Investigation on Production of Bleachable Chemi-Mechanical Pulp from Wheat Straw

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Abstract

In an attempt to develop pulping process suitable for small scale implementation, production of bleachable chemi-mechanical pulp from wheat straw was investigated. Four levels (10, 12, 14 and 16% based on oven dry weight of straw) NaOH and one pulping time of 40 minutes at 95°C pulping temperature were used. After digester yield varied between 64.4 and 72.2% and the total yield after defibration was measured as 55.5% and 58.2%. Unrefined pulp freeness varied between 708 and 790 ml CSF. Pulps produced applying 10-16% NaOH, 40 minutes pulping time and 95°C pulping temperature was selected from further evaluation. These pulps were refined to about 365 ml CSF in a PFI mill and then hand sheets were made for strength evaluation. The apparent density of the hand sheets varied between 430-489 kg/m^3, tear index between 6.51-7.11 $mN.m^2/g$, and tensile index between 29.2 -30.8 N.m/g. Significant difference at 99% was not observed between the strength of the pulps. Then pulp produced applying 10% NaOH, 40 minutes pulping time and 95°C pulping temperature were selected for bleaching trials. Totally Chlorine Free (TCF) bleaching sequences was used for bleaching. Pulps bleached applying 4% H_2O_2 and 3.5% NaOH , 3% sodium Silicate, 0.5% MgSO4 and 0.3% DTPA for 2 hours showed the highest brightness of 50.69% compared to 29.2% for unbleached pulp.

Keywords: Wheat Straw, Chemi-Mechanical Pulp, Yield, Strength, Totally Chlorine Free Bleaching

Introduction

Paper was invented using non wood fibers and during the course of its development thru Asia and then Europe, non woods such as wheat straw were utilized. However, the abundant sources of wood in Europe and easy processing of this fiber supply replaced non woods. During late 20th century, global shortage of wood has emerged and paper industry was forced to look for alternatives sources of fibrous raw material. Countries and regions with limited paper production are also trying to develop domestic production capacities, relying on local but unconventional raw material. Two production trends; utilization of non-wood fiber supply and re-utilization of recycled paper have been followed.

Regions like Asia and also some countries in the Middle East concentrated on utilization of non woods as raw material. Therefore, it is believed that the non wood pulp production will take the momentum at the annual rate between 12-15%, even though it seems unrealistic (Pande 2009). In this expansion path, the share of undeveloped countries which are faced with wood fiber supply limitation will be more than fiber rich countries. Annual plant pulping found more and more importance especially in fiber deficient regions and since 1970, the non wood plant fiber pulping capacities increased two to three times as fast as wood pulping capacity on global basis (Hedjazi et al. 2009). It has been estimated that the pulp production from wheat straw in China will reach almost 13 million tons in 2020 (Zhao et al. 2010).

The general desire on non wood pulping initiated interest worldwide and various research groups started research, development, improvement and implementation of non wood pulping (Mackean and Jacobs 1997). Such research activities cover a wide range of pulping processes from conventional soda pulping of bagasse and cereal straw to non conventional fibers such as date palm residues (Kristova et al. 2005). Wheat straw has been the prime non wood fiber supply and different pulping processes have been studied (Ates et al. 2008, Hedjazi et al 2008). Wheat straw Alkaline Peroxide Mechanical Pulping was investigated to develop raw material efficient pulping method (Pan and Leary 2002) and enzyme and hot water treatment of wheat straw was studied to improve the brightness of the wheat straw pulp (Zhao et al 2004 and Mustajoki et at 2010).

For annual plant and wheat straw, mostly soda pulping has been applied. Soda pulping is well-established process with the potential to process vast variety of annual plant raw material, but this process has particular disadvantages such as low yield. Chemi-mechnical pulping has been developed to reach higher yield and more efficient use of raw material. However, the strength properties of this pulp are inferior to normal soda pulp. Therefore, we concentrated on the modification of the chemi-mechanical pulping process to preserve the yield and carbohydrate, providing suitable properties.

In this investigation, our attempts are focused on the development of simple pulping process for wheat straw suitable for small scale production and characterize the pulp properties to be utilized as supplementary pulp for corrugating fine grade paper.

Experimental

Material

Wheat straw in bales was collected from Agriculture and Natural Resources College Experimental Station, Islamic Azad University, Karadj Branch. Samples were cleaned and leaves and debris were separated and then the cleaned straw was chopped into 2-4 centimeter length pieces. The chopped straw was dried at ambient temperature and after reaching equilibrium moisture, it was stored in plastic bags until used.

Pulping

Experimental conditions for Chemi-Mechanical Pulping (CMP) of wheat straw were set as follow:

Four levels of active alkali (10, 12, 14, and 16%, based on NaOH), one pulping times (40 minutes after reaching the pulping temperature) were studied. Pulping temperature and liquor to straw ratio were constant at 95°C and 8/1 respectively. For each combination of variables, three replica pulps were prepared.

All cooks were performed in a 4 liter rotating digester "Ghomes Wood and Paper Equipment Manufacturing Co." using 100 g of wheat straw chips (dry basis). At the end of each cook, the content of cylinder was discharged on 200 mesh screen and the cooked material was washed using hot water and the remaining liquor was separated by hand pressing the cooked material. Cooked material was defibrated using 25 cm laboratory single disc refiner, and then the pulp was screened using a set of two screens, 14-mesh screen on top of 200 mesh screens. Material remained on 14 mesh screen was considered as rejected (shives) and the fibers passed 14 mesh screen and remained on 200 mesh screen was considered as accepted pulp (screened yield).

Bleaching

The selected CMP pulp from pulping trails were used for bleaching experiments applying Totally Chlorine Free (TCF) bleaching sequence. First the pulp consistency and pH were adjusted at 3% and 5 respectively and then these samples were chelated by 0.3% DTPA for 30 minutes at 70°C in polyethylene bags. At the end of chelating period, the pulp was thoroughly washed with de-ionized water and dewatered manually. TCF bleaching of chelated pulps was performed using a combination of one of the three levels (2, 3 an 4.5% based on the dry weight of the pulp) NaOH and one of the three levels (3, 3.5 and 4%, based on the dry weight of the pulp) H_2O_2. Other chemicals including sodium silicate and $MgSo_4$ were constant at 3% and 0.5% respectively. The pulp consistency, bleaching time and temperature was constant at 3%, 120 minutes and 70°C respectively. Bleaching experiments were conducted in polyethylene bags and hot water bath and during the bleaching periods, the sample was hand kneaded. At the end of each bleaching trail, pulp was thoroughly washed with tap water and the pH of the bleached pulp was adjusted at 3 using diluted sulfuric acid. Finally the pulp was dewatered and hand sheets were prepared for further testing.

Following Tappi test methods were used for pulp analysis: Beating; T248 om-88: Freeness; T227 om-04: Hand sheet preparation; T205 sp-06: Brightness; T452 om-08: Opacity; T425 om-06: Tear strength; T414 om-04: Tensile strength and breaking length; T494 om-92: Burst strength; T403 om-02.

Results

Pulping

Soda pulping has been applied on wheat straw to produce pulps suitable for further chlorine (CEH) bleaching of the pulp for writing and printing paper production. This pulping process requires the application of high temperature in the range of 175°C and consequently, the equipments are under pressure. The pulping yield will be very low and therefore the raw material efficiency is limited and only high capacity, capital intensive plants can be erected. Therefore, recently, alternative pulping of wheat straw has been investigated. The most recent available reports are on APMP of wheat straw (Pan and Leary 2002, Zhao et al 2004, Mustajoki et at 2010). In this study, we concentrated on the development of simple pulping to produce pulp on small scale suitable as supplementary pulp for fine paper production applying low temperature, but varying active alkali and pulping. To optimize the puling conditions for CMP pulping of wheat straw, in preliminary tests, we had to select different chemical charge and pulping times to reach appropriate pulping condition for suitable pulping yield. It was found that pulping time is not influential on the pulping yield, but the effect of active alkali charge was statistically significant $p<0.05$). Therefore, we measured the strength properties of pulps produced using different active alkali charge. The results of the measurements are summarized in Table 1.

Active Alkali (%)	Digester Yield (%)	Defibration Yield (%)	Initial Freeness (mL CSF)	Refined Freeness (mL CSF)	Apparent Density (kg/m^3)	Tensile Index (N.m/g)	Tear Index ($mN.m^2/g$)	Brightness (% ISO)
10	72.2	58	790	365	440	56.6	6.51	29.2
12	67.2	56.2	755	367	430	58	6.86	28.4
14	67.2	55.5	772	384	437	60.1	7.11	29.3
16	64.6	58.3	708	343	489	56.2	6.97	30.8

Table 1- Chemi-Mechanical Pulping of Wheat straw (pulping time; 40 minutes, pulping temperature: 95°C and liquor to straw ration:8/1)

The results indicated that the impact of active alkali at 40 minutes pulping time on the strength of the pulps was not significant, but its effect on pulping yield was statistically significant. Therefore, based on the analysis of pulping results and considering the pulping yield and pulp strength (Table 1), pulp produced applying pulping temperature of 95°C, pulping time of 40 minutes and active alkali of 10% was selected for TCF bleaching. The total yield after chemical treatment and defibration of this pulp was measured as 72.2% and 58% respectively. However, the actual defibration yield at continuous pulping operation is usually a few percent higher due to process water circulation and consequent fine saving.

Pulp Bleaching

The results of TCF bleaching trails on wheat straw CMP pulp are summarized in Table 2. Applying 4% hydrogen peroxide and 3.5% sodium hydroxide increased the pulp brightness from the initial value of 29.2% ISO to the final value of 50.69% ISO. Even though TCF bleaching of the wheat straw CMP pulp reduced the yellowness of the pulp, but the existence of the yellow pigments in this pulp do not permit the production of very bright pulps. TCF bleaching of this pulp did not exert any detrimental impact on the strength of the paper.

H_2O_2 (%)	NaOH (%)	Brightness (%ISO)	Opacity (%ISO)	Yellowness (%ISO)	Tensile Index (Nm.g)	Tear Index ($mN.m^2/g$)	Burst Index ($kPa.m^2/g$)
3	2	45.24	46.37	76.13	43.6	9.5	2.23
3	2.5	43.17	49.43	77.04	40.2	8.93	2.69
3	3	47.79	45.68	75.92	39.1	9.04	2.73
4	2	41.78	50.69	77.48	37.5	9.54	2.84
4	2.5	45.58	47.16	76.47	44.7	10.24	2.64
4	3	47.02	46.24	76	43.3	9.55	2.72

4	3.5	50.69	42.85	76.76	33.3	9.97	2.72
5	3	48.69	42.65	76.66	31.1	9.74	3.01
5	3.5	46.19	46.67	77.27	37.4	10.5	2.57
5	4	46.44	46.22	76.5	41.5	9.97	2.49
5	4.5	46.37	46.36	77.13	30.8	9.47	3.23

Table 2- The results of TCF bleaching of wheat straw CMP pulp (Temperature; 70 °C: Time 120 minutes: consistency;3%: sodium silicate;3% and MgSo4:0.5%)

Discussion

The objective of this study was to develop pulping process suitable for small scale production of semi-bleached pulp suitable for low cost fine paper production. The pulps produced applying different dosages of sodium hydroxide ratios and 40 minutes pulping time at 95°C showed promising properties. These pulps were selected for strength evaluation. Pulps were refined to about 360 ml CSF and hand sheets were made. Changing the sodium hydroxide dosage did not significantly influence both tear and tensile indices of the pulps.

Our results are compared with similar research results reported in the literature (Pan and Leary 2002, Zhao et al 2004, Mustajoki et at 2010).The information demonstrated the suitability of wheat straw CMP pulp for fine grade papers as writing and printing papers for mass production.

Even though the pulping yield as CMP pulp is lower than usual CMP, but for material such as wheat straw and the strength of the pulps, it deserves to scarify the yield for better strength of final product.

Conclusion

World paper industry under pressure from environmentalist is searching for alternative raw material for future fiber supply and the situation in fiber deficient countries especially Middle East is so severe that these countries can not develop national paper industry. Therefore, different research groups have been looking at alternative fiber resources including wheat straw, sunflower stalks, as well as corn stalks as investigated.

CMP pulps from wheat straw applying 10% NaOH, 95°C pulping temperature and 40 minutes time provides a good compromise between the yield and strength. This pulp was TCF bleached using 4% H_2O_2 and 3.5% NaOH to the final brightness of 50.69% ISO.

Tensile index, burst index and tear index of this pulp (72.2% total digester yield) were measured as 33.3 N.m/g, 2.72kPa.m^2/g and 9.97mN.m^2/g. Based on the finding of this study, CMP pulping of wheat straw with application of only 10% NaOH as the pulping chemical will open new way for utilization of this unused material, to fulfill the pulp fiber shortage in fiber deficient countries.

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