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Delignification of sugarcane bagasse using pretreatment strategies for bioethanol production

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ABSTRACT

Sugarcane bagasse has proved to be a promising feedstock for bioethanol production due to its high cellulosic content and huge availability. For bioethanol production to be effective, pretreatment is the most crucial step to remove recalcitrant lignin and make cellulose more accessible to enzymes for hydrolysis. The most widely used pretreatment techniques employ high temperature and pressure which generate biological growth inhibitors such as furfural and hydroxy methyl furfural (HMF). Hence, adaptation of a pretreatment technique operating at ambient temperature and pressure is mandatory as it reduces the inhibitors being formed. Alkaline hydrogen peroxide (AHP) is notable among all the pretreatments as it operates at room temperature and it is found to increase the efficiency of hydrolysis. Moreover, there is no or very less inhibitors formation in this treatment which in turn improves fermentation. Thus, the present study reviews about current pretreatment technologies and their drawbacks due to inhibitors formation, and importantly examines the key roles of AHP in refining the biomass particularly sugarcane bagasse for bioethanol production.

1. Introduction

Dwindling fossil fuels and inability to replenish them due to complete exploitation of crude oil, coal and petroleum based non-renewable energy creates a necessity to replace fossil fuels with bio based fuels (Paramjeet et al., 2018). Among existing forms of bioenergy, biofuels mainly bioethanol is considered as potential replacement for conventional petroleum fuels because of its numerous and overwhelming environmental and socio-economic benefits (Devarapalli and Atiyeh, 2015). When comparing with conventional energy fuel, ethanol is very clean, pure and renewable, which are the main advantages in making it favourable to use (Wang et al., 2011). One of the efficient feedstocks for bioethanol production is lignocellulosic biomass, in which agricultural residues are more significant. It is estimated that about 114.5 billion tons of biomass from plant photosynthesis is generated every year on earth, and most of them are lignocelluloses (Wang et al., 2011). Lignocellulosic biomass mainly includes biomass such as woody materials, grasses, agriculture residues such as wheat straw, sugarcane bagasse, rice straw, etc., and other waste plant materials in the field which can be used as sustainable alternative feedstocks that can be employed for bioethanol production. Moreover, it is reported that 442 billion liters of bioethanol can be produced from lignocellulosic materials per year (Haq et al., 2016). Utilizing agricultural residues for bioethanol production also reduces the food vs fuel debate and it is called as second generation bioethanol. Sugarcane bagasse, a secondary agricultural residue, is considered as a promising feedstock for bioethanol production (Anwar et al., 2014) which helps in replacing fossil fuels and mitigating greenhouse gases (Thakur et al., 2015). International Energy Agency (IEA) report published on 2010 stated that 25% of residues which can be converted to biofuels can yield 13.0–23.3 EJ of energy and they could meet 10.3–14.8% of the transport fuel demand globally by the end of 2030 (Niphadkar et al., 2018).

Sugarcane bagasse is a solid residue left over after extraction of juice from sugarcane which is composed of cellulose, hemicellulose and lignin. Brazil, China and India are the major producers of sugarcane and it is estimated that almost 500 MT of sugarcane bagasse are produced every year from cane sugar industries from these countries (Yu et al., 2015). Sugarcane bagasse can be used for variety of purposes such as generation of electricity (Rabelo et al., 2012), paper and many other value added products (Yu et al., 2015). Though it is used in many sectors, its abundance is high and fortunately it can be effectively used for bioethanol production. The main advantages in producing bioethanol from sugarcane bagasse is that it is less carbon intensive compared to fossil fuel which helps in reducing air pollution (Iram et al., 2018). But its chemical structure makes it recalcitrant and requires a pretreatment for breaking the structure to release sugars for ethanol

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fermentation.

Pretreatment is one of the most crucial step in biomass conversion as it directly impacts the efficiency of bioethanol production. The main aim of the pretreatment is to disrupt the recalcitrant lignin structures in the sugarcane bagasse and to make cellulose more accessible to the enzymes for efficient conversion into fermentable sugars (Xu and Huang, 2014). The lignin removal efficiency depends on the type of pretreatment employed and the optimum conditions maintained during the pretreatment. Pretreatment processes can be physical, chemical, biological or it can be combination of these methods. Although different pretreatments are available, development of pretreatment with no or very less inhibitors formation is a challenge in bioethanol production (Rabelo et al., 2011). Improvements should be done in pretreatments to develop a cost effective pretreatment without production of inhibitors at the same time with maximum efficiency. Considering all these aspects, alkaline hydrogen peroxide (AHP) pretreatment is one such treatment which can be performed at low cost and at mild conditions without using acids (Rabelo et al., 2011). AHP is an oxidative process which acts on the cell wall of biomass and breaks ester linkages with less sugar degradation and increased digestibility (Dutra et al., 2017). This type of pretreatment is carried out at low temperature and pressure and it is low energy consumption process. Importantly, AHP pretreatment does not generate inhibitors like hydroxy methyl furfural and furfural (Rabelo et al., 2011).

Thus this review discusses about currently available pretreatment technologies and their drawbacks due to inhibitors formation and examines the key roles of alkaline hydrogen peroxide pretreatment in refining the biomass particularly sugarcane bagasse considering sugarcane bagasse as a potential feedstock for bioethanol production.

2. Sugarcane bagasse (SCB)

2.1. Sugarcane processing

Sugarcane processing is the process of extracting juice from cane and converting them into sugar crystals. Juice from the cane is extracted by rotating knives, shredders, and crushers which is then converted to thick syrup by heating juice followed by crystallizing it into granules. The hard fibrous layer of the cane which is removed by crushing initially is called as the bagasse. This bagasse has become an economically viable raw material.

2.2. Sugarcane bagasse (SCB) composition

SCB is a lignocellulosic biomass composed of cellulose, hemicelluloses, lignin and other plant extractives. Bagasse composition usually differs as it depends on various factors such as location, variety of crop, chemical composition of soil, fertilizers, climatic conditions and physical factors. Approximately SCB is made up of 45–50% cellulose, 25–30% of hemicelluloses,25% lignin and 2.4–9% ash (Karp et al., 2013). The lower ash percentage is of great value when compared to the rice straw and wheat straw which is around 17.5% and 11.0%, respectively. Due to its high cellulose content, it can be used for bioethanol production. Apart from this, bagasse can also be used in electricity generation, paper and pulp industries and as solar energy reservoir (Karp et al., 2013). The hard composition of the sugarcane cell wall and rich fibrous matter makes it feed for cattle like wheat straw, rice straw and sorghum straw. This makes it easier for commercialization.

2.3. Sugarcane agronomy and sugarcane bagasse production

Sugarcane (*Saccharum officinarum*), is a species of tall perennial true grasses of the genus *Saccharum*, tribe *Andropogoneae* (Canilha et al., 2012). The main product of sugarcane is sucrose and it gets accumulated in the stalk internodes which can be extracted and purified in specialized cane sugar industries. Sugarcane is commonly grown throughout the world, largely in tropical and sub tropical countries. A variety of sugarcanes are grown and it differs by its stem colour and length. Brazil is the largest producer of sugarcane, which is followed by India, China and Thailand. Brazil alone is responsible for 41% of the world total with an annual production of 186 million tons (Karp et al., 2013). About 200 other counties cultivate sugarcane and India is second largest producer of sugar in the world producing a quantity of 19.2 million tones. The left over residue after extraction, which is SCB is a valuable feedstock and its production is in line with the sugarcane production and processing as it is a by product from these industries. All the sugarcanes produced are processed in industries and they generate several million tonnes of SCB which can be exploited for bioethanol production and other commercial uses.

3. Recalcitrance of lignocellulosic sugarcane bagasse and goal of pretreatment

Chemical structure of lignocellulosic substrates like sugarcane bagasse makes them recalcitrant for enzyme hydrolysis. Cellulose (45–55%) is a structural material formed by a plant from glucose, a common six-carbon sugar and polysaccharides in cellulose should be reduced to simple sugars (glucose) on hydrolysis. But the orientation of the linkages and hydrogen bonds makes cellulose a rigid polymer which cannot be broken down easily. Hemicellulose (20–25%) are the most soluble macromolecular polysaccharides in plant biomass containing sugars like glucose (six carbon), galactose (six carbon),mannose (six carbon) but mainly xylose (five carbon) and arabinose (five carbon). Hemicellulose binds with pectin to cellulose to form a network of cross-linked fibres which should be hydrolysed (Qian, 2014). Lignin (25%) is a very complex molecule formed from phenyl propane and methoxy units and non-carbohydrate polyphenolic substance linked in a three-dimensional structure. It is considered to be glue which holds the cellulose fibrils and it is very difficult to degrade and remove them (Qian, 2014). For any lignocellulosic ethanol production to be cost effective, the challenge is the removal of lignin and its by products. Lignin can be degraded only by few organisms and certain physical and chemical treatments. Pretreatment removes physical and chemical barriers in recalcitrant bagasse and makes cellulose amenable to enzymatic hydrolysis. Therefore advanced pretreatments technologies are required with the aim of maximal lignin removal to uncover the cellulose for saccharification.

4. Challenges faced in using available pretreatment technologies

4.1. Acid-based pretreatments

In the industries, acid hydrolysis is considered as the most prominent pretreatment method. It is generally carried out with mineral acids, organic acids and sulfur dioxide is also an option (Naik et al., 2017). Acid breaks down the covalent bonds in the composite linkages in the lignocellulosic structure and results in formation of reducing sugars. The most commonly used acids are sulphuric acid, nitric acid, and hydrochloric acid (Xu and Huang, 2014). Out of these acids sulphuric acid is mostly used because of its low cost and high efficiency in lignin removal (Sindhu et al., 2011). It is carried out at 120-210 °C with acid concentration of less than 4 wt% and the incubation time may differ from minutes to hours. This technique is one of the efficient techniques with less cost and it is easy to operate. While acid pretreatment is cost effective, it has some of the draw backs of high reactor cost for their usage, gypsum formation during neutralization after pretreatment, and formation of inhibitory by-products. The main inhibitors formed in acid pretreatment are hydroxy methy furfural, furfural and product by products such as phenylic compounds and aliphatic carboxylic acids (Jönsson and Martín, 2016).

4.2. Alkali based pretreatments

Alkali based pretreatments are used also widely used in industries for increasing the digestivity of cellulose and in removing the lignin (Sindhu et al., 2014). Sodium hydroxide and potassium hydroxide are most commonly used while few other alkali like calcium hydroxide and ammonia can also be used. It involves a delignification process in which part of the lignin is removed using alkali and hemicellulose is solubilised (Xu and Huang, 2014). The reaction behind the alkaline pretreatment is the saponification reaction of the ester bonds cross linking the hemicelluloses and lignin which further causes cleavage of bonds, improving the contact between cellulose and enzymes for hydrolysis to take place. But the high cost of alkali is a serious limitation. In this process there is less formation of inhibitory compounds when compared to acid pretreatments. They generate acetic acid, hydroxyl acids and minor amounts of furan aldehydes (Jönsson and Martín, 2016).

4.3. Pulping based pretreatments

Pulping is commonly used in the paper production industries and chemical pulping can be implemented on lignocellulosic biomass to degrade lignin. Two types of pulping processes are used generally, which are kraft and sulfite pulping. Kraft pulping is based upon sodium hydroxide and sodium sulfide. In sulfite pulping, aqueous mixture of bisulfite (HSO_3)and sulphite are used. In both the processes lignin and some hemicelluloses are degraded in black liquor which can be removed. The pulping pretreatment process results in the formation of aliphatic acids (Jönsson and Martín, 2016).

4.4. Solvent based pretreatments

In solvent based pretreatments, organic solvents and ionic liquids can be used for the removal of lignin. It works by breaking the non-covalent bonds between the lignocellulosic components and disrupting the recalcitrant structures. The cellulose can be recovered from ionic liquid and organic solvents which have increased enzymatic conversion rate. They are performed at slightly higher temperatures and comparatively inhibitor formation is less in this process. The main drawback of this process is the left out small ionic liquids and solvents in the biomass which is toxic to enzymes and microorganisms (Jönsson and Martín, 2016).

4.5. Hydrothermal pretreatments

This is comparatively a mild pretreatment method in which the water as liquid phase or vapour phase is used. It does not need any catalyst or cause any corrosive issues during pretreatment. The high pressure water is penetrates directly into the biomass and celluloses which removes most of the hemicelluloses and a only very less amount of lignin which is a disadvantage The hemicelluloses solubilisation is catalysed by hydronium ions resulting from water auto-ionization. The inhibitor formation can be reduced by neutralizing the pH and the by-products formed are acetic acids and furan aldehydes (Jönsson and Martín, 2016).

5. Role of AHP in biomass refining

Hydrogen peroxide is a highly reactive and a powerful oxidizing agent which is not flammable and it is miscible with water capable of being mixed in all proportions. It is generally available in an aqueous solution with concentrations ranging between 20 and 60% (w/v). As it is highly oxidising, it can be used to improve the enzymatic digestibility of agricultural primary and secondary residues. AHP pretreatment is one of the most effective pretreatment for delignification and a variety of lignocellulosic agricultural residues such as rice husks (Ayeni et al., 2018), rapeseed straw (Karagöz et al., 2012), wheat straw (Qiu et al., 2017; Yuan et al., 2018), sugarcane bagasse (Rabelo et al., 2014), sweet sorghum bagasse (Cao et al., 2016), cashew apple bagasse (Correia et al., 2013) are pretreated with AHP. It has an oxidative action on the cell wall of biomass and that breaks ester linkages in them with less sugar degradation and increased digestibility. No or very less secondary product formation occurs during the AHP pretreatment (Dutra et al., 2017). Thus, employing AHP pretreatment can be effectively used to achieve higher lignin removal during the pretreatment.

6. Mechanism of AHP treatment

Hydrogen peroxide requires alkaline pH for the production of oxidising radicals to degrade lignin. The most favourable pH of this pretreatment is 11.5 and increasing or decreasing pH above or below the range of 10–12.5 will result in improper delignification or it will degrade the sugar molecules. The pH can be maintained by addition of NaOH.

The chemical reactions using hydrogen peroxide as oxidizing agent in the alkaline liquid medium is depicted (Dutra et al., 2017). The dissociation of hydrogen peroxide at alkaline pH generates the hydroperoxide anion (HOO −) through Eq. (1)

$$H_2O_2 \ + \ H_2\,O \leftrightarrow \ HOO^- \ + \ H_3O^+ \tag{1}$$

In the alkaline medium, the hydroperoxide anion can react with H_2O_2, leading to the formation of superoxide and hydroxyl radical, as expressed in Eq. (2).

$$H_2O_2 \ + \ HOO^- \ \leftrightarrow \ OH \ + O_2^- H_2O \tag{2}$$

These radicals are strongest oxidisers and delignification takes place through splitting of α-O-4 and β-O-4 bonds and generation of other compounds, which are removed by oxidation of phenolic groups into aldehydes and carbonyl compounds.

7. Pretreatment parameters

Efficiency of pretreatment depends on the parameters which are to be optimized for maximum delignification. The main parameters affecting the AHP pretreatment are incubation time of the reaction, biomass concentration, hydrogen peroxide concentration and temperature maintained during the pretreatment. The way in which these parameters affect the pretreatment efficiency are discussed below:

7.1. Effect of pretreatment time

The contact time between biomass with AHP solution generally varies from several minutes to hours. Reaction time reported in literatures varies from 1 to 24 h depending on the biomass and hydrogen peroxide concentration (Dutra et al., 2017). The increase in time increases the sugar yield up to certain level but it does not have much influence in the pretreatment. The optimum time for sugarcane bagasse was 1 h which yielded high glucose with 7.35% H_2O_2 concentration incubated at 25 °C (Rabelo et al., 2011).

7.2. Effect of biomass loading

Biomass loading is the solid concentration in the pretreatment which is the amount of mass to be pretreated by the mass or volume of the pretreatment reaction. Biomass loading determines the efficiency of the pretreatment. Usually in industrial scale, high biomass loading is required as it reduces cost and at the same time the overall release of sugars is also increased. It is important to combine pretreatment and hydrolysis at high solid concentrations generally above 15% to make the process economical. However very high solid loading may increase viscosity and this may result in increase in energy for mixing and agitation (Dutra et al., 2017).

Table 1
List of alkaline hydrogen peroxide pretreatment reported in sugarcane bagasse.

S.No	Pretreatment	Optimum conditions	Yield	Reference
1	Alkaline hydrogen peroxide	7.35% (w/v) of peroxide at 25 °C for 1 h and biomass loading was 4 g	Glucose - 691 mg/g Lignin removal-85%	Rabelo et al. (2011)
2	supercritical CO_2 followed by alkaline hydrogen peroxide	460 K temperature,15.6 MPa pressure and reaction time was 40 min for supercritical CO_2 and 1.0% for hydrogen peroxide concentration for 3 g of sugarcane bagasse	Glucose recovery - 97.8%	Phan and Tan (2014)
3	Alkaline hydrogen peroxide	1.85 mL hydrogen peroxide/g bagasse (7.36% (v/v)) for 1 h at 25 °C, Biomass -4 g	Glucoe recovery- 92.59%.	Rabelo et al. (2014)
4	Wet disk milling and hydrogen peroxide treatments	70 °C using 2.5% biomass with 1% or 2% (w/v) hydrogen peroxide at 200 rpm for 48 h	87% glucan was recovered	Gao et al. (2012)
5	H_2O_2 under influence of dual salt	$MnSO_4.H_2O$ and ZnO with 1% H_2O_2, 1 g SCB for 30 min at 100 °C	cellulose recovery - 94% lignin removal - 74.18%.	Ramadoss and Muthukumar (2015)
6	Alkaline hydrogen peroxide and organosolv pretreatments	Biomass - 5%, (w/v), 1% (w/w) EDTA, 0.6 g H_2O_2/g of biomass at 80 °C for 3 h, with shaking at 100 rpm	lignin removal - 37.3%	Yu et al. (2015)
7	Steam pretreatment impregnated with H_2O_2	1% hydrogen peroxide incubated at 210 °C for 15 min, bagasse sample with 500 g dry matter	cellulose conversion - 86.9% hemicellulase - and lignin removal - 92.4% and 29.7%	Rabelo et al. (2012)

7.3. *Effect of hydrogen peroxide concentration*

Hydrogen peroxide concentration is one of the most significant parameter as it reduces the recalcitrance of biomass and improves the accessibility of biomass to enzymes and acids for hydrolysis (Rabelo et al., 2011). Hydrogen peroxide concentration depends on the type of biomass and for sugarcane bagasse, it varied from 1 to 5%.(v/v). Increasing the concentration of hydrogen peroxide increases the release of sugars but this may also increase the cost of the pretreatment. Hence optimum concentration should be chosen which results in maximum yield and at the same time it should be economically viable (Dutra et al., 2017).

7.4. *Reaction temperature*

Temperature plays a major role among the parameters as high temperatures maintained during the pretreatment may lead to formation of fermentation inhibitors and also energy requirements will be high. AHP treatment is generally carried at milder temperature range from 25 to 70 °C (Dutra et al., 2017). Most of the AHP treatments employed in sugarcane bagasse were carried out at 25 °C and yielded high amount of sugars during hydrolysis.

8. AHP treatment in sugarcane bagasse

Rabelo et al., reported that pretreatment with alkaline hydrogen peroxide at optimum conditions of 7.35% (w/v) of peroxide at 25 °C for 1 h led to the higher glucose yield of 691 mg/g after enzymatic hydrolysis. The lignin removal was about 85% and it has been reported that pretreatment with peroxide requires less time than with lime and it occurs at ambient temperature which resulted in high glucose yields (Rabelo et al., 2011). Phan et al., pretreated sugarcane bagasse with supercritical CO_2 followed by alkaline hydrogen peroxide and reported that the optimum pretreatment parameters were 460 K for temperature,15.6 MPa pressure and reaction time of 40 min for supercritical CO_2 and 1.0% hydrogen peroxide concentration was used for 3 g of sugarcane bagasse. The glucose recovery was about 97.8% and this method was found to be superior to individual pretreatments with supercritical CO_2, hydrogen peroxide, ultrasound and combination of supercritical CO_2 and ultrasound (Phan and Tan, 2014). Rabelo et al., treated sugarcane bagasse with alkaline hydrogen peroxide followed by enzymatic hydrolysis and reported that the pretreatment increased enzymatic digestibility without the need for prior size reduction. The optimum conditions of the pretreatment was 1.85 mL hydrogen peroxide/g bagasse (7.36% (v/v)) for 1 h at 25 °C.The highest yield of glucose was about 92.59% (Rabelo et al., 2014). Gao et al., performed combination of wet disk milling and hydrogen peroxide treatments for enhancing saccharification of sugarcane bagasse. Finally, cellulose rich material containing 87% glucan was obtained by performing the hydrogen peroxide treatment at 70 °C using 2.5% biomass with 1% or 2% (w/v) hydrogen peroxide. It was reported that the cellulose rich material derived from this pretreatment showed high performances in saccharification and cellulose production (Gao et al., 2012). Ramadoss et al. Pretreated sugarcane bagasse with hydrogen peroxide under the influence of dual salt. They performed study to evaluate the influence of different dual salts on the pretreatment of sugarcane bagasse with hydrogen peroxide. The maximum cellulose recovery and delignification was obtained using $MnSO_4.H_2O$ and ZnO at optimum conditions of 1% hydrogen peroxide, 1 g SCB for 30 min at 100 °C.The cellulose recovery was about 94% and the lignin removal was about 74.18% (Ramadoss and Muthukumar 2015). Yu et al., performed comparative study of alkaline hydrogen peroxide and organosolv pretreatments of sugarcane bagasse and reported that the total lignin removal was about 37.3% with green liquor combined with hydrogen peroxide (Yu et al., 2015). Rabelo et al., performed steam pretreatment with hydrogen peroxide in sugarcane bagasse at optimum conditions of 1% hydrogen peroxide

Table 2

Life cycle analysis of alkaline hydrogen peroxide pretreatment reported in sugarcane bagasse.

S.No	Pretreatment	Optimum conditions	Lignin removed (%)	Cellulose recovered (g)/%	Glucose yield/Glucose recovery	Reference
1	Alkaline hydrogen peroxide	7.35% (w/v) of peroxide at 25 °C for 1 h and biomass loading was 4 g	85	39.9	691 mg/g	Rabelo et al. (2011)
2	supercritical CO_2 followed by alkaline hydrogen peroxide	460 K temperature,15.6 MPa pressure and reaction time was 40 min for supercritical CO_2 and 1.0% for hydrogen peroxide concentration for 3 g of sugarcane bagasse	–	–	97.8%	Phan and Tan (2014)
3	Alkaline hydrogen peroxide	1.85 mL hydrogen peroxide/g bagasse (7.36% (v/v)) for 1 h at 25 °C, Biomass -4 g	87.12	92.5%	92.59%.	Rabelo et al. (2014)
4	Wet disk milling and hydrogen peroxide treatments	70 °C using 2.5% biomass with 1% or 2% (w/v) hydrogen peroxide at 200 rpm for 48 h	73.2	87%	–	Gao et al. (2012)
5	H_2O_2 under influence of dual salt	$MnSO_4.H_2O$ and ZnO with 1% H_2O_2, 1 g SCB for 30 min at 100 °C	74.18	94%	15.26 ± 0.37 g/L	Ramadoss and Muthukumar (2015)
6	Alkaline hydrogen peroxide and organosolv pretreatments	Biomass - 5%, (w/v),1% (w/w) EDTA,0.6 g H_2O_2/g of biomass at 80 °C for 3 h, with shaking at 100 rpm	37.3	–	41.7%	Yu et al. (2015)
7	Steam pretreatment impregnated with H_2O_2	1% hydrogen peroxide incubated at 210 °C for 15 min, bagasse sample with 500 g dry matter	29.7	86.9%	–	Rabelo et al. (2012)

incubated at 210 °C for 15 min which resulted in cellulose conversion of 86.9% and maximum removal of hemicellulases and lignin of about 92.4% and 29.7% respectively (Rabelo et al., 2012). The details of AHP pretreated sugarcane bagasse are presented in Table 1.

9. Techno economic analysis

Cost of ethanol production from lignocellulosic sugarcane bagasse is mainly affected by pretreatment process. Maximum delignification and cellulose recovery with minimum use of pretreatment reagents, lower temperature conditions and reduced time duration for pretreatments helps in minimizing the production cost (Cuong and Tabil, 2018). In case of AHP pretreatment, the principle operating costs were the energy consumed for the entire pretreatment process, the cost of hydrogen peroxide used for the treatment and the cost of sodium hydroxide used to maintain the alkaline condition of hydrogen peroxide during the process (Rabelo et al., 2014). As the AHP treatment was carried out at low temperature, energy consumption was less when compared to acid and alkali pretreatment. While acid and alkali pretreatments require a recovery step which adds up to the operating cost, AHP treatment doesn't require such recovery steps and it involves only the cost for the amount of water spent for washing process after the pretreatment. Hence, it is no doubt that AHP pretreatment is a better option than other pretreatments both in efficacy and cost wise.

10. Life cycle analysis

Life cycle assessment is a powerful tool for investigating emissions and analyzing influence on product from beginning of the process to the end (Soam et al., 2016). It was found that no inhibitory by products were formed during the AHP pretreatment. Life cycle analysis was presented in Table 2 which represents the yield and byproducts from the pretreatment.

11. Conclusion

Thus alkaline hydrogen peroxide pretreatment does not result in formation of inhibitory products like hydroxy methyl furfural (HMF) during the pretreatment and the pretreatment is carried out mostly at room temperatures which minimizes the inhibitors formation and at the same time the energy spent is also reduced thus minimizing the overall cost of the pretreatment. Moreover the cost of hydrogen peroxide is also economically viable. Main shortcoming of this technique is the need to maintain alkaline conditions during the pretreatment for which NaOH is required. However the sugar yields are comparatively higher in using AHP pretreatment mainly in sugarcane bagasse. Hence it can be a promising technique for maximum delignification and also in increasing the overall production of bioethanol by minimizing the formation of fermentation inhibitors.

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