Journal of Cleaner Production 127 (2016) 562–566

Contents lists available at ScienceDirect

Journal of Cleaner Production

journal homepage: www.elsevier.com/locate/jclepro

Note from the field

Sunflower stalk neutral sulfite semi-chemical pulp: an alternative fiber source for production of fluting paper

Hamidreza Rudi [a,*], Hossein Resalati [b], Rabi Behrooz Eshkiki [c], Hossein Kermanian [a]

[a] Department of Cellulose and Paper Technology, Faculty of New Technologies and Energy Engineering, Shahid Beheshti University, Zirab, Mazandaran, Iran
[b] Department of Wood and Paper Science and Technology, Faculty of Natural Resources, Sari University of Agricultural Sciences and Natural Resources, Iran
[c] Department of Wood and Paper Science and Industry, Faculty of Natural Resources and Marine Sciences, Tarbiat Modares University, Iran

ARTICLE INFO

Article history:
Received 12 October 2015
Received in revised form
2 April 2016
Accepted 12 April 2016
Available online 20 April 2016

Keywords:
Corrugated medium test
Fluting paper
Neutral sulfite semi-chemical
Ring crush test
Sunflower stalk

ABSTRACT

Sunflower stalk was evaluated as a potential fiber source to make fluting paper using neutral sulfite semi-chemical pulping process, in comparison with Mazandaran wood and paper industry mill made hardwood-based neutral sulfite semi-chemical (NSSC) pulp. Sunflower stalk consists of two distinct fractions including inner bulky pith and outer woody wall. The stalk has to be de-pithed for the purpose of papermaking because of lower cellulose, and higher ash content in pith-containing stalk. The results of pulping showed that the rate of delignification in NSSC cooking of de-pithed sunflower stalk with 20% lignin was surprisingly very low, despite of being a non-wood fiber source. However, sunflower stalk NSSC pulp showed very good response to refining and produced denser sheet due to lower digester yield and higher fiber flexibility coefficient, in comparison with Mazandaran wood and paper industry pulp sample. In addition, sunflower stalk pulp has been demonstrated to be an appropriate fiber source for making fluting paper at higher or comparable tensile-loaded strength properties such as tensile and burst, and higher compression-loaded strength properties including corrugated medium test and ring crush test.

1. Introduction

Non-wood fibers have begun to receive considerable attention in forest industry in recent years to alleviate the shortage in woody raw materials. The use of agro-fiber wastes in paper production is beneficial in terms of environmental and socio-economic aspects (Akgul and Tozluoglu, 2009; Rodriguez et al., 2010). Therefore, several studies examined the viability of substituting wood-based materials with crops residues to produce pulp and paper (Samariha and Khakifiroz, 2011; Matin et al., 2015; Sharma et al., 2015).

The main fibrous resources available for pulp and papermaking in Iran are hardwoods, recycled papers and non-wood fibers (Sarkhosh and Talaiepour, 2009). However, the current available fiber supply is not coping with the ever-increasing demand for local paper mills including Mazandaran wood and paper industries (MWPI), the largest Iranian paper manufacturer. Therefore, it may be expected to solve the fiber shortage anticipated to arise in the future by utilization of non-wood fibers. In fact, some researches carried out with rather favorable results, suggested that sunflower stalk can be an appropriate alternative to make pulp and paper (Eroglu et al., 1992; Khristova et al., 1998; Lopez et al., 2005).

Sunflower plant (*Helianthus annus*) grows in the central and northern regions of Iran in approximately 28,000 ha, produces about 1.255 tons oil seeds per hectare (Anonymous, 2005). The stalks of this annual crop consist of two parts, including an inner non-cellulosic pith and an outer woody ring of lingocellulosic fibers. Taking into account the stalk/seed weight ratio of about 2.3 (Lopez et al., 2005), the wall/pith ratio of about 9:1 and wooden wall density of 0.44 g/cm^3 (both determined in this study), large amounts of residual stalks are available annually which could be used to obtain paper pulp rather than being burnt as often occurs nowadays.

In this work, we characterized sunflower stalk in terms of its contents in cellulose, lignin, 1% NaOH solubles, alcohol-acetone extractables and ash. Also, we have measured the dimensions of fibers taken from different sections of stalk including node and inter-node sections at base, middle and top parts of the stalk. Then,

* Corresponding author. Shahid Beheshti University, Zirab, Savad Kuh, Mazandaran, P.O. Box 47815-168, Iran. Tel.: +98 1142451092; fax: +98 1142455003.
E-mail address: h_rudi@sbu.ac.ir (H. Rudi).

http://dx.doi.org/10.1016/j.jclepro.2016.04.049
0959-6526/

we evaluated handsheets properties (density, air permeability, tensile index, burst index, corrugated medium test (CMT), and ring crush test (RCT)) of making NSSC pulp from sunflower stalk and compared it with the mixed hardwood NSSC pulp in MWPI to produce fluting paper.

2. Experimental

2.1. Raw material

Samples of sunflower stalk (SS) were collected from Northern farms of Iran. The stalks was about 5 months old, with 99.64 cm height, 13.92 mm diameter, 1.12–5.07 mm wall thickness, 0.40–0.48 g/cm^3 density, and about 11.94 pith percent, were delivered to the Research and Development (R&D) lab in MWPI mill, de-pithed by hand, and then chopped into 3–5 cm length pieces.

2.2. Fiber dimensions measurement and chemical characterization

Samples were taken from node and inter-node sections of the base, middle and top of the stalk. The samples were prepared according to the method of Franklin (1954) and the fiber dimensions were measured using IMT-2 Olympus microscope. In addition, slenderness ratio, flexibility coefficient and Runkel ratio were calculated (Saikia et al., 1997), to assess the suitability of sunflower stalk fibers for paper production. For chemical characterization, different samples were milled to produce sunflower stalk meal to pass through a 40 mesh screen and retain on a 80 mesh one, using a vibrating screen, Haver EML 200 digital T. Chemical composition were determined as follows: cellulose (Rowell and Young, 1997), 1% NaOH solubility (T212), lignin (T222), ash (T211), and extractives (T204).

2.3. NSSC pulping and refining

NSSC pulping was done using a 10-L rotating and cut-off electrically heated digester (HATTO). NSSC white liquor was made from sodium sulfite (Na_2SO_3), and sodium carbonate (Na_2CO_3). The cooked sunflower stalk was defibrated by 30 cm local made disc refiner and was fully washed on 200 mesh screen by tap water. NSSC pulp samples were analyzed using corresponding TAPPI standard methods: Shive content (T274 sp-97), freeness (T227), pulp yield (T257), and kappa number (T236). NSSC pulp from sunflower stalk at initial freeness of 615 mL (CSF) was refined by Labtech PFI Mill to 328 and 372 mL (CSF) target freenesses (T248-cm-85) and to achieve a shive content less than 2.5%, equal to refined NSSC shive content in MWPI mill. NSSC pulp from MWPI was refined to get a freeness of 414 mL (CSF). Fiber classification of both sunflower and MWPI NSSC pulp were done using Messmer Buechel fiber classifier (TAPPI 233-cm-82).

2.4. Sheet making

Handsheets with 127 g/m^2 basis weight were made by laboratory Labtech Handsheet Maker (TAPPI 205), and were then conditioned (SCAN-P2:75). Handsheets analysis was done as follows: density (TAPPI 426), air permeability (TAPPI 547), tensile index (TAPPI 404), burst index (TAPPI 403), CMT (TAPPI 809), and RCT (TAPPI 818). Statistical differences between all properties were evaluated using an analysis of variance test (ANOVA), at a 95% probability level.

3. Results and discussion

3.1. Fiber dimensions

The fiber dimensions of samples taken from different parts of sunflower stalk were shown in Table 1. Statistical analysis of the results indicated that among all fiber dimensions, only the fiber length in top of the stalk was significantly higher than that of other sections of the stalk. The average of fiber length of sunflower stalk measured in this study, 0.96 ± 0.30 mm, were longer than cotton stalk fibers, 0.83 mm (Ververis et al., 2004), and shorter than bagasse fibers, 1.59 mm (Samariha and Khakifiroz, 2011), rice straw, 1.29 (Rodriguez et al., 2010). In addition, there were no statistically significant differences in fiber dimensions between node and internode sections.

Some derived values from fiber dimension data were presented in Table 2. From ANOVA analysis, it is clear that both Runkel and slenderness ratios in fibers of top of the stalk were higher than that of measured for fibers in middle and base of the stalk, while flexibility coefficient of fibers in top of the stalk was lower than that of derived from middle and base of the stalk. Average Runkel ratio for sunflower fibers (0.49) was higher than that of aspen fibers (0.23) (Law and Jiang, 2001), but lower than that of bagasse fibers (1.16) (Samariha and Khakifiroz, 2011). Average slenderness ratio of sunflower fibers (45.55), was higher than that of cotton stalk (42.35) (Ververis et al., 2004), but lower than that of aspen (46.15) (Law and Jiang, 2001), and bagasse fibers (75.85) (Samariha and Khakifiroz, 2011). Since, the acceptable value for slenderness ratio is believed to be more than 33 (Xu et al., 2006) and according to a ranking system (Bektas et al., 1999), the fibers of sunflower stalk can be included in the group of elastic fibers, having an average flexibility coefficient of 50.49, which is higher than that of bagasse fibers (46.37) (Samariha and Khakifiroz, 2011), but lower than cotton fibers (65.31) (Ververis et al., 2004).

3.2. Chemical characterization

The chemical characterization of whole stalk versus de-pithed stalk was shown in Fig. 1. According to ANOVA for results of chemical composition, there were only meaningful differences between cellulose and ash content in whole and de-pithed stalk. Different letters refer to the statistical differences between ingredient content. The differences indicated that the stalk with pith fraction, in comparison with de-pithed stalk, contained significantly lower cellulose, and higher ash. Cellulose content of de-pithed stalk was significantly higher than that of pith-containing whole stalk (47.37% vs. 39.93%). De-pithed sunflower stalk has higher cellulose than that of rice straw (41.20%) (Rodriguez et al., 2008), and lower than bagasse fibers (52.42%) (Rezayati-Charani and Mohammadi-Rovshandeh, 2005).

3.3. NSSC pulping

Pulping of de-pithed stalks was conducted at different level of chemical charges using NSSC process. The results of digester yield and kappa number was shown in Fig. 2. It was surprising to find that NSSC delignification rate of sunflower stalk, as a non-wood fiber source, was too low as was indicated by high kappa number after 180 min cooking time even at high chemical charge and cooking temperature of 170 °C, pulp yield of 43.8% at kappa number of 82.5. This finding was in agreement with the work reported by Lopez et al., 2005. In addition, the pulping selectivity was also too low as was indicated by high yield loss at almost similar kappa number by extending the pulping reactions.