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# Wheat Straw Pulping for Paper and Paperboard Production

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Additional information is available at the end of the chapter

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## Abstract

This chapter covers relative topics on wheat straw applied as fibrous raw materials for pulping and papermaking industry, i.e., chemical components and anatomy of wheat straw, pulping process and pulping properties, paper and paperboard products from wheat straw pulps, as well as environmental protection issues. Wheat straw is a kind of annual vascular-bundled herbal arthroplyte containing cellulose fibers that are acceptable for pulping and papermaking. The chemical components and anatomy of wheat straw were discussed; practically, soda or soda-AQ chemical pulping processes are common techniques often applied for chemical pulping from wheat straw, conventional and advanced bleaching sequences were introduced, and especially ECF and TCF bleaching techniques have been successfully applied in China's paper mills. Cooking and black liquor extraction equipment and facilities are explained; chemi-mechanical pulping properties of wheat straw, corrugated medium, and linerboard products from wheat straw CMP pulps are evaluated; and chemical recovery from chemical cooking black liquor and effluent treatment processes are discussed. In this chapter, not only laboratory research results but also some commercial operation experiences are shared. These information and knowledge described in this chapter will help readers to have a good understanding about wheat straw pulping and papermaking; they are useful for pulping and papermaking engineer as reference for design and operation management of wheat straw pulping lines.

**Keywords:** wheat straw, chemical components, fiber anatomy, chemical pulping, chemi-mechanical pulping, writing and printing paper, linerboard, corrugated medium, effluent characteristics

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## 1. Preface

Wheat cultivation area is the world's largest agricultural lands, wheat being the most prolific and most widely distributed food crops. At present, the global sum of wheat plant area is of more than 2.2 million ha, with the annual wheat grain output of 730 million tons, accounting for one-third of the world's total food production [1]. Wheat straw is a good fiber material, produced annually in huge quantities worldwide in a much shorter growing cycle than wood. The utilization of no-woody fiber materials to produce cellulosic pulps is the most economically justified solution fitting with the EU's environmental directives, which aim to reduce the consumption of wood fiber in paper and board products and replace it with other plant biomasses [2]. From the production point of view, the world's largest wheat production country is China, followed by India, the United States, and Russia, and these four countries produce 45% of the total world wheat production. Therefore, there are more than 650 million tons of wheat straws available annually [3, 4]. How to utilize these lignocellulosic biomass resources efficiently has been becoming a very urgent issue worldwide [3]. Practically, some countries start to produce electricity by using biomass fuel boilers, and some parts of the world feed straws back to agricultural land by cutting, but most of those resources have not been properly utilized. There are some countries making paper and paperboard products from wheat straw, such as China, Spain, and so on.

The term "pulping," in technical processes or methods for production of fibers from cellulosic raw materials, might be classified mainly as chemical pulping, chemi-mechanical pulping, and mechanical pulping processes. The principle of pulping is to separate cellular fibers from plant tissues by chemical cooking to remove lignin or mechanical separation combined with chemical softening, etc.

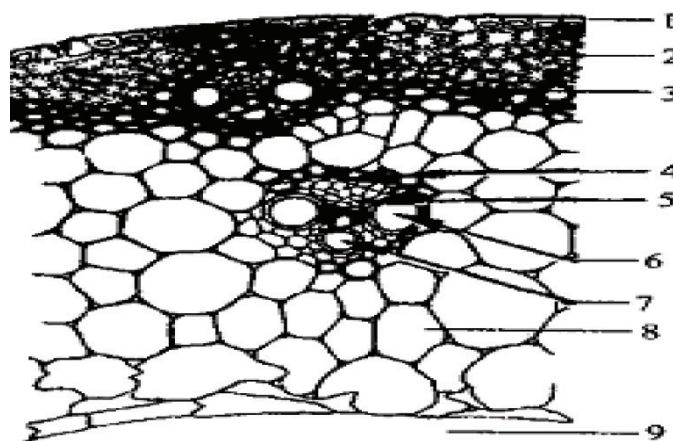
## 2. Fiber anatomic structure, chemical composition and pulping properties of wheat straw

Wheat is a kind of annual vascular-bundled herbal arthrophyte (**Figures 1 and 2**) [5], containing spike head, straw stalk (nodes and internodes), and root parts. Countering its mass percentage of each part, there are proximate ranges of internodes (68% w/w), leaves-sheaths (20% w/w), leaves-blades (6% w/w), nodes and fines (4% w/w), and grain and debris (2% w/w). Practically, only internode parts are acceptable for pulping [6]. The physical and optical properties of the stubble pulp were better than those of whole wheat straw pulp [7]. Therefore, at a commercial pulping process line, about 25–30% w/w loss of biomass, unsuitable parts for pulping, should be separated during wheat straw chip preparation (**Figure 3**), for purposes of chemical saving and pulp quality improvement as well as silica content decrements of black liquor from cooking [6, 8].

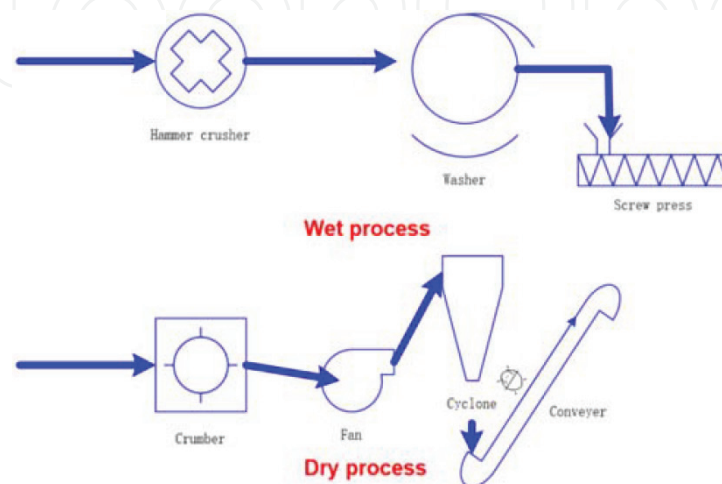
Papermaking is the process to form a fiber mat by a mesh net from fiber suspension stock through draining water. Fibers are the key element of pulp furnishes for papermaking. With contrast to wood fibers, wheat straw fibers are characterized as shorter in average fiber length and narrow in width, and there are more non-fiber cell contents. After proper pulping, cleaning, and screening, pulps from wheat straw can be used for manufacturing various paper product grades, such as linerboard, corrugated medium, writing and printing papers, etc.



**Figure 1.** Baled wheat straw.



**Figure 2.** Cross section of wheat straw [5]. (1) Outer epidermal cells, (2) fibrous tissue band, (3) vessel, (4) bundle sheath, (5) vascular bundle, (6) xylem, (7) phloem, (8) parenchyma cell, (9) internal epidermal membrane.



**Figure 3.** Two types of pretreatment processes for wheat straw chip preparation [6, 8].

In some case, it also can be used in cigarette paper furnish with less than 30% proportion to adjust paper’s air permeability. Fiber morphology data of wheat straw are listed in **Table 1**.

With contrast to wood materials, there are less lignin and more hemicellulose contents in wheat straw [9] and extremely high content of extractives by 1% caustic soda solution, but its biological organizations are bulky and loosened, which is helpful for pulping process. In fact, there were a series of pulping processes, successfully employed by wheat straw pulping practices, such as soda pulping (soda), kraft pulping (KP), and neutral or alkaline sulfite pulping (NS or AS) for production of brown pulps and bleached pulps. Chemical compositions of one kind of wheat straw from Hebei province, China, are illustrated in **Table 2** [10].

Zhan et al. [11] analyzed chemical components of differential parts from wheat straw, and results show significant differences on chemical compositions from each part, listed in **Table 3**. Internodes of wheat straw contain higher hemicellulose which is the key element of pulps.

Species	Fiber length (mm)		Width (um)		Rate of L/W	Wall thickness (um)	Lumen diameter (um)	2 W/D	Non-fiber cell content (%)
	Avg.	Range	Avg.	Range					
Wheat straw	1.32	1.03–1.60	12.9	9.3–15.7	102	5.2	2.5	4.16	37.9
Birch ( <i>Betula alba</i> )	1.21	1.01–1.47	18.7	14.7–22.0	65	—	—	—	26.7-
<i>Pinus massoniana</i>	3.61	2.33–5.06	50.0	36.3–65.7	72	3.8E) 8.7(L)	33.1 (E) 16.6 (L)	0.23 (E) 1.05 (L)	1.5

**Table 1.** Fiber morphology datum of wheat straw and wood [10].

Sample	Ash	Extractives				Pentosanes	Lignin	Nitrate-EtOH cellulose
		Cold water	Hot water	Benzene-EtOH	1%NaOH			
Wheat straw (Hebei)	10.65	5.36	23.15	—	44.56	25.56	22.34	40.40

**Table 2.** Chemical composition of wheat straw (% wt/wt) [10].

	Internodes	Nodes	Leaves
Klason lignin (%)	19.66	19.98	14.18
Holocellulose (%)	70.27	67.97	60.95
Ash (%)	6.27	8.69	12.06

**Table 3.** Chemical compositions of wheat straw parts (% wt/wt) [30].



### 3. Chemical pulping and pulp bleaching

Soda and soda-anthraquinone (AQ) cooking, as sulfur-free processes, are more suitable in producing pulp fibers from some no-woody raw materials [12]. Most common operated chemical pulping processes are soda or soda-AQ cooking, using caustic soda or caustic soda-AQ solution as cooking liquor to dissolve and remove lignin from wheat straw. It was proven that AQ can improve selectivity of delignification by caustic soda to prevent carbohydrates from hydrolysis [12, 13].

Since chemical pulping process was employed for wheat straw pulping, some disadvantages occurred during commercial practices, i.e., higher steam consumption, shortage of heat recovery, changeable in pulp qualities, lower pulp yield, poor pulp drainability, high viscosity of black liquor, and so on, which caused some challenges as high production cost, limited application of pulps, difficulties on chemical recovery, etc. Some advanced techniques have been improved and invented in the past decades [14], summarized as follows: (1) the wheat straw chip preparation processes combined with dry method and wet method were developed to remove nonfibrous components selectively and efficiently; (2) rapid cooking process at lower temperature combined with mechanical fiber dissociation to enhance uniform cooking effects and improve pulp qualities; and (3) elemental chlorine-free and total chlorine-free bleaching processes invented to eliminate generation of AOX and other bio-toxicities from pulp bleaching operations.

The first installation of continuous cooking system with an annual capacity of 100,000 metric tons of wheat straw pulps was operated at Quanlin Paper Group, Shandong, China. This successful practice scales up an individual pulp production line capacity from non-wood materials in the world and improves significantly technical specifications of wheat straw pulping. The detailed technical specifications are shown in **Table 4** [8].

A new type of pulp washer series, i.e., serialized ZXV-type pulp washers, has been innovated by Wenrui Machinery Co. Ltd., Shandong, China. The new pulp washers, with the maximum filtration area of each drum being up to 120 m<sup>2</sup>, and with a conical chamber structure designed and plane distributing valves being applied to improve water flow turnover and keep higher vacuum degree in sucking chambers, resulted in a good pulp cleanness and high extraction rate of black liquor; on the other hand, dispersing press, agitating device applied to improve washing efficiency [3]. The proposed acceptable washing-screening process is the sequence with press extraction—replacement washing—closure screening; it has been proven by many commercial operations that the new concept of the combined countercurrent washing sequence improves black liquor extraction rate significantly, resulting a remarkable water-saving effect. For instance, the black liquor extraction rate reaches up to 94.6%. The water consumption can be reduced to 40 m<sup>3</sup>/t pulp or less in Xinya Paper Group, contrasting to normal water consumption of more than 100 m<sup>3</sup>/t pulp by traditional process [4].

The bleaching techniques had experienced a long-term development in China's wheat straw pulping practices. Early, the single-stage low consistency bleaching with hypochlorite was commonly applied in many non-wood pulping lines, and a three-stage bleaching sequence

of CEH (chlorination—alkali extraction—hypochlorite) was not applied until the 1980s of the twentieth century [14]. All of the above bleaching sequences contain elemental chlorine chemicals with generation of AOX and other organic toxicities in these bleaching effluents. Due to poor bleaching selectivity upon residue lignin, there were a large amount of carbohydrates degraded while bleaching, resulting a large water consumption and high chemical dosage, to produce bleached pulps with low brightness and weak physic strength as well as poor drainability of water. Following more and more strict regulations to effluent discharge, elemental chlorine chemicals were forbidden to be used for pulp bleaching, and the bleaching techniques were developed toward more environmentally friendly processes, such as ECF (elemental chlorine-free) and TCF (totally chlorine-free) bleaching sequences. The first mid-consistency and shortened TCF bleaching sequence in the world, namely, OQPo (oxygen delignification—chelating metal ions—peroxide bleaching assisted with oxygen) sequence, was successfully commercially operated with the capacity of 150 t/d by Xianhe Co., Henan, China (**Figure 4**) in 2008 [15]. By this bleaching sequence, bleached wheat straw pulps (BWSPs) with brightness of more than 80%ISO, pulp viscosity of 653 ml/g and breaking length of more than 7000 m (**Tables 5 and 6**) and less amount bleaching effluent generated about 30 m<sup>3</sup>/t pulps, decreased by more than 60% of a traditional CEH bleaching process for wheat straw pulps [15]. Later, a bleached wheat straw pulp production line by TCF sequence with an annual capacity of 200 t/d was installed in Baiyuan Paper Co., Henan, China. Also, enzymes have been considered by many pulp scientists to assist bleaching operation with a decrement of chlorine-contained bleaching chemicals, providing an optional measure for bleached pulp quality improvement and chlorine-contained bleaching chemical dosage decrement toward an environmentally friendly clean production concept.

Items	Technical specification
1. Biomass lose rate at wheat straw chip preparation stage (% w/w)	23–28
2. Caustic soda dosage in cooking on raw materials saved (% w/w)	2.5
3. Bleached pulp yield increased on raw materials (% w/w)	5.0
4. Pulp brightness after oxygen delignification (% ISO)	50–55
5. Tensile strength of the unbleached wheat straw pulp (N.m/g)	58.8
6. Black liquor properties at the exit of the black liquor extraction stage:	
(i) Extraction efficiency (%)	>90
(ii) Viscosity of black liquor (cp) (100°C, 50% solid consistency)	<500
7. Black liquor properties at the exit of normal vacuum evaporation system (%w/w)	60–62
8. Mid-stage water discharge	
(i) Water discharge amount (m <sup>3</sup> /t o.d. pulp)	<50
(ii) COD of treated effluent (mg/L)	<60

**Table 4.** Advanced technical specifications of wheat straw pulping in Quanlin paper group [15].

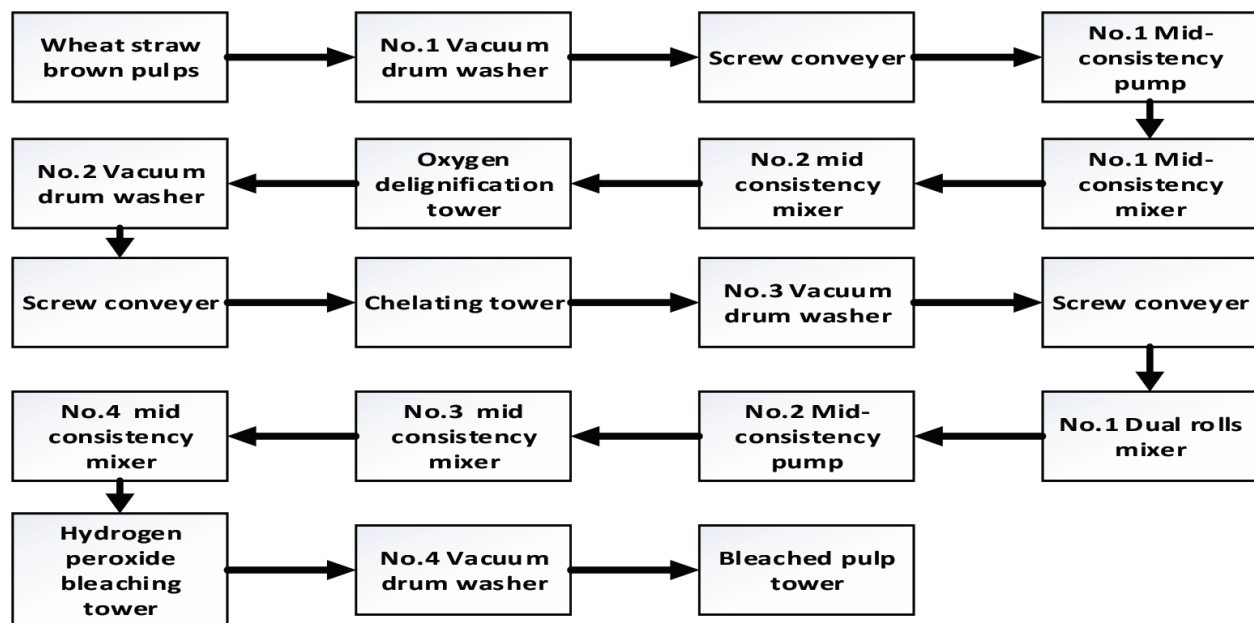


Figure 4. A short OQPo bleaching sequence for production of bleached wheat straw pulps [15].

Grammage (g/m <sup>2</sup> )	Beating degree (°SR)	Tensile (N.m/g)	Breaking length (km)	Tear (mN. m <sup>2</sup> /g)	Burst (kPa. m <sup>2</sup> /g)	Fold endurance times (1.5 kgf tension)
58.3	44.3	71.23	7.16	4.83	4.68	24

Table 5. Physical strength properties of bleached wheat straw pulps by an OQPo sequence [15].

Wheat straw pulps	Brightness (%ISO)	Viscosity (mL/g)
Screened brown pulp	34.7	965
Pulp after oxygen stage	48.0	850
Pulp after Po stage	81.6	653

Table 6. Viscosity and brightness of wheat straw pulps from different stages [15].

## 4. Paper products from wheat straw pulps

As previous discussed, bleached wheat straw pulps can be characterized with good strength properties, reasonable brightness, good printability, etc., which can be used to manufacture a wide range of paper and paperboard grades, such as light-weighted printing paper [16], letterpress printing paper, typing paper, writing paper, aluminum foil base paper, cylinder polished paper, tissue and sanitary papers, white board, coated ivory board, and almost all grades of paper and paperboard grades [17–22]. Practically, to improve pulp stock wet-web



Pulps	Ratio (%)	Beating degree (°SR)	Wet weight (g)
Bleached wheat straw pulp	70–50	48–53	>2.2
Bleached softwood pulp	30–50	48–65	5–8

**Table 7.** Portion of furnish for bible paper [18].

Specific properties		unit	Bible paper product	
			Produced product	GB 1913–1989 (Grade A)
Grammage		g/m <sup>2</sup>	40	40 ± 1.5
Density		g/cm <sup>3</sup>	0.80	≥0.8
Fold endurance CD		Times	5	≥5
Breaking length		m	3000	≥2500
Smoothness	Average of T-B surfaces	s	102	≥100
	Variation	%	23	≤25
Brightness		%	80.0	≥79.0
Opacity		%	87.0	≥85.0
Dust content	0.3–0.5 mm <sup>2</sup>	Number/m <sup>2</sup>	40	≤50
	>1.5 mm <sup>2</sup>		no	Not allowed
Moisture content		%	6.0	6.0 ± 1.0
Ash		%	19	—

**Table 8.** Quality specification to bible paper products [18].

run ability in paper machine, wheat straw pulp furnishes must be mixed with some portion of bleached wood pulps or bamboo pulps occasionally [18, 20].

Some paper mills produce Bible paper products from bleached wheat straw pulps, the formula of pulp furnishes is given in **Table 7**, and the quality specifications of Bible paper are illustrated in **Table 8** [18].

### 5. Chemi-mechanical pulping process and CMP pulp properties

The chemi-mechanical pulping process, combined with multiple stages as chemical pretreatment, fiber mechanical separation, and enzymatic hydrolysis modification, has many significant advantages contrasting to chemical pulping process, i.e., higher pulp yield, lower pollution load, and easily treated effluent. In fact, chemi-mechanical pulping process has been developed rapidly and widely applied for wood pulping. In the early 1990s of the

twentieth century, China's wood pulp production from fast-grown woodchips by promotion of chemi-mechanical pulping technologies, such as CTMP (chemi-thermo-mechanical pulping), APMP (alkaline peroxide mechanical pulping), P-RC APMP (preconditioning-refiner chemical APMP), and CTMP-c (chemi-thermo-mechanical pulping with enhanced chemical impregnation) processes, has increased rapidly [23].

Chemi-mechanical pulping from wheat straw studies lasted for more than 30 years in China. In the early 1990s of the twentieth century, Liu and Fang [24] investigated chemi-mechanical pulping properties from wheat straw using caustic soda impregnation, characteristics of effluent, and proper treatment process. It was proven that wheat straw can be used to produce chemi-mechanical pulps using small amount of caustic soda with advantages as high pulp yield, good physical strength, and proper biodegradable effluents [25–27]. A-grade corrugated medium was produced from this kind of wheat straw CMP pulps (**Table 9**), and also A-grade linerboard from WSCMP mixed with 15–30% kraft wood pulps was prepared [17, 24].

Zhang et al. [28] also investigated wheat straw chemi-mechanical pulping properties using two-stage caustic soda impregnation followed with two-stage atmospheric refining, while a total dosage of caustic soda 3–5% was applied at the impregnation stage, resulting pulp yield of 73.1% w/w–78.9% w/w, pulp tensile strength of 19.49–41.27 N.m/g, the specific refining energy consumption from 827 to 336 kWh/t pulp (**Table 10**), and COD load in effluent of 270.5–446.0 kg/t o.d. pulp (**Table 11**); the relationships between pulp yield versus caustic soda dosage and COD load versus pulp yield are illustrated in **Figures 5** and **6**.

Specification	GB1302	Corrugated medium from WSCMP (g/m <sup>2</sup> )	
		140	180
Grammage (g/m <sup>2</sup> )	140 ± 2.0	140.3	180.6
Density (g/cm <sup>3</sup> )	≥0.5	0.56	0.61
Breaking length (m)	≥4.30	4.94	4.71
Ring crush (N.m/g)	≥	14.61	16.94

**Table 9.** Quality specifications of corrugated medium from wheat straw CMP pulps [17].

Pulp sample	Caustic soda dosage (%)	Pulp yield (%)	Specific refining energy (kWh/t pulp)	Bulk (cm <sup>3</sup> /g)	Tensile (N.m/g)	Burst (kPa. m <sup>2</sup> /g)	Tear (mN. m <sup>2</sup> /g)	Breaking length (m)
CTMP-1	3.0	78.9	827	3.23	19.5	1.04	4.23	2460
CTMP-2	4.0	75.5	555	2.66	32.6	1.60	4.56	3330
CTMP-3	5.0	73.1	336	2.35	41.3	2.31	4.08	4210

**Table 10.** CTMP pulping properties of wheat straw [28].

Effluent	Caustic dosage (%)	Color times	pH number	Pollutant load (kg/t)						
				TOC	SS	TS	COD	BOD5	TN	TP
CTMP-1	3.0	5166	9.1	150	47.6	188.3	271	181	6.04	1.90
CTMP-2	4.0	5244	9.6	173	78.5	277.1	369	200	6.75	1.92
CTMP-3	5.0	6127	10.1	219	124.3	315.9	446	228	8.08	1.93

Table 11. Characteristics of effluent from wheat straw CTMP pulping [28].

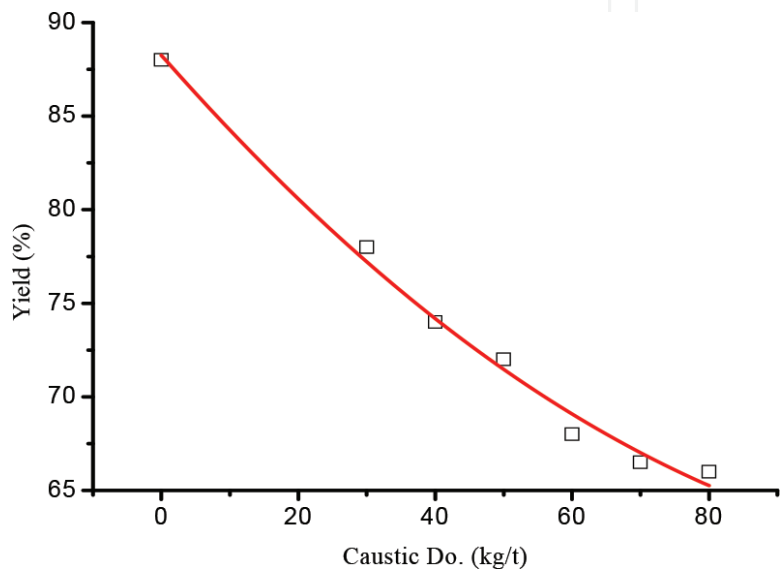


Figure 5. Wheat straw CTMP pulp yield decreases with increment of caustic soda dosage [24, 28].

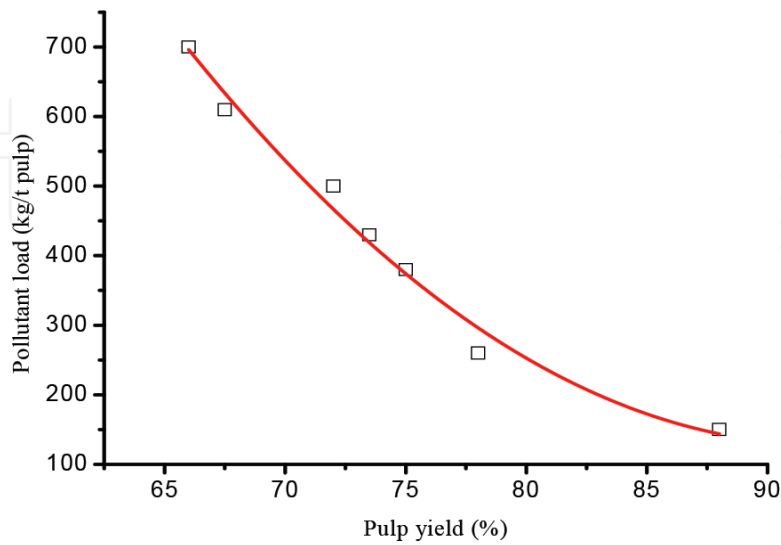


Figure 6. Pollutant load of effluent decreases with increment of pulp yield [24, 28].

## 6. Effluent treatment

It is clear that pollution load from pulping process can be decreased by increasing pulp yield. Liu and Fang [24] summarized a relationship between COD load (y) and pulp yield (x) of wheat straw pulping, i.e.,  $y = 4929.58426 - 104.0789x + 0.5883x^2$ ,  $r^2 = 0.910$ . It was proven that effluent from wheat straw chemi-mechanical pulping has a good biodegradability contrasting with that from OCC (old corrugated container) pulping. Effluent from wheat straw CTMP pulping has been characterized and illustrated in **Table 12** [24].

The proposed flow diagram for installation of effluent treatment plant is illustrated in **Figure 7** [24].

Since less amount of chemicals is applied for wheat straw impregnation, the contaminant of such pulping effluent consists of low polymerized or monomolecular carbohydrate compounds, which are biodegradable. With consideration of effluent characteristics from each stage and quality requirements of process water, it is possible to reuse the used water in a short circuit after suitable individual specific treatment. If chemi-mechanical pulping line is going to be installed in recycled fiber pulping and papermaking mill, the integrated effluent from wheat straw CTMP or CMP line will contribute to improve biodegradability for recycled fiber pulping effluent, carefully considering the water balance, and it is possible to produce wheat straw chemi-mechanical pulps without consumption of any fresh water [17]. Therefore, the total volume of discharge effluent will not be increased. It means that the original effluent treatment can be operated with improvement of efficiency [17, 25, 27].

Parameters	Wheat straw CTMP effluent		
	Screw press after pre-steaming	Pulp washing	Integrated effluent
Effluent discharge (m <sup>3</sup> /BDT)	0.32	12.05	12.37
pH	8.3	8.5	8.1
COD concentration (mg/L)	13,580	17,280	17,185
COD load (kg/BDT)	4.35	208.19	212.54
BOD concentration (mg/L)	—	—	7888
BOD load (kg/BDT)	—	—	97.57
Ratio of BOD <sub>5</sub> /COD	—	—	0.459
SS (g/L)	3.7	11.81	11.60
TS (g/L)	7.7	19.04	19.32
Ash content in TS (%)	26.7	35.20	34.06
TN (mg/L)	110.0	146.0	145.0
TP (mg/L)	99.0	57.0	58.0

**Table 12.** Effluent characteristics from wheat straw CTMP pulping [24].

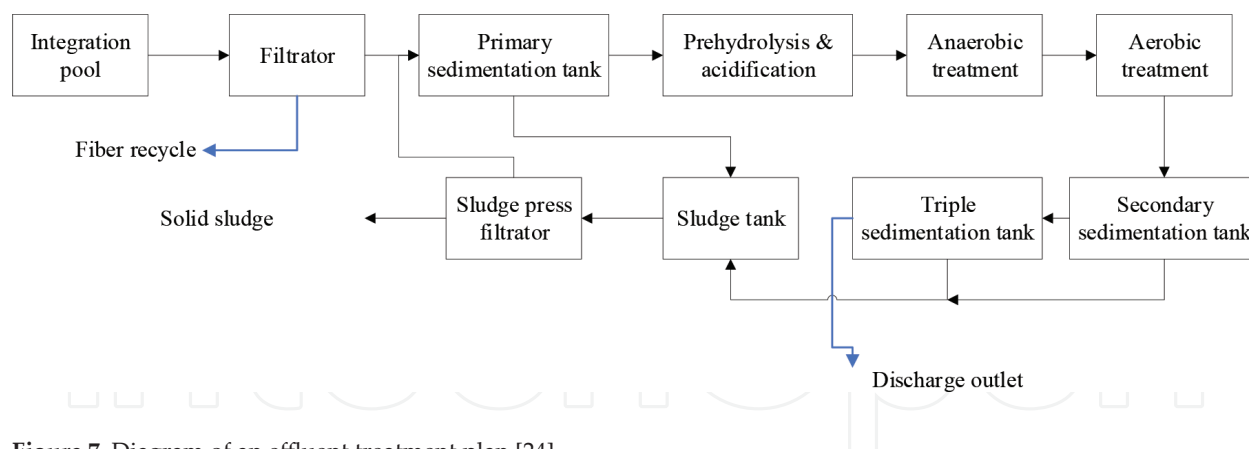


Figure 7. Diagram of an effluent treatment plan [24].

## 7. Desilication and chemical recovery of black liquor

### 7.1. Desilication in wheat straw cooking

Two different kappa number pulps of wheat straw soda-AQ cooking were studied followed by  $O_2$  cooking for elucidating the effects of alkali charge, temperature and oxygen pressure on the black liquor desilication, pulp yield, and pulp delignification. The results showed that the soda-AQ cooking conditions had an influence on the properties of the pulp and the black liquor in the  $O_2$  cooking stage. And, there were proper alkali charge, temperature and pressure ranges for the desilication, the pulp yield, and the black liquor viscosity in the  $O_2$  cooking system at given other conditions. The results also showed that silica content in the  $O_2$  cooking pulp did not always decrease with the rise of system pH and silica content of black liquor did not always increase with the rise of system pH. The  $O_2$  cooking in soda-AQ/ $O_2$  two-stage cooking cannot only successfully desilicate from the black liquor but also delignify effectively itself. Hence, the soda-AQ/ $O_2$  cooking process could be an environmentally friendly potential pulping process [29].

Desilication kinetics of the  $O_2$  stage in the wheat straw soda-AQ/ $O_2$  two-stage cooking were investigated. In addition, the pulp yield, alkali concentration, and  $O_2$  pressure in the  $O_2$  cooking were studied. The results showed that desilication reaction from the  $O_2$  cooking black liquor could be divided into two phases, a rapid initial desilication phase followed by a slow final desilication phase. They both follow pseudo-first-order reaction toward the silica concentration in black liquor with the reaction energy 64 and 79 kJ/mols, respectively. The differential state expressions of two phases were deduced [8, 29].

Studies also indicated that under the experiment conditions, the pulp yield increased by 0–3.5% and the  $O_2$  pressure and alkali concentration in the system decreased with the extending time at given temperature in the  $O_2$  cooking process.

The successful experiences for chemical recovery in China's wheat straw chemical pulping mills indicate the following: (1) to enhance the loss of wheat straw preparation is helpful to decrease the silica content and viscosity of black liquor; (2) rapid cooking at lower temperature



can prevent degradation of cellulose and provide wheat straw chemical pulps with good physic strength and drainability; and (3) high-efficient extraction washer for black liquor is helpful to increase the initial concentration of black liquor, resulting steam savings during thickening black liquor and also decrement of fresh water consumption in pulp washing stage [4, 8].

For instance, Quanlin Paper Group has successfully operated its chemical recovery system for wheat straw chemical pulping black liquor, with an alkali recovery rate of more than 85%, and its mid-stage water can be treated economically to meet an extremely strict effluent discharge standard (COD concentration is less than 60 mg/L). There are many new techniques applied in its wheat straw pulping line, such as application of flying hammer chipper to separate more non-fiber components and to improve uniform cooking effects resulting in short cooking time and lower chemical dosage, decrement of black liquor viscosity from 1000cp to less than 500cp (solid content (55%) and temperature (100°C)); a vertical replacement cooking digester with large ration of chips to water was installed, leading to significant chemical dosage decrement and initial concentration of black liquor increment to save evaporation cost and to obtain more thickened black liquor which is a benefit for chemical recovery boiler [3, 4].

## 7.2. Application of straw industrial lignin

Although being a highly abundant aromatic feedstock, lignin is still largely regarded simply as a source for heat and power for the biorefining or pulping process that liberates the lignin. The lack of established processes that add value to the lignin component can be largely attributed to its chemical recalcitrance and structural complexity. Adding to this complexity, the lignin structure is highly dependent on both the feedstock and lignin isolation process [30]. However, a part of lignin could be converted into value-added products including bio-based aromatic chemicals, as well as building blocks for materials [31]. The soda lignin has more value than kraft lignin from wheat straw in manufacturing lignin-derivative compounds in terms of the industrial lignin structure and the lignin recovery cost [30, 32]. Lignosulfonates and their modified products have always been traditionally and extensively employed as a class of thinning agent for drilling fluids. SFP lignin is a kind of lignosulfonate in the waste liquor from the pulping of wheat straw with  $\text{Na}_2\text{SO}_3$ , HCHO, and AQ [33, 34]. Experimental results showed that SFP lignin exerts three effects on drilling fluid dilution, foaming, and flocculation. Therefore, SFP lignin and its modified products can be used as a thinning and foaming agent for drilling fluids, as well as a flocculating agent for treating waste drilling fluids [34, 35].

## 8. Conclusion

Wheat is a kind of annual vascular-bundled herbal arthrophyte with only internodes of about 68%w/w of the whole stalk being acceptable for pulping and the remainder of 20–30%, i.e., leaves-sheaths, leaves-blade, nodes, grain, debris, etc., being removed for chemical saving and pulp quality improvement as well as silica content decrements of black liquor from cooking at a commercial pulping process line. There are a series of pulping processes, such as

the soda, soda-AQ, KP, NS and AS process, etc., successfully employed by wheat straw pulping practices for production of brown pulps or bleached pulps, among which the soda-AQ (anthraquinone) process is most commonly applied in producing the bleached pulps from wheat straw, for AQ to be used in improving selectivity of delignification.

The first installation of continuous cooking system with an annual capacity of 100,000 metric tons of wheat straw pulps was successfully operated in China, scaling up an individual pulp production line capacity from non-wood materials in the world, with the tensile strength of wheat straw pulp up to 6000 m, the mid-water discharge amount of less than 50 m<sup>3</sup>/t o.d. pulp, COD less than 60 mg/L of treated effluent, and the black liquor extraction rate up to 94.6%.

The first mid-consistency and shortened TCF bleaching sequence in the world, namely, OQPo (oxygen delignification—chelating metal ions—peroxide bleaching assisted with oxygen) sequence, was successfully commercially operated in China in 2008, with the brightness of bleached wheat straw pulps (BWSPs) of more than 80%ISO, the pulp viscosity of 653 ml/g, breaking length of more than 7000 m, less amount bleaching effluent generated about 30 m<sup>3</sup>/t pulps, and decrease by more than 60% of a traditional CEH bleaching process. The BWSPs can be used to manufacture a wide range of paper and paperboard grades as the full or part furnishes, such as light-weighted printing paper, letterpress printing paper, typing paper, writing paper, aluminum foil base paper, cylinder polished paper, tissue and sanitary papers, white board, coated ivory board, and almost all grades of paper and paperboard grades.

Chemi-mechanical pulps, meeting the requirement of manufacturing A-grade corrugated medium, A-grade linerboard, etc., can be produced from wheat straw using a small amount of caustic soda with advantages as high pulp yield (73.1–78.9%), good physical strength (a tensile strength of 19.49–41.27 N.m/g), and proper biodegradable effluents. A relationship between COD load (y) and pulp yield (x) of wheat straw pulping, i.e.,  $y = 4929.58426 - 104.0789x + 0.5883x^2$ ,  $r^2 = 0.910$ , is summarized, and it is proven that effluent from wheat straw chemi-mechanical pulping has a good biodegradability contrasting with that from OCC (old corrugated container) pulping.

The O<sub>2</sub> cooking in soda-AQ/O<sub>2</sub> two-stage cooking is benefited for the desilicate of black liquor from wheat straw chemical pulping line. The successful experiences for chemical recovery in China's wheat straw chemical pulping mills indicate the following: to enhance the loss of wheat straw preparation being helpful to decrease the silica content and viscosity of black liquor, rapid cooking at lower temperature preventing the degradation of cellulose and providing wheat straw chemical pulps with good physic strength and drainability, and high efficient extraction washer for black liquor added to increase the initial concentration of black liquor and to result in steam savings during thickening black liquor and also decrement of fresh water consumption in pulp washing stage. SFP lignin, a kind of lignosulfonate in the waste liquor from the pulping of wheat straw with Na<sub>2</sub>SO<sub>3</sub>, HCHO, and AQ and its modified products, can be used as a thinning and foaming agent for drilling fluids, as well as a flocculating agent for treating waste drilling fluids.

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## References

- [1] Lu YJ, Li X, Jiang N. The development and trend analysis of the world wheat industry in 2017. *China Market*. 2017;(26):63-65. DOI: 10.13939/j.cnki.zgsc.2017.26.063
- [2] Danielewicz D, Surma-Słusarska B. Properties and fiber characterization of bleached hemp, birch and pine pulps: A comparison. *Cellulose*. 2017;**24**:5173-5186
- [3] Li ZZ. Overview of recent development of non-wood fibers pulping in China. *China Pulp & Paper*. 2011;**30**(11):55-63
- [4] Lin WY. Review on progress of non-wood fibers pulping and chemical recovery in China. *China Pulp & Paper Industry*. 2005;**26**(5):22-26
- [5] Wu YM. *Chemistry of Plant Fiber*. 2nd ed. Beijing: China Light Industry Press; 1991. p. 54
- [6] Li ZZ. Non-wood fibers pulping theories and techniques. *China Pulp & Paper Industry*. 2007;**26**(12):71-74
- [7] Tutuş A, Çiçekler M. Evaluation of common wheat stubbles (*Triticum aestivum* L.) for pulp and paper production. *Drvna Industrija*. 2016;**67**(3):271-279. DOI: 10.5552/drind.2016.1603
- [8] Song MX, Li ZZ, Chen ST. Principals for non-wood fibers pulping—A successful wheat straw pulping practice in Quanlin paper group. *China Pulp & Paper*. 2009;**28**(2):69-72
- [9] Plazonić I, Barbarić-Mikočević Ž, Antonović A. Chemical composition of straw as an alternative material to wood raw material in fiber isolation. *Drvna Industrija*. 2016; **67**(2):119-125. DOI: 10.5552/drind.2016.1446

- [10] Yang SH. Chemistry of Plant Fiber. 3rd ed. Beijing: China Light Industry Press; 2011. pp. 19-44
- [11] Zhan DT, Liu XB, Li ZZ. Fiber morphology and chemical compositions of different parts of wheat straw. *China Pulp & Paper*. 1990;9(4):16-21
- [12] Saeed HAM, Liu Y, Lucia LA, Chen HL. Suitable approach using agricultural residues for pulp and paper manufacturing. *Nordic Pulp & Paper Research Journal*. 2017;32(4): 674-682. DOI: 10.3183/NPPRJ-2017-32-04-p674-682
- [13] Zhan HY. The Principle and Engineering of Pulping. 3rd ed. Beijing: China Light Industry Press; 2011. pp. 74-77
- [14] Zan HY, Fu SY, Li HL. Technical progress of non-wood fibers pulping in China- bamboo and wheat straw. *China Pulp & Paper Industry*. 2011;32(9):12-16
- [15] Li J, Li K, Wu HM, Li WW, Zeng J, Xu J, Chen KF. Commercial operation of wheat straw pulping bleaching by a OQPo sequence. *China Pulp & Paper*. 2009;28(10):79-81
- [16] Zhang Q, Peng JJ, Chen LH, Shen ZH. Manufacture of low density printing paper using wheat straw chemical pulp. *China Pulp & Paper*. 2017;36(8):30-34
- [17] Fang GG, Liu MS, Shen KZ, Deng YJ, Li YR, Chen TA. Pollution controllable non-wood fibers pulping techniques—High yield pulping. In: *Proceedings of Materials Science and Engineering Technology*; Beijing: The Third Annual Youth Academy of China Association for Science and Technology; 1998. pp. 276-278
- [18] Shen KZ, Fang GG, Liu MS, Li P. Technology of producing bible paper with a furnish of wheat-straw bleached chemical pulp and Bleached SKP. In: *Proceedings of the Ninth Annual Academic Conference of China Paper Society*; Nanjing; 1999. pp. 873-876
- [19] Zhao SZ, Li YL, Ying SY, Ye JL. A new application technology of chemicals to decrease wet-deformation and to increase surface strength of wheat straw-base paper. *World Pulp and Paper*. 2001;20(4):16-22
- [20] Huang SR. The produce high-grade cultural paper from the mixture of bleached wheat straw pulp and bleached bamboo pulp. In: *Proceedings of the Eleventh Annual Academic Conference of China Paper Society, Transactions of China Pulp and Paper*; 18(z) Rizhao; 2003. pp. 195-197
- [21] Wang FM, Wang DF. Synthetic surface sizing agent to size offset paper made by wheat straw pulp. *Paper and Paper Making*. 2003;(Z1):15-16
- [22] Xu HY, Zhou GW, Qi GW, Huang KP. Micro-particle retention and drainage system for producing offset using wheat straw pulp. In: *Proceedings of the Fourteenth Seminar on the Development and Application Technology of Papermaking Chemicals*; Shanghai: China Paper Chemical Industry Association; 2007. pp. 219-231
- [23] Shen KZ, Fang GG. State-of-the-art bleaching technology of mechanical pulps. In: *Proceedings of the Sixth Annual Academic Conference of China Paper Society, Transactions of China Pulp and Paper*, 29(z), Beijing; 2014. pp. 13-20

- [24] Liu GL, Fang GG. Promotion and development of non-wood fibers high yield pulping-a successful solution to pollution control for non-wood fibers pulping mills. *Sichuan Paper*. 1997;**26**(1):30-32
- [25] Li HB, Fang GG, et al. High brightness bleaching of wheat straw CMP pulps. *China Paper Industry*. 2008;**29**(24):44-47
- [26] Li HB, Fang GG, et al. Enforced chemical impregnation measures for wheat straw CMP pulping. *Chemistry and Industry of Forest Products*. 2009;**29**(2):81-84
- [27] Wang Q, Chen JC, et al. Factors screening for wheat straw CMP pulping. *China Pulp & Paper Industry*. 2009;**30**(6):48-51
- [28] Zhang HL, Fang GG, et al. Characterization of effluent and pollution load from a two-stage impregnation wheat straw CMP pulping process. *Biomass Chemistry and Engineering*. 2016;**50**(5):39-44
- [29] Cao YF, Yang YQ, Zhang XL, Li ZZ. Properties of black liquor of two-stage alkali-oxygen pulping of wheat straw. *Transactions of China Pulp and Paper*. 2002;**17**(1):64-67
- [30] Constant S, Wienk HLJ, Frissen AE, Peinder P, Boelens R, Es DS, Grisel RJH, Weckhuysen BM, Huijgen WJJ, Gosselink RJA, Bruijninx PCA. New insights into the structure and composition of technical lignins: A comparative characterization study. *Green Chemistry*. 2016;**18**:2651-2665. DOI: 10.1039/c5gc03043a
- [31] Santos JI, Fillat U, Martin-Sampedro R, Eugenio ME, Negro MJ, Sallesteros I, Rodriguez A, Ibarra D. Evaluation of lignins from side-streams generated in an olive tree pruning-based biorefinery: Bioethanol production and alkaline pulping. *International Journal of Biological Macromolecules*. 2017;**105**(1):238-251. DOI: 10.1016/j.ijbiomac.2017.07.030
- [32] Kumar H, Alén R, Sahoo G. Characterization of hardwood soda-AQ lignins precipitated from black liquor through selective acidification. *BioResources*. 2016;**11**(4):9869-9879
- [33] Cao JW. Separation and modification of lignin from wheat straw pollution-free decomposition solution [master's dissertations]. Shaanxi University of Science and Technology; 2011. pp. 1-88
- [34] Liu QX. Study on comprehensive utilization of lignin in alkaline pulping black liquor [doctoral dissertations]. Tianjin College of Light Industry; 2001. pp. 1-110
- [35] Zhou Q. Catalytic sulfonation of wheat straw alkali lignin and its application in petroleum recovery [doctoral dissertations]. South China University of Technology; 1998. pp. 1-132



