi et al., 2006; Dale & Moehlman, 2000; Tucker et al., 2003; Chung et al., 2005; Kim et al., 2005; Agbogbo & Wenger, 2006).

There are two types of dilute acid pretreatment processes: at moderate temperatures (T < 160 °C) and higher temperatures (T > 160 °C) (Silverstein et al., 2007). Dilute acid pretreatments at moderate temperatures are using sulfuric acid or phosphoric acid to convert LCM, including hemicellulosic fraction, into soluble sugars, followed by enzymatic hydrolysis of cellulosic fraction to glucose (Um et al., 2002). Higher pretreatment temperatures have a higher yield of xylose recovery and increased enzymatic digestibility of cellulosic residues (Tucker et al., 2003).

**Alkaline pretreatment**

Alkaline pretreatment uses temperatures and low pressures compared to other technologies. This process can remove lignin without having large effects on other components (McMillan, 1997). NaOH treatment increases internal surface of LCM, decreases the degree of crystallinity and breaks the lignin structure (Li et al., 2004). Alkaline pretreatment reduces lignin and hemicellulose content of biomass, increasing the surface and allowing penetration of water molecules in the inner layer as well as breaking connections between hemicellulose and lignin (Lee, 2005). This treatment removes acetyl and uronic acid from hemicellulose, which
slows the enzyme accessibility of hemicellulose and cellulose surface (Ramirez, 2005; Balat et al., 2008).

**Wet oxidation pretreatment**

LCM is subjected to the action of water at elevated temperatures in the presence of oxygen (Schmidt & Thomsen, 1998). This treatment has the advantage of not generating the degradation products, such as furfural and HMF (Klinke et al., 2002; Varga et al., 2003). The presence of oxygen makes this process more expensive but allows working at lower temperatures than the autohydrolysis.

**Ozonolysis pretreatment**

Ozone can be used for the degradation of lignin and hemicellulose in many LCM. This treatment has a delignification effect on the feedstock and practically does not affect the cellulose. The main advantages of the ozonolysis process are: high efficiency in removing lignin; it does not produce toxic products which could affect the following processes; reactions are carried out under conditions of ambient temperature and atmospheric pressure (Vidal & Molinier, 1988).

**Organosolv pretreatment**

Organosolv pretreatment represents an alternative method for the delignification of LCM. This method is using an organic or aqueous organic solvent with addition of a catalyst (HCl or H2SO4) to break the internal lignin and hemicellulose bonds. Among the organic solvents used in the process are: methanol, ethanol, acetone and ethylene-glycol (Sun & Cheng, 2002).

**Table 3.** Comparison between different pretreatment methods for improving the enzymatic hydrolysis of LCM

<table>
<thead>
<tr>
<th>Feedstock</th>
<th>Type of pretreatment</th>
<th>Temp (°C)</th>
<th>Time (min)</th>
<th>Solid loading</th>
<th>Enzyme loading</th>
<th>Yield (%)</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eucalyptus globulus</td>
<td>Steam explosion</td>
<td>210</td>
<td>4</td>
<td>10</td>
<td>15</td>
<td>62.5</td>
<td>Ballesteros et al., 2004</td>
</tr>
<tr>
<td>Populus nigra</td>
<td>Steam explosion</td>
<td>210</td>
<td>4</td>
<td>10</td>
<td>15</td>
<td>71.2</td>
<td>Ballesteros et al., 2004</td>
</tr>
<tr>
<td>Sorghum sp.</td>
<td>Steam explosion</td>
<td>210</td>
<td>2</td>
<td>10</td>
<td>15</td>
<td>62.5</td>
<td>Ballesteros et al., 2004</td>
</tr>
<tr>
<td>Brassica carinata</td>
<td>Steam explosion</td>
<td>210</td>
<td>8</td>
<td>10</td>
<td>15</td>
<td>60.9</td>
<td>Ballesteros et al., 2004</td>
</tr>
<tr>
<td>Wheat straw</td>
<td>Steam explosion</td>
<td>190</td>
<td>8</td>
<td>10</td>
<td>15</td>
<td>68.1</td>
<td>Ballesteros et al., 2004</td>
</tr>
<tr>
<td>Corn stover</td>
<td>Liquid hot water</td>
<td>195</td>
<td>15</td>
<td>13</td>
<td>15</td>
<td>201</td>
<td>Xu et al., 2010</td>
</tr>
<tr>
<td>Rapeseed straw</td>
<td>Liquid hot water</td>
<td>193</td>
<td>27</td>
<td>5</td>
<td>15</td>
<td>94.8</td>
<td>Diaz et al., 2010</td>
</tr>
<tr>
<td>Olive stones</td>
<td>Liquid hot water</td>
<td>200</td>
<td>2</td>
<td>-</td>
<td>15</td>
<td>82.8</td>
<td>Cuevas et al., 2009</td>
</tr>
<tr>
<td>Wheat straw</td>
<td>Liquid hot water</td>
<td>220</td>
<td>-</td>
<td>4</td>
<td>15</td>
<td>92</td>
<td>Pérez et al., 2008</td>
</tr>
<tr>
<td>Hybrid</td>
<td>Liquid hot</td>
<td>200</td>
<td>10</td>
<td>15</td>
<td>40</td>
<td>76.7</td>
<td>Kim et al., 2010</td>
</tr>
</tbody>
</table>
Feedstock | Type of pretreatment | Temp (°C) | Time (min) | Solid loading | Enzyme loading | Yield (%) | References |
--- | --- | --- | --- | --- | --- | --- | --- |
Poplar | water | 220 | 10 | | 15\(^4\)+15\(^8\) | 75\(^{14}\) | 2009 Cara et al., 2007 |
Olive tree residues | Liquid hot water | 215 | - | | 15\(^{14}\) | 86\(^{17}\) | 2001 Allen et al., 2001 |
Corn fiber | Liquid hot water | 90 | 5 | 1\(^{2}\) | 31.3\(^{3}\)+33.3\(^{6}\) | 88.5\(^{14}\) | 2007 Alizadeh et al., 2005 |
Corn stover | AFEX | 100 | 5 | - | 15\(^{4}\)+40\(^{4}\) | 93\(^{14}\) | 2009 Gao et al., 2010 |
Switch grass | AFEX | 110 | 30 | - | 30\(^{2}\)+15\(^{7}\) | 32.4\(^{13}\) | 2005 Ferreira-Leitão et al., 2010 |
Rice straw | CO\(_2\) explosion | 220 | 5 | 2\(^{1}\) | 65\(^{3}\)+17\(^{8}\) | 97.2\(^{13}\) | 2001 Allen et al., 2001 |
Sugarcane bagasse | CO\(_2\) explosion | 121 | 60 | - | 2\(^{4}\)+1\(^{10}\) | 76.5\(^{14}\) | 2007b Martín et al., 2007b |
Wheat straw | Acid hydrolysis | 195 | 10 | 2\(^{1}\) | 67\(^{4}\)+246\(^{6}\) | 90\(^{14}\) | 2009 Pan et al., 2008 |
Wheat straw | Wet oxidation | 195 | 10 | 2\(^{1}\) | 25\(^{4}\)+0.46\(^{9}\) | 93.6\(^{14}\) | 2008 Martin et al., 2008 |
Clover and ryegrass bagasse | Wet oxidation | 195 | 15 | 2\(^{1}\) | 25\(^{4}\)+0.46\(^{9}\) | 74.9\(^{14}\) | 2007b Mesa et al., 2010 |
Sugarcane bagasse | Organosolv | 175 | 60 | 10\(^{1}\) | 15\(^{4}\)+300\(^{11}\) | 92.8\(^{13}\) | 2010 Sannigrahi et al., 2010 |
Pine | Organosolv | 170 | 60 | 2\(^{1}\) | 8\(^{3}\)+16\(^{11}\) | 70\(^{14}\) | 2010 Park et al., 2010 |
Pinus taeda | Organosolv | 180 | - | 1\(^{1}\) | 700\(^{12}\)+250\(^{7}\) | 80\(^{14}\) | 2007 Araque et al., 2007 |
Pinus rigida | Organosolv | 195 | 5 | 2\(^{1}\) | 20\(^{3}\)+40\(^{11}\) | 99.5\(^{13}\) | 2008 Pan et al., 2008 |
Pinus radiata | Organosolv | 187 | 60 | 2\(^{3}\) | 20\(^{3}\)+40\(^{11}\) | 100\(^{14}\) | 2008 Pan et al., 2008 |
Pine beetle killed Lodgepole pine | Organosolv | 187 | 60 | 2\(^{3}\) | 20\(^{3}\)+40\(^{11}\) | 100\(^{14}\) | 2008 Brosse et al., 2009 |
Miscanthus giganteus | Organosolv | 170 | 60 | 2\(^{3}\) | 20\(^{3}\)+40\(^{11}\) | 100\(^{14}\) | 2008 Brosse et al., 2009 |

1 solid (g solid/100 g dissolution); 2 glucan (g glucan/100 g dissolution); 3 cellulose (g cellulose/100 g dissolution); 4 cellulase (FPU/g dry matter); 5 cellulase (mg protein/g of glucan); 6 β-glucosidase (mg protein/g of glucan); 7 β-glucosidase (CBU/g dry matter); 8 β-glucosidase (IU/g dry matter); 9 β-glucosidase (CBU/ml); 10 pectinase (g pectinase/100 g dry matter); 11 xylanase (IU/g dry matter); 12 endo-glucanase (EGU/g dry matter); 13 ethanol conversion (g ethanol/100 g theoretical ethanol); 14 glucose (g glucose/100 g potential glucose); 15 ethanol (g ethanol/kg of substrate); 16 ethanol (g ethanol/100 g potential ethanol); FPU – Filter Paper Units; IU – International Units; CBU – Cellobiase Units; EGU – Endo-Glucanase Units

Conclusions

Pretreatment process is an important step for bioethanol production from LCM, changing the structure of cellulosic biomass, making it more accessible for...
enzymes in order to improve the rate of enzymatic hydrolysis and the increasing yields of fermenting sugars from cellulose and hemicellulose. The main advantages of pretreatment methods for LCM are: steam explosion causes hemicellulose degradation and lignin transformation; liquid hot water, CO₂ explosion and wet oxidation do not cause formation of inhibitory compounds; AFEX increases accessible surface area; acid pretreatment hydrolyzes hemicellulose to xylose and other sugars; alkaline pretreatment removes hemicelluloses and lignin; ozonolysis reduces lignin content; organosolv hydrolyzes lignin and hemicellulose. LCM is economically attractive for obtaining bioethanol as an alternative fuel source.

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