WOOD RESEARCH
61 (6): 2016
927-936

THE UTILIZATION OF TOMATO STALK IN FIBER PRODUCTION: NAOH AND CAO PULPING PROCESS

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(Received January 2016)

ABSTRACT

This study was conducted to explore the utilization of tomato stalk in the paper industry. Fiber morphology of the material was determined according to standard test methods and average fiber length was found to be 980 μm and the width of the fiber was 15 μm. As a result, slenderness ratio was resolved to be around 60. This was considered to be comparable fiber with the most of the hardwood species. Tomato stalks were cooked with soda and lime in a separate process. Screened pulp yield was determined to be 35-45 %. Soda pulp of tomato stalks showed good mechanical properties when temperature raised to 135°C and low alkali concentration (10 %) and lime pulps showed properties as well as that soda pulp at 135°C and high alkalinity ratio (30 %).

KEYWORDS: Slenderness ratio, fiber, pulping, lime, soda, mechanical properties.

INTRODUCTION

The increased demand and cost of wood and descending supply induce fiber utilized industry to search for alternative sources. As a result, forest products industries are working to solve shortage and cheap sources using the annual plant residues, which features all kinds of fibrous materials such as vegetables, fruits and bark residues, agricultural residues and waste paper. There are 1000 kinds of fiber plants in the world that can be utilized in the fiber production (Rowell et al. 1997). Even though many of these plants economically are not feasible, their fibers are still used to meet local requirements.

Agricultural wastes cannot be adequately harnessed. In rural areas, these wastes were used in heating, collected near the fields, near sea edges, creek beds to form piles and abandoned to rot or used in landfills. Abandoning these wastes leads to environmental pollution (Fig. 1). In order to prevent this, the remnants of agricultural product were intended to be used as an inputs in the paper industry. Many researchers have demonstrated that these agricultural residues can be utilized in pulp and paper production (Rowell et al. 1997; Jarabo et al. 2012; Requejo et al. 2012; Gonzalez-Garcia et al. 2010; Harris et al. 2008; Rodriguez et al. 2008; Antunes et al. 2000; Marrakchia et al. 2011; Cordeiro et al. 2004; Khiari et al. 2010; Mousavi et al. 2013; Pahkala and Pihala 2000; Jimenez et al. 2006; Ververis et al. 2004; Law et al. 2001). Fiber morphology is an important character to utilize in pulp and paper industry. There could be certain fiber length to provide interfiber bonding (Law et al. 2001, Smook 1992). As a result, mechanical properties of paper could be obtained enough to provide certain properties. Fiber dimension and derived values can affect the characteristic of paper.

Tobacco stalk cooked with soda and some modified soda methods to obtain a pulp (Ateş et al. 2010). Total pulp yield was obtained 48 % and kappa number was 53. These pulp viscosity was 437 cP, paper breaking length was 2.5 km and tear strength was 2.44 $mN.m^2.g^{-1}$. These properties were enough to compare with other lignocellulosic materials. In other research, sorghum and canola stalk were utilized to prepare pulp and paper (Sahin 2012; Erdönmez 2010). Paper prepared from sorghum provided breaking length of 2.08-2.13 km and brightness was 33-36 % ISO brightness. In addition to that, utilization of organosolve pulping process and antraquinone in pulping of nonwood material improved physical and optical properties of the paper (Akgül and Tozluoğlu 2009).

Fig. 1: Tomato plants in greenhouse and stalks collected and stored on a side after production.

Tomato is the most widely grown and consumed vegetable in different countries of the world and it adapts easily to different ecology. In 2011, tomato production was 159 million tons in the World and 11 million ton in Turkey (FAO 2012). As a result of that, large amount of waste is generated from the agricultural land and they become important. Around 100000 tons of dry matter arises from the greenhouse every year only from South West part of Turkey. These can be utilized in fiber production after pulping. In general, alkali pulping process is utilized to produce fiber from nonwood materials. It has the advantages of recycling chemicals and better cooking conditions. In contrast, silica in plants causes to differentiate chemical recovery. Lime process is old, but provides a uniform cooking and fairly inexpensive method. Therefore, the objective of this research was to determine the cooking condition of tomato residue with lime. Raw material and paper were characterized by standard test methods to utilize in paper production. It helps to control waste in addition to providing raw materials for the paper industry.

MATERIAL AND METHODS

Material

Tomato stalks were obtained from southwest part of Turkey. It was allowed to dry constant moisture content in room conditions. Once dried, the stalks were ground in a mill to obtain the 4–6 cm size fraction. Samples were collected to determine ash (TAPPI 211), cold-water solubility (TAPPI 207 om-88), hot-water solubility (TAPPI 207 om-88), soda 1 % solubility (TAPPI 212), ethanol–benzene extracts (TAPPI 204), holocellulose (Yokoyama et al. 2002), α-cellulose (TAPPI 203 cm-99), and lignin (TAPPI 222 om-98) content. Fiber analysis were carried out according to Spearin and Isenberg (Spearin and Isenberg 1947) methods. Materials were macerated with acetic acid and sodium chlorite. After maceration, materials agitated to obtain the individual fiber. Dehydrated with ethyl alcohol and stored in glycerin to measure fiber properties. The fiber length, fiber width, lumen width of 50 randomly selected fibers were measured with optical microscope.

Methods

Pulping

The raw material was cooked in 10L batch reactor that was heated with oil. Each cooking was performed with 500 OD g of chips. The cooking conditions were given in Tab. 1. After each cook, the mixture was cooled with water and rinsed for about an hour to remove alkali. The chips were then disintegrated with hammer mill. After washing pulp stored in air tight polyethylene bags.

Tab. 1: Pulping conditions of tomato stalks.

Cooking	NaOH (%)	Cooking period (hr)	Max. temperature (°C)	Liquor/Chip
1	10	5	75	5/1
2	15	5	75	5/1
3	20	5	75	5/1
4	10	5	105	5/1
5	15	5	105	5/1
6	20	5	105	5/1
7	10	5	135	5/1
8	15	5	135	5/1
9	20	5	135	5/1
Cooking	**CaO (%)**	**Cooking period (hr)**	**Max. temperature (°C)**	**Liquor/Chip**
1	10	5	75	5/1
2	20	5	75	5/1

3	30	5	75	5/1
4	10	5	105	5/1
5	20	5	105	5/1
6	30	5	105	5/1
7	10	5	135	5/1
8	20	5	135	5/1
9	30	5	135	5/1

Pulpand paper property testing

Kappa numbers were performed according to Tappi standard T 236 cm-85. Viscosity of pulp was determined with Cannon ubbelohde viscometer according to Tappi standard T 230 om-94 (capillary viscometer method). Physical testing was carried out according to Tappi standard given below. Handsheets were prepared from 2 % consistency of pulp, Physical testing of pulp handsheets T 220 sp-96, Tensile strength T 494 om-88, Burst strength T 403 om-91, Tear strength T 414 om-88, Brightness T 452 om-92.

RESULTS AND DISCUSSION

Chemical composition of tomato stalks

Chemical composition of tomato stalks was given in Tab. 2.

Tab. 2: Chemical composition of tomato stalks and various lignocellulosic materials.

Annual Plants and Wood	Chemical content				Solubility				Source
	Holocellulose (%)	Alpha cellulose (%)	Lignin (%)	Ash (%)	Alcohol-benzene (%)	NaOH 1 % (%)	Hot Water (%)	Cold Water (%)	
Tomato stalk	72.14	42.07	17.05	13.67	10.05	50.36	20.9	15.77	Determined (Tomato stalks)
Pepper Stalk	78.70	-	27.80	5.80	2.49	29.40	9.22	8.87	Çöpür et al. 2012
Eggplant stalk	66.40	-	29.70	7.24	10.50	43.80	17.90	22.10	Çöpür et al. 2012
Straw	77.60	40.20	17.29	7.09	5.46	42.06	12.95	8.97	Çiçekler 2012
Wheat	77.10	39.62	18.33	7.12	5.48	40.90	12.25	7.65	Tutuş and Eroğlu 2003
Cotton stalk	72.20	41.60	19.30	2.40	6.10	42.90	17.80	16.70	Akgül and Tozluoğlu 2009
Corn Stalk	64.80	35.60	17.40	7.50	9.50	47.10	14.80	-	Eroğlu et al. 1992
Tobacco stalk	64.30	-	15.20	14.40	8.10	50.60	21.60	17.20	Ateş et al. 2010
Urtica	66.51	29.10	13.03	10.70	9.16	50.20	22.30	23.87	Akgül et al. 2012
Kenaf	81.20	37.40	14.50	4.10	5.00	34.90	12.80	11.70	Doğan 1994
Softwood	63-74	-	25-32	0.2-0.5	1-5.8	8-10	1-5	0.5-4	Kırcı 2006
Hardwood	72-82	-	18-26	0.2-0.7	1-6.2	12-25	1-8	0.2-4	Kırcı 2006

Extraneous material such as coloring, inorganic materials, sugars, gums are usually purgeable with cold and hot water (T 207 om-93). Hot water solubility also determines starches in addition to previous substances. These materials react with pulping chemicals to consume some of them. Tomato residue contains some extraneous materials to consume and reduce the effect of chemical reagent. 1 % NaOH solubility is the determination of extracts and low molecular weight carbohydrates. The highest percentage of these materials were also an indication of medium to low yield pulp. It causes to yield loss. Alkali solubility of tomato stalks was high compare to other fiber sources (Tab. 2). Low molecular weigth carbohydrates and some of the link between carbohydrates and lignin were broken and small molecules dissolved in cooking liqour. As a result of that, porosity in the cell wall increases. Extractives removable with alcohol, benzene are wax, fatty resins. These contents can cause foam formation and saponification during the pulping process. It can also stick to the paper surface to cause discoloration and breaking problems. Ash content was considerably high (13.67 %) in tomato stalks (Tab. 2). These materials can damage refiner blade and also give rise to problems during chemical recovery of the cooking liquor (Tutuş and Eroğlu 2003). Pulp yield is negatively correlated with extractive and ash contents. The α-cellulose content of pulp contributes to mechanical properties. Tomato stalks contain average α-cellulose content of 42.07 %. The lignin content (17.05 %) of tomato stalks was similar to some hardwood species. Apparent density of the materials was around 0.117-0.125 $g.cm^{-3}$. This density is lower than woody plants. However, it could be appropriate substrates for fiber production (Çöpür et al. 2012). Woody tissue on tomato stalks contain secondary xylem (URL 1). This secondary xylem is composed of fiber, trachery elements and parenchyma cells. Parenchyma cells stores nutrients and fiber supports stem and provides mechanical properties. Chemical treatments decompose, removes some of the content from the materials opens up space and reduce yield.

Fiber dimension and morphological indices of the tomato stalk were given in Tab. 3. Tomato stalks have an average fiber length of 980 μm. This fiber length was similar to most of the hardwood species. It falls in between 500 and 3000 μm (Fengel and Wegener 1984). High slenderness ratio implies higher tear strength. Most of the hardwood species fall in between 55 and 75 (Smook 1992). In the past, fiber length was believed to be the important factors that affect the properties of paper, however, studies showed that fiber length to width ratio of the fibers have revealed more effective than only fiber length (Panshin and de Zeeuw 1970).

Tab. 3: Fiber properties.

Pulping process	Fiber Properties	Mean	Std deviation	Slenderness ratio
Raw materials	Fiber length (mm)	0.98	0.15	64.26
	Fiber width (μm)	15.25	2.01	
Soda (NaOH) process	Fiber length (mm)	0.85	0.16	53.04
	Fiber width (μm)	16.07	2.43	
Lime (CaO) process	Fiber length (mm)	0.89	0.14	60.25
	Fiber width (μm)	14.74	3.37	

Pulping

Tomato stalks were cooked with NaOH solution at various concentrations and temperature with the 5/1 liquor/stalk ratio for 5 h. The pulp screened yield was given in Fig. 2. As can be seen the lowest screen yield (43.6 %) was obtained with the highest temperature (135°C) and the alkali concentration in soda cooking. The cooking condition was severe compare to low temperature and alkali concentration. Extractive and pectic substance can easily removed with the solvent. The part of hemicelluloses probably dissolved and removed with the alkali solution. In addition to that, alkali hydrolysis can take place and removes part of the cellulose. Therefore, alkali degrades the some of the carbohydrates and dissolves and reduces the yields. Compare to NaOH, CaO gives less screened yield (Fig. 3). Under this condition, reactions was not severe enough and CaO can not penetrate in the pulp to react to content due to viscosity. NaOH dissolves in water and form clear solvent, in contrast, CaO forms $Ca(OH)_2$ and viscose solvent.

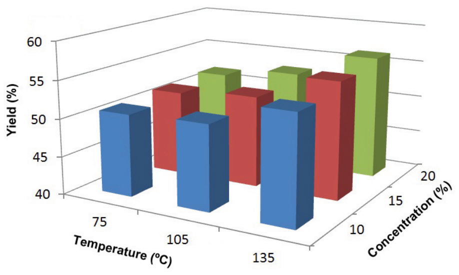

Fig. 2: Tomato stalks screened pulp yield at various temperature and alkali (NaOH) concentration.

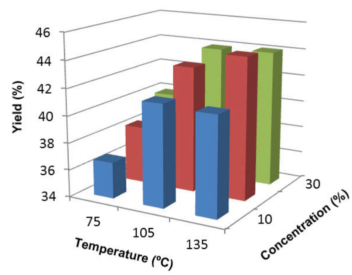

Fig. 3: Tomato stalks screened pulp yield at various temperature and alkali (CaO) concentration.

Kappa number is the reflection of lignin in the pulp. NaOH removes a considerable amount of lignin from the pulp and also causes some damage to cellulose through peeling reaction. Yield becomes low under this condition. However, under these conditions effectiveness of the lime is low and the most of the lignin remains in the pulp. If lime cooking needs to be compared with the other pulping process, it could be similar to the chemimechanical pulping process. During lime cooking process, cellulose under less severe condition and viscosity was higher than the NaOH cooking process (Tab. 4).

Tab. 4: Kappa number and viscosity for each cooking process.

Cooking tempe rature (°C)	NaOH (%)	Kappa No.	Viscosity (mPa*s (cP))	Total yield (%)	Screened yield (%)	Rejects (%)	CaO (%)	Kappa No.	Viscosity (mPa*s (cP))	Total Yield %	Screened Yield %	Rejects %
75	10	81.32	42.19	56.00	49.16	6.84	10	92.16	46.70	44.92	36.67	8.25
75	15	74.25	40.38	54.71	48.73	5.98	20	89.75	45.22	46.08	38.24	7.84
75	20	70.10	37.74	53.40	48.36	5.04	30	86.33	43.84	47.09	39.90	7.19
105	10	74.65	41.42	53.92	48.83	5.09	10	89.54	45.71	49.31	41.54	7.77
105	15	61.46	39.61	52.76	47.93	4.83	20	76.80	44.01	50.42	43.27	7.15
105	20	59.96	38.35	50.94	47.03	3.91	30	73.85	43.07	50.46	43.90	6.56
135	10	62.57	37.19	50.61	45.83	4.78	10	73.45	42.96	47.89	41.34	6.55
135	15	57.99	36.59	47.21	44.56	2.65	20	69.70	41.84	49.45	44,47	4.98
135	20	51.31	34.67	45.67	43.66	2.01	30	61.46	42.14	49.50	44,04	5.46

Paper properties

In order to examine paper properties made from tomato stalks, standard paper handsheets were prepared from both pulps. The mechanical properties of hand sheet paper were given in Tabs. 5 and 6. The results showed that paper obtained from soda cooking has a tensile index of 10 to 76 and 35 to 73 $N.m.g^{-1}$ after lime cooking. In general, most paper and paperboard has a tensile index between 10 and 100 $N.m.g^{-1}$ (Olf 1997). Therefore, tomato stalks provides a nominal tensile index after lime cooking. The highest tensile index in soda cooking was obtained with 10 % alkali concentration and 135°C. Same properties were obtained when high concentration of

CaO and temperature were utilized. It probably provides better pulping conditions. Slenderness ratio was close to raw materials when it is cooked with lime. Its tear index better in lime cooking. The high slenderness ratio gives better tear index. The slight decline in the tear index is possibly due to fibre-fibre bonding. Tear strength decreases when beating exceeds a certain point. In this case the hammer mill was utilized to fiberized the cooked materials. This was due to fiber cutting and decreased fiber strength that gives a similar effect of excessive beating (Tabs. 5 and 6).

Tab. 5: Handsheet obtained from the NaOH cooked tomato stalk.

Alkali Concentration (%)	Cooking temperature (°C)	Tensile index ($Nm \cdot g^{-1}$)	Tear index ($mNm^2 \cdot g^{-1}$)	Burst index ($kPam^2 \cdot g^{-1}$)	Optical brightness (ISO)
10	75	10.83	1.64	0.67	39.61
20	75	10.92	1.56	0.69	38.68
30	75	14.42	1.47	0.75	34.99
10	105	28.16	2.91	1.49	34.93
20	105	39.70	2.77	1.53	36.91
30	105	38.17	2.08	1.58	34.91
10	135	76.70	5.19	1.56	31.06
20	135	35.82	2.77	1.65	26.37
30	135	11.97	1.73	1.70	22.39

Tab. 6: Handsheet obtained from the CaO cooked tomato stalk.

Alkali Concentration (%)	Cooking temperature (°C)	Tensile index($Nm \cdot g^{-1}$)	Tear index ($mNm^2 \cdot g^{-1}$)	Burst index ($kPa.m^2 \cdot g^{-1}$)	Optical brightness (ISO)
10	75	30.66	2.08	1.16	36.54
20	75	40.63	2.34	1.58	40.32
30	75	45.71	2.60	2.14	40.74
10	105	48.29	2.68	2.18	36.11
20	105	49.99	2.77	2.18	34.38
30	105	50.68	2.94	2.27	33.13
10	135	49.35	2.86	2.24	35.96
20	135	51.95	2.94	2.28	35.49
30	135	73.38	3.29	2.71	35.48

In general paper properties of most paper and paperboard has the tear index of 1 to 20 $mNm^2 \cdot g^{-1}$ and burst index of 0.5 to 5 $kPa \cdot m^2 \cdot g^{-1}$. Therefore tomato stalks provide these numbers eventhough it provides lower strength values. Optical brignthness increase with the alkali concentration and temperature in soda cooking. However, brightness were not changed much in CaO cooking.

CONCLUSIONS

The paper industry is in a downturn due to lack of raw material and environmental concern in some countries. Agricultural residues can be utilized in pulp production where native wood species are limited or insufficient. It appears to be tomato stalks is suitable for the fiber production. Chemical analysis of tomato stalks showed similar values with the other annual plants and agricultural residues. Soda and CaO was utilized to cook. The lowest screened yield (43.66 %) was obtained with the high temperature and alkali concentration in soda cooking. In addition to that, optical and mechanical properties werealso low in this condition. The better mechanical properties and optical brightness (31.06) were obtained from the highest cooking temperature (135ºC) and low alkali concentration (10 %).

The highest screened yield was obtained from high temperature and alkali concentration. Fibers comformability is not suitable and mechanical properties were also low under this condition in lime cooking. However, the highest mechanical properties and brightness were obtained when high temperature and lime concentration were utilized. Therefore, CaO can be utilized to cook tomato stalk on the site where local stalks enough to support insufficient wooden materials. It also contributes environmental concern to control waste material.

ACKNOWLEDGMENT

The authors would like to acknowledge SDU Scientific Research Project Management Office (Project No SDUBAP 3927-YL1-14) for their support.

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