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Research Article

Experimental Study on Calcium Hydroxide-Assisted Delignification of Hydrothermally Treated Sweet Sorghum Bagasse

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The hydrothermally treated sweet sorghum bagasse (SSB) powder was treated using $Ca(OH)_2$ to extract the lignin from it. Changes in chemical composition of SSB and the formation of sugars and hydrolytic products were studied. The optimum conditions of 10% (g/g substrate) $Ca(OH)_2$ and 106.3 min of isothermal treatment residence time at 394 K resulted in 69.67 ± 1.26% of the lignin extracted from the hydrothermally treated SSB powder, producing a solid residue containing 68.29 ± 0.31% residual cellulose and 13.26 ± 0.32% residual lignin in it. The $Ca(OH)_2$ concentration and isothermal treatment residence time were significant in the responses observed. Treatment using $Ca(OH)_2$ is one of the potential processes for the on-farm processing of lignocellulosic materials.

1. Introduction

Many processes are being developed for biorefinery that hasten the move from the fossil-based economy towards the biobased economy. This movement also put forth the potential for small scale processing of lignocellulosic biomass for large scale biorefinery operations which can be economically, socially, and environmentally beneficial [1] to both developed and developing countries. The small scale processing of lignocellulosic biomass requires safe and simple technologies that need only minimum capital investment. It should be integrated with other technologies to produce energy for the processing of biomass as well as products required in the local society [1].

Small scale processing of lignocellulosic materials can be performed at farms by the biomass producers and the industries. One of the approaches to process biomass at farms is the fractionation of the substrate into components using mild chemicals at mild temperature. Integrated multiple processes are required for the fractionation of lignocellulosic materials because of the different characteristic properties of the biomass components. Hemicellulose can be extracted without severely affecting lignin and cellulose using water as the catalyst at mild to moderately high temperatures (323–453 K). The residue obtained after the hemicellulose extraction will be rich in lignin and cellulose. The lignin from this residue can be extracted using alkaline catalysts such as calcium hydroxide ($Ca(OH)_2$) that will have minimum effect on the cellulose component of the residue [2]. Alkaline extraction of lignin from lignocellulosic materials will produce a residue containing high amount of cellulose than untreated material. The extracted lignin will be present in the alkaline liquor, which has pH around 12, obtained through the treatment, and lignin can be isolated from this liquid by reducing its pH using acidifying agent like CO_2 or mineral acids [3, 4].

In comparison to other pretreatment processes available, treatment of lignocellulosic biomass using $Ca(OH)_2$ is safe and economical for the production of biofuels and biomaterials. Lime ($Ca(OH)_2$) pretreatment is a proven method

to remove the lignin from lignocellulosic biomass without affecting its carbohydrate portion. The treatment conditions vary depending on the raw materials. For example, feedstocks such as softwoods containing high concentration of lignin require additional oxygen for the delignification whereas feedstocks such as straws containing low concentration of lignin may not require additional oxygen for effective delignification using $Ca(OH)_2$. Lime pretreatment removes about 80% of the lignin along with 95% of the minerals in the lignocellulosic biomass [5] into the aqueous solution leaving a solid residue rich in cellulose. But, most of the $Ca(OH)_2$ pretreatment studies were done at ambient to moderately higher temperatures of 323 to 333 K. These conditions demand longer retention times ranging from 8 to 150 days but were the simplest pretreatment processes for lignocellulosic substrates. As mentioned earlier, increasing the temperature will decrease the treatment time significantly. This will also reduce the treatment area required in industrial scale operations. An increase in treatment temperature from ambient to moderately high (323–333 K) temperature also demands higher water inputs as the high heat capacity and heat transferability of water ensure uniform temperature distribution in the mixture. High water loading also ensures the proper distribution of $Ca(OH)_2$ in the mixture [6].

This study evaluates the potential of $Ca(OH)_2$ treatment as a process for on-farm pretreatment of lignocellulosic materials. Autohydrolysis followed by delignification at 394 K was studied for the fractionation of SSB and the extent of sugar degradation during the process stages was also investigated.

2. Materials and Methods

2.1. Substrate for the Pretreatment. Bagasse powder of sweet sorghum variety CSSH45 was initially treated using water to extract the hemicellulose from it. Hydrothermally (394 K, 13% substrate concentration, and 90 min isothermal treatment residence time) treated sweet sorghum bagasse (HTSSB) powder was used as the substrate for this study. The residue obtained from the hydrothermal treatment was washed using tap water to remove the free sugars from it and subsequently dried at 378 K overnight to remove the moisture from it. The physicochemical properties of the substrates and the solid residues obtained after the treatment were analysed to estimate the bulk density and chemical composition.

2.2. Ca(OH-)$_2$ Assisted Treatment of Hydrothermally Treated Sweet Sorghum Bagasse. The dried HTSSB was treated using $Ca(OH)_2$ solution at 394 K for 30, 75, and 120 min. The substrate concentration was 10% (g/g) and the $Ca(OH)_2$ concentrations were 0, 10, and 20% g/g of the substrate. Higher substrate concentrations lead to difficulty in proper mixing of the substrate and the reagent, thus reducing the delignification efficiency of the process. The substrate concentration used was 10% (g/g) in order to increase the reaction of $Ca(OH)_2$ with the substrate [7]. The solid residues obtained after the $Ca(OH)_2$ treatment were analysed for cellulose, lignin, hemicellulose, and ash. The $Ca(OH)_2$ solution obtained after treatment was analysed for lignin, sugars, total carbohydrates, and sugar degradation products in it. This study selected the process conditions that resulted in maxima of delignification, cellulose concentration, and solids recovery.

The Ca(OH-)$_2$ assisted treatment of the hydrothermally treated SSB (HTSSB) was carried out in an autoclave (DSE-8000, NAPCO, USA). In the experimental treatments, 10 g HTSSB was mixed with 90 g aqueous $Ca(OH)_2$ solution containing 0, 1, or 2 g $Ca(OH)_2$ powder. The $Ca(OH)_2$ quantity varied to get slurries having different $Ca(OH)_2$ concentrations (0, 10, and 20% (g $Ca(OH)_2$/g substrate)). The mixture was then kept in a steam saturated autoclave for the hydrothermal treatment at 394 K. Once the temperature reached 394 K, the mixture was kept at that temperature for 30, 75, and 120 min. The treatment was stopped by releasing the steam pressure and keeping the mixture under cold tap water to bring the temperature of the mixture to the room temperature. The mixture was separated using a nylon cloth to obtain solid and liquid samples for further analyses and studies. The wet solid samples were washed under tap water until the pH of the wash water became neutral and then dried in a hot air oven and finally used for compositional analyses. The liquid samples (hydrolysate) were refrigerated at 277 K and were used for the compositional analyses.

2.3. Experimental Design. The experiments were conducted to estimate the effect of independent variables such as isothermal (394 K) treatment residence time (30, 75, and 120 min) and $Ca(OH)_2$ concentration (0, 10, and 20% (g/g substrate)) on the delignification responses such as lignin extraction, cellulose recovery, ash removal, hemicellulose removal, solid recovery, carbohydrate recovery, and sugar degradation. It was investigated using a response surface design prepared using the JMP 10 software (SAS Institute USA). The response surface design reduced the number of experimental runs and resulted in response surfaces showing the linear and quadratic effects of the independent factors on the responses. The second order polynomial regression equation as shown in (1) was used to fit the responses to understand the effect of the isothermal treatment residence time and $Ca(OH)_2$ concentration:

$$Y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_{12} x_1 x_2 + \beta_{11} x_1^2 + \beta_{22} x_2^2, \quad (1)$$

where Y is the response such as lignin extraction, solid recovery, and sugar degradation, x_1 and x_2 are the independent factors such as isothermal treatment residence time and $Ca(OH)_2$ concentration, β_0 is the intercept, β_1 and β_2 are the linear coefficients, β_{12} is the interaction coefficient, and β_{11} and β_{22} are the quadratic coefficients. Analysis of variance was conducted to determine the statistical significance (P value ≤ 0.05) of the variables on the response and to estimate the fit of the polynomial prediction equation to the observed responses [8]. The coefficient of determination (R^2) and the root-mean-square-error (RMSE) values were used to estimate the fit of the model to the observed responses and to estimate the usability of the model to predict the response in similar experimental conditions.

All the treatments including the two centre points (10% $Ca(OH)_2$ concentration and 75 min of treatment time) and the analyses of the solid and liquid samples were conducted in triplicates. The solid residues obtained after the treatment were analysed for cellulose, hemicellulose, lignin, and ash concentrations. Similarly, the liquid samples obtained after the $Ca(OH)_2$ treatment were analysed for total reducing sugars, pentose sugars, total carbohydrates, sugar degradation products (hydroxymethyl furfural (HMF) and furfural), and dissolved lignin. The treatment conditions were optimized to obtain the maximum extraction of lignin, maximum cellulose concentration in the residue, maximum recovery of solids, and minimum sugar degradation.

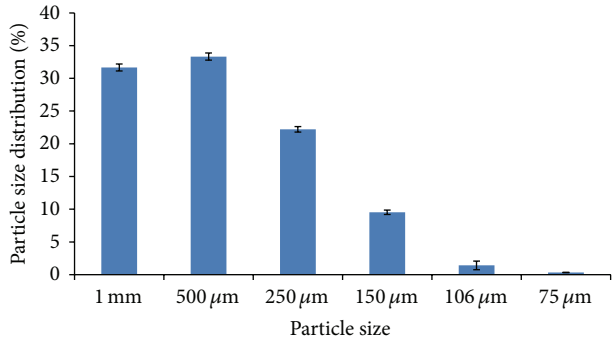

Figure 1: Particle size distribution of the HTSSB used for the study.

2.4. Analytical Methods. The particle size distribution of the substrate used for the treatments was estimated using the sieve analysis method [9]. The bulk density of the solid samples before and after the treatment was estimated using a 100 mL measuring cylinder [10]. Gravimetric and spectrophotometric methods were used to estimate the chemical composition of the substrate and the residues before and after the $Ca(OH)_2$ treatment.

The gravimetric methods for forage fiber analyses were used to estimate the concentration of cellulose, hemicellulose, lignin, and minerals in the solid HTSSB samples before and after the treatments [11]. These methods were selected because they are simple and are convenient for routine analyses in biomass treatment studies [12].

The concentration of total reducing sugars, pentose sugars, sugar degradation products, and lignin in the liquid samples were analysed using UV-Vis spectroscopy. Estimation of pentose sugars was done using the parabromoaniline method developed by Deschatelets and Yu. Similarly, the TPTZ (2,4,6-tripyridyl-s-triazine) method was used to estimate the concentration of total reducing sugars in the liquid samples [13]. The total carbohydrate present in liquid samples was estimated by using the anthrone reagent method [14]. The concentrations of furfural and hydroxyl-methyl furfural (HMF) in liquid samples were estimated using the ultraviolet (UV) spectroscopy [15]. Similarly, lignin solubilised in the liquid was estimated by measuring the absorbance at 278 nm [4, 16].

3. Results and Discussion

3.1. Physicochemical Composition of the HTSSB. The hydrothermally treated material contained, on an extractive free and oven dry basis, about 56% cellulose, 31% lignin, 1% ash, and 11% hemicellulose in it. The bulk density of the substrate was 137.89 ± 6.40 kg/m^3, estimated using a 100 mL measuring cylinder [10]. The bulk density of the substrate was 60% higher than the untreated sweet sorghum bagasse (SSB) powder. The particle size distribution of the HTSSB was mainly from 250 microns to 1 millimeter (Figure 1) estimated through the sieve analyses [9].

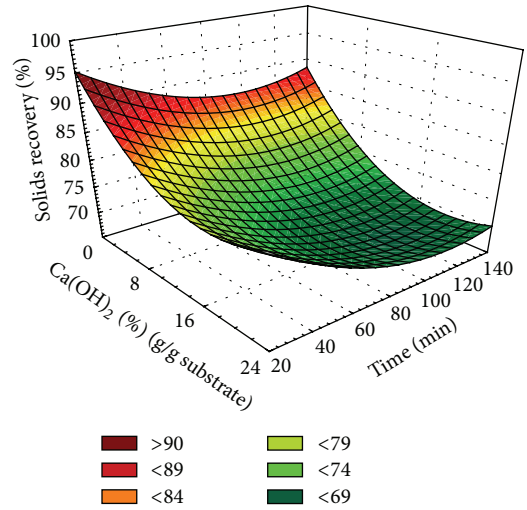

Figure 2: Solids recovery (%) during $Ca(OH)_2$ treatment of HTSSB.

3.2. Solids Recovery during the $Ca(OH)_2$ Treatment of HTSSB. The solids recovery varied from 66.9 to 93.4% and it decreased with increase in isothermal treatment residence time and $Ca(OH)_2$ concentration (Figure 2). Maximum solids recovery is required while extracting the lignin from a lignocellulosic material. The significant (P value < 0.05) response surface quadratic model for the solids recovery is given in (2). The R^2 value of the model was 0.94 with an RMSE value of 2.14. The model has a nonsignificant lack-of-fit (P value > 0.05) and therefore can be used to predict the solids recovery response while treating the HTSSB with $Ca(OH)_2$ at 394 K and conditions investigated here. The recovered solids after the $Ca(OH)_2$ treatment had a bulk density of about 317.40 ± 4.20 kg/m^3 which was higher than the bulk density of HTSSB used for the treatment. Consider the following:

$$\text{Solids recovery}\,(\%) = 73.49 - 7.72A - 4.15B - 0.25AB + 3.97A^2 + 3.14B^2, \quad (2)$$

where A and B are isothermal treatment residence time (min) and $Ca(OH)_2$ concentration (% g/g substrate), respectively.

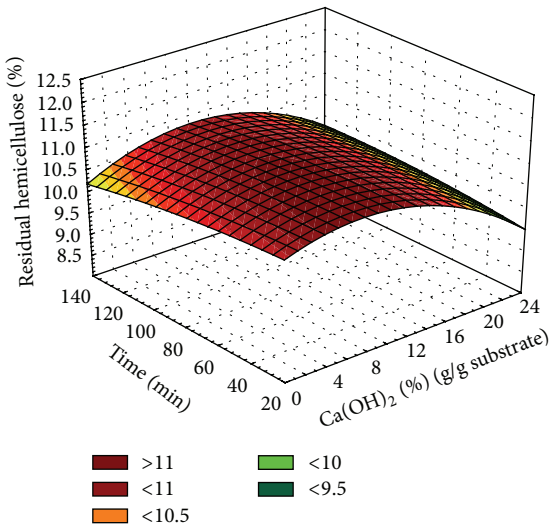

Figure 3: Residual hemicellulose concentration (%) in $Ca(OH)_2$ treated HTSSB.

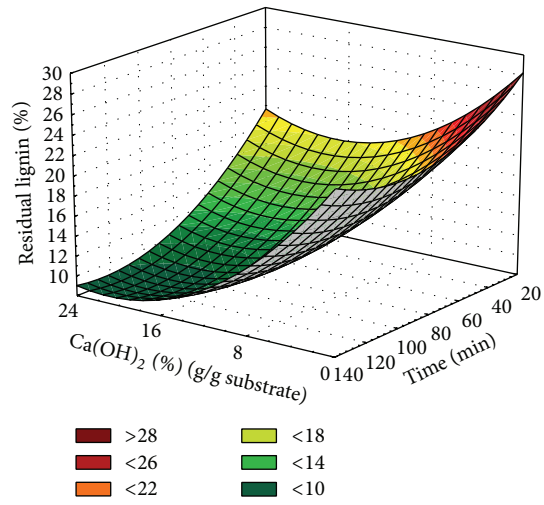

Figure 4: Residual lignin concentration (%) in $Ca(OH)_2$ treated HTSSB.

3.3. Effect of $Ca(OH)_2$ Treatment on Chemical Composition of HTSSB. The concentration of residual hemicellulose in the $Ca(OH)_2$ treated HTSSB was decreased with increase in $Ca(OH)_2$ concentration (Figure 3). The concentration of residual hemicellulose in the final residues varied from 8.45 to 11.87% (g/g). Hemicellulose removal from HTSSB was minimum as most the hemicellulose content was removed during the initial hydrothermal treatment. The response surface model for the removal hemicellulose into the liquor was found not significant (P value > 0.05) with an R^2 value of 0.24 and is not useful to predict the concentration of residual hemicellulose in $Ca(OH)_2$ treated HTSSB residues. Consider the following:

$$\text{Residual hemicellulose (\%)} = 10.97 - 0.36A - 0.06B + 0.14AB - 0.59A^2 - 0.04B^2, \quad (3)$$

where A and B are isothermal treatment residence time (min) and $Ca(OH)_2$ concentration (% g/g substrate), respectively.

3.4. Lignin Extraction through $Ca(OH)_2$ Treatment of the HTSSB. Calcium hydroxide treatment of the HTSSB (10% g/g) at 394 K for 100 min removed about 55% of lignin from it. The final residue contained about 74% cellulose and 17% lignin in it. The maximum lignin extraction observed in this investigation was 78.36% which is comparable with the lignin extracted (62.25%) from dewaxed bamboo through the use of ethanol and NaOH [17].

The response surface quadratic equation for the residual lignin (4) was found significant (P value < 0.05) with an R^2 value of 0.94 and an RMSE value of 1.51. The concentration of residual lignin (%) in the final residue varied from 9.99 to 27.66% and was found decreasing with increase in $Ca(OH)_2$ concentration and isothermal treatment residence time and the response is shown in Figure 4. The extraction of lignin

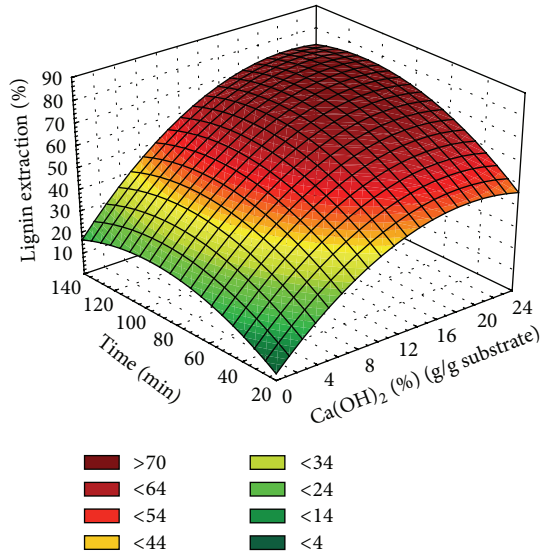

Figure 5: Lignin extraction (%) from HTSSB through $Ca(OH)_2$ treatment.

(%), which was estimated as the difference in concentration of lignin in substrates before and after the $Ca(OH)_2$ treatment, varied from 17.59 to 78.33% and was found increasing with increase in $Ca(OH)_2$ concentration and isothermal treatment residence time (Figure 5). The response surface quadratic equation for the residual lignin (5) was found significant (P value < 0.05) with an R^2 value of 0.99 and an RMSE value of 2.46. The concentration of solubilized lignin (g/L) in the liquor of $Ca(OH)_2$ treatment of HTSSB varied from 8.44 to 35.26 g/L and was also found increasing with increase in $Ca(OH)_2$ loading and isothermal treatment residence time (Figure 6). The response surface quadratic equation for the residual lignin (6) was found significant (P value < 0.05)

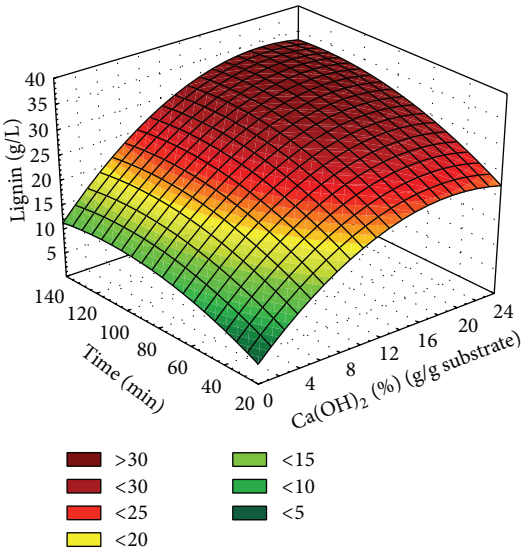

Figure 6: Solubilised lignin (g/L) in liquor of $Ca(OH)_2$ treatment of HTSSB.

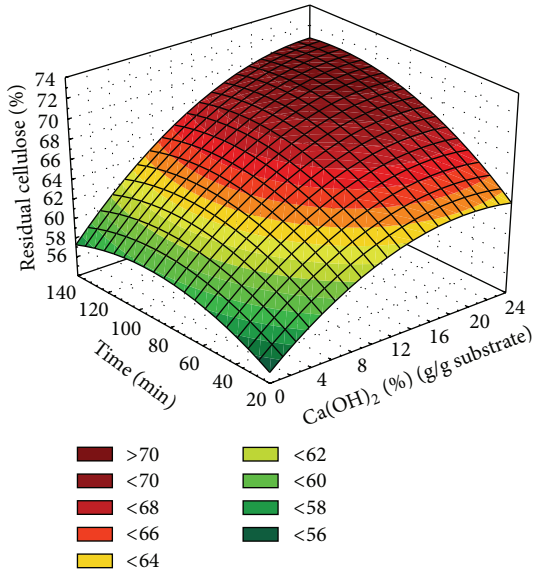

Figure 7: Residual cellulose concentration (%) in $Ca(OH)_2$ treated HTSSB.

with an R^2 value of 0.98 and an RMSE value of 1.18. Consider the following:

$$\text{Residual lignin (\%)} = 15.11 - 5.95A - 2.67B - 1.37AB + 2.60A^2 + 2.08B^2. \quad (4)$$

$$\text{Lignin extraction (\%)} = 65.08 + 20.37A + 9.06B + 2.06AB - 12.90A^2 - 7.30B^2. \quad (5)$$

$$\text{Solubilized lignin (g/L)} = 28.96 + 8.27A + 3.87B + 0.60AB - 5.61A^2 - 2.02B^2. \quad (6)$$

Higher quantity (>80%) of lignin can be extracted through the sequential use of organic chemicals such as dioxane or inorganic chemicals like NaOH or KOH on the substrate [18–20]. However, the applicability of such processes for the on-farm treatment of lignocellulosic material may be limited.

3.5. Effect of $Ca(OH)_2$ Treatment on Cellulose Content of HTSSB. The cellulose content of HTSSB slightly dissolved during $Ca(OH)_2$ treatment. The $Ca(OH)_2$ concentration and isothermal treatment residence time were significant factors affecting the concentration of cellulose in the residue. The residual cellulose concentration varied from 58.21 to 70.61% and the concentration found increasing with increase in $Ca(OH)_2$ concentration and isothermal treatment residence time (Figure 7).

The regression analysis of the responses created a model expression for the cellulose concentration after $Ca(OH)_2$ treatment is given in (7). The model was found significant (P value < 0.05) with an R^2 value of 0.91 and an RMSE value of 1.48. Consider the following:

$$\text{Residual cellulose (\%)} = 67.29 + 4.41A + 2.12B + 0.82AB - 2.31A^2 - 1.45B^2, \quad (7)$$

where, A and B represent $Ca(OH)_2$ concentration in percentage (g/g substrate) and treatment time in min, respectively. The substrate concentration had both linear and quadratic effect on the cellulose concentration while the isothermal treatment residence time had only linear effect on the cellulose concentration.

3.6. Effect of $Ca(OH)_2$ Treatment on Ash Content of HTSSB. The ash content of the final residue was increased after the calcium hydroxide treatment which may be due to the binding of the calcium to the polysaccharide and lignin of the residue [21]. Repeated washing of the delignified residue until the pH of the residue became neutral did not remove the bounded minerals from it. Increase in $Ca(OH)_2$ concentration for the delignification increased the ash content in the residue and increase in the isothermal retention time decreased the ash content in the residue (Figure 8). The quadratic response surface model for the concentration of residual ash in the $Ca(OH)_2$ treated HTSSB was found significant (P value < 0.05) and is shown in (8). The R^2 value was 0.99 and the RMSE value was 0.06. Consider the following:

$$\text{Residual ash (\%)} = 4.32 + 3.91A + 0.10B + 0.20AB + 0.35A^2 - 0.053B^2 \cdots, \quad (8)$$

where, A and B represent $Ca(OH)_2$ concentration in percentage (g/g substrate) and treatment time in min, respectively.

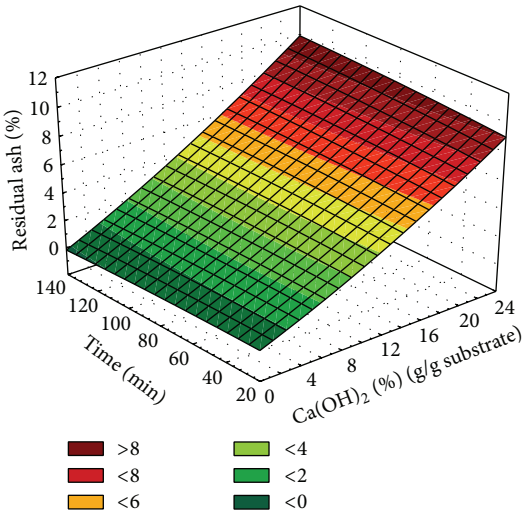

Figure 8: Residual ash concentration (%) in $Ca(OH)_2$ treated HTSSB.

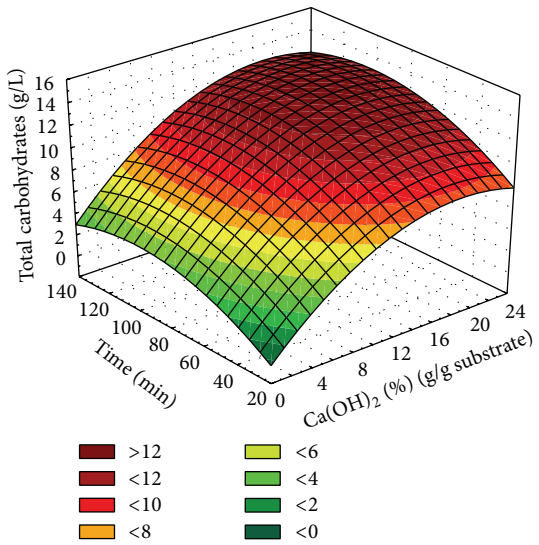

Figure 9: Total carbohydrates in liquor of $Ca(OH)_2$ treatment of HTSSB.

3.7. Conversion of Polysaccharides to Furfural, Hydroxymethyl Furfural during $Ca(OH)_2$ Treatment of HTSSB. Some quantity of the cellulose and hemicellulose in the HTSSB was converted into sugars and estimated as total carbohydrates, pentose sugars, and reducing sugars. The concentration of total carbohydrates in the liquor ranged from 3.27 to 13.67 g/L and the concentration increased with increase in $Ca(OH)_2$ loading and the isothermal treatment residence time (Figure 9). The quadratic response surface model for the concentration of total carbohydrates in the liquor was found significant (P value < 0.05) and is given in (9). The R^2 value of the model was 0.97 and the RMSE value was 0.68. Similarly, the concentration of pentose sugars and total reducing sugars was also increased with increase in $Ca(OH)_2$ loading and the isothermal treatment residence time (Figures 10 and 11). The concentration of pentose sugars varied from 1.67 to 6.98 g/L while the concentration of total reducing sugars varied from 3.19 to 13.34 g/L. The quadratic response surface models for the concentration of pentose sugars and total reducing sugars in the liquor were found significant (P value < 0.05) and are given in (10)-(11). The R^2 value of the model for pentose sugar concentration was 0.97 and the RMSE value was 0.30. Similarly, the R^2 value of the model for total reducing sugar concentration was 0.97 and the RMSE value was 0.66.

A fraction of the sugars formed from the polysaccharides was converted into sugar degradation products such as furfural and 5-hydroxymethyl furfural (HMF). The sugar degradation and thus the concentration (g/L) of furfural and HMF in the liquor were gradually increased with increase in isothermal treatment residence time and $Ca(OH)_2$ loading (Figures 12 and 13). The concentration of furfural varied from 0.48 to 1.99 g/L and the concentration of HMF varied from 0.35 to 1.44 g/L depending on the $Ca(OH)_2$ loading and the isothermal treatment residence time. The quadratic response surface models for the concentration of furfural and HMF in the liquor were found significant (P value < 0.05) and were

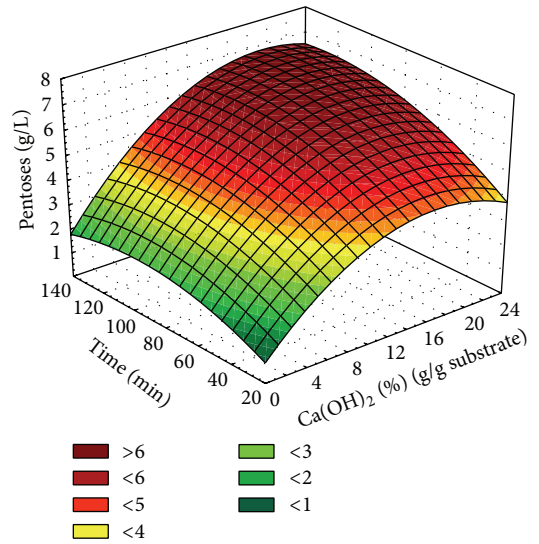

Figure 10: Total pentose sugars in liquor of $Ca(OH)_2$ treatment of HTSSB.

given in (12)-(13). The R^2 value of the model for furfural concentration was 0.75 and the RMSE value was 0.37. Similarly, the R^2 value of the model for HMF concentration was 0.68 and the RMSE value was 0.30. Consider the following:

$$\text{Total carbohydrates (g/L)} = 11.69 + 3.56A + 1.70B + 0.13AB - 2.60A^2 - 1.42B^2 \quad (9)$$

$$\text{Pentose (g/L)} = 5.94 + 1.56A + 0.80B + 0.28AB - 1.34A^2 - 0.48B^2 \quad (10)$$

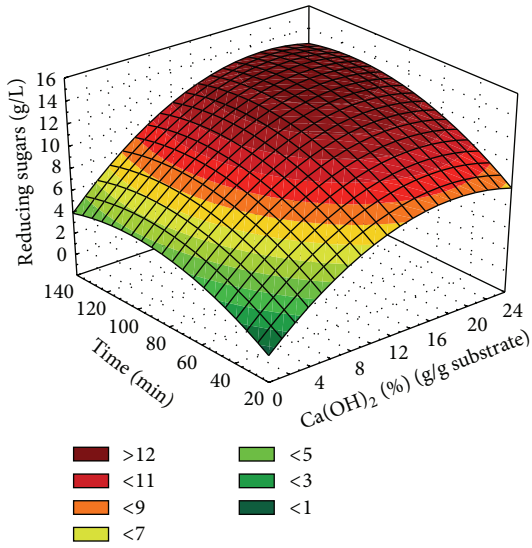

Figure 11: Total reducing sugars in liquor of $Ca(OH)_2$ treatment of HTSSB.

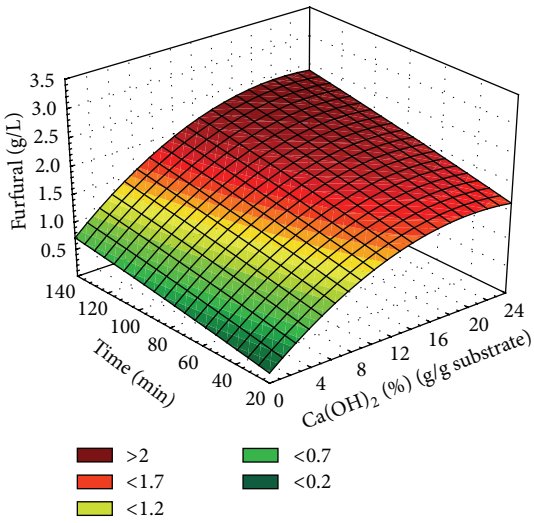

Figure 12: Furfural concentration in liquor of $Ca(OH)_2$ treatment of HTSSB.

$$\text{Reducing sugars (g/L)} = 11.79 + 3.29A + 1.84B + 0.23AB - 2.48A^2 - 1.26B^2 \quad (11)$$

$$\text{Furfural (g/L)} = 1.78 + 0.65A + 0.24B + 0.033AB - 0.38A^2 - 0.013B^2 \quad (12)$$

$$\text{HMF (g/L)} = 1.29 + 0.40A + 0.23B + 0.11AB - 0.070A^2 - 0.26B^2. \quad (13)$$

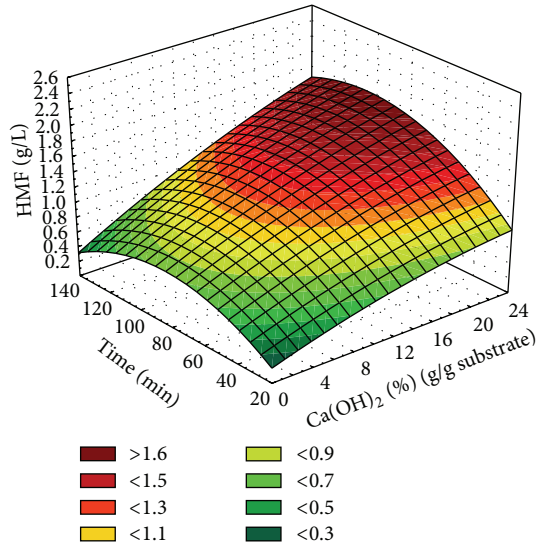

Figure 13: HMF concentration in liquor of $Ca(OH)_2$ treatment of HTSSB.

The A and B represent in (9)–(13) $Ca(OH)_2$ concentration in percentage (g/g substrate) and isothermal treatment residence time in min, respectively.

3.8. Optimization of the $Ca(OH)_2$ Treatment of HTSSB. The $Ca(OH)_2$ treatment was optimized for maxima of lignin extraction (70.35%, 31.66 g/L solubilised lignin), residual cellulose concentration (68.65%), solids recovery (71.2%), minima of concentration of sugars (12.85 g/L total carbohydrates, 6.46 g/L pentoses, and 12.62 g/L reducing sugars) and sugar degradation products (furfural 2.01 g/L, 1.38 g/L HMF) in the liquor using the JMP 10 software. The optimum conditions were predicted as a $Ca(OH)_2$ concentration of about 11.24% (g/g substrate) and an isothermal treatment residence time of 105 min. Under the optimum conditions the predictions for residual lignin, residual hemicellulose, and residual ash were 13.35%, 10.87% and 4.87%, respectively.

The optimization experiment was performed with $Ca(OH)_2$ loading of 10, 11, and 12% (g/g substrate) and 100, 105, and 110 min of isothermal treatment residence time. The optimum conditions giving maxima of lignin removal, solids recovery, and residual cellulose were found as 10% $Ca(OH)_2$ loading and 106.35 min of isothermal treatment residence time. Even though the lignin extraction increased with increase in $Ca(OH)_2$ loading and isothermal treatment residence time, the solids recovery decreased with increase in these factors. Therefore, the optimum condition was largely dependent on the solids recovery of the process. Optimum conditions resulted in 76.75 ± 0.15% solids recovery, 68.29 ± 0.31% residual cellulose, 13.26 ± 0.32% residual lignin, 69.67 ± 1.26% lignin extraction, 10.77 ± 0.15% residual hemicellulose, and 4.25 ± 0.39% residual ash in the solid residue. It also resulted in 31.14 ± 0.14 g/L solubilised lignin, 12.43 ± 0.14 g/L total carbohydrates, 12.12 ± 0.24 g/L total reducing sugars, 6.41 ± 0.38 g/L pentose sugars,

1.76 ± 0.06 g/L furfural, and 1.29 ± 0.04 g/L HMF in the liquor.

3.9. Prospect of the Two-Step Fractionation of Sweet Sorghum Bagasse for an on-Farm Fractionation Process. The two-step fractionation of sweet sorghum bagasse includes a first step to extract the hemicellulose and a subsequent step to extract the lignin from the substrate. The first step results in a hydrolysate rich in hemicellulosic sugars and the second step results in a residue rich in cellulose and a liquor containing lignin in it. The solid residue obtained after the $Ca(OH)_2$ treatment has about 270% higher bulk density and 51.7% higher cellulose concentration than the raw bagasse with bulk density of about 85 kg/m^3 containing only about 45% cellulose in it. The high bulk density and cellulose content will help the biomass producers to get higher price for it and the biorefineries can get these products that will help them to reduce their capital investment for the processing of biomass as well as provide them with the raw material irrespective of the regional and seasonal variations [22]. The process needs further developments to make it suitable for implementation in farm conditions.

4. Conclusion

The $Ca(OH\text{-})_2$ assisted treatment of the hydrothermally treated sweet sorghum bagasse at 394 K for 106 min of isothermal treatment results in about 69% of lignin extraction. The optimum $Ca(OH)_2$ loading is about 10% (g/g substrate) that resulted in a solid residue containing about 68% residual cellulose in it. The ash concentration of the residue was higher than the HTSSB and the effect of it on further processing of the residue needs to be studied. The process using $Ca(OH)_2$ is considered as safe and inexpensive for the treatment of lignocellulosics and therefore, it can be used for the on-farm fractionation of lignocellulosic materials. The solid product of the $Ca(OH)_2$ treatment contains higher amount of cellulose in it and it can be further value added at centralized biorefineries to biofuels and biomaterials. The liquid product of this process needs further treatment to isolate the dissolved lignin, $Ca(OH)_2$ and other components from it. The potential of the on-farm fractionation of lignocellulosic materials using hydrothermal and subsequent $Ca(OH)_2$ treatments needs to be studied in field conditions.

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

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