A Pulping Technique for Agricultural Fibers

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Laboratory experiments were conducted to determine the influence of chemical concentration and pressure on the mechano-chemical pulping of wheat straw and sugarcane bagasse. At atmospheric pressure, a Dynopulper produced pulps having characteristics similar to pulps produced in a Hydrapulper. Maximum lignin was removed and bleach requirements were minimum when pressure in a Dynopulper ranged from 25 to 30 p. s. i.; however, efficiency of lignin removal per unit of applied pulping chemical decreased with increases in pressure. This technique of applying pressure produces readily bleachable pulps while retaining the advantages of the mechano-chemical process.

The practicality of using annual plants or agricultural byproducts, particularly straw and sugarcane bagasse, for the manufacture of pulp and paper is demonstrated by commercial operations in many countries. In fact, the quantities being used are increasing in Portugal, Indonesia, Peru, Ceylon, Greece, Thailand[1], India, Cuba and the Phillipines[2]. Other countries as Italy, Poland, Netherlands, France, Spain, Mexico, Brazil and Argentina continue to consume large quantities of these raw materials. Much progress has been made in recent years in mechanical methods of harvesting, collecting and storing annual plants. Nevertheless, straw as a pulp source has been abandoned in the United States because of unfavourable economics associated with its collection and processing. Development of improved processing techniques such as those presented in this report, should offset some of the disadvantages of increased raw material costs and chemical requirements.

In earlier studies at the Northern Laboratory, fine paper pulps with good strength characteristics were prepared by alkaline pulping of straws[3]. Higher yields of pulp with somewhat lower strength characteristics were subsequently realized by a neutral sulfite process[4]. The mechano-chemical technique[5] produces quality pulps at atmospheric pressure in greater yields than by any chemical means. Equipment for the mechano-chemical treatment is less costly and cooking cycles are shorter than for conventional procedures. These advantages, however, are offset in part by the power required and the greater amounts of chemicals required to bleach pulps to an acceptable brightness. Neither increased amounts of chemicals in pulping nor extension of cooking time provided the degree of delignification needed for easy bleaching that is achieved by conventional pressure methods.

The object of our investigation was to develop a pulping technique to produce easily bleachable pulps from wheat straw and sugarcane bagasse while retaining the advantages of the mechano-chemical process. We achieved our objective by studying the influence of chemical concentration, heat and moderate pressure on pulp characteristics.

Results and Discussion

Pulping at atmospheric pressure with a Hydrapulper subjects fibrous materials to repetitive compressive and expansive forces while the materials are submerged in pulping liquor at or near the boiling point. According to Aronovsky and Lathrop[5] the alternating forces facili ate introduction of pulping chemicals into the materials, solubilization of the fiber encrustants and loosening of fiber bundles and individual fibers.

The principal mechanical action in a Dynopulper and a Hydrapulper is similar but their designs differ. In the Dynopulper with an impeller at each end of the horizontal digestion chamber, a double vortex is formed. Suspended fibrous material is drawn vigorously into a vortex toward the center of each impeller and then moves radially over impeller faces to the walls of the chamber.

Yields, bleach requirements and physical characteristics of pulps prepared by these two types of pulpers at atmospheric pressure were essentially the same. Because foaming was a problem in cooking with an open Dynopulper, several pulps were prepared at 3 p.s.i. instead of at atmospheric pressure. Pulping within a closed system required controlled heating. Effects are shown in Table 1 of vortex pulping of

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TABLE I

Effects of Pressure and Chemicals on Yields, Composition, Bleachability and Physical Characteristics of Wheat Straw and Bagasse Pulps

Cooking Conditions[a]		Yields[b]		Chemical Analysis[c]			Bleaching		Strength Characteristics at 500 ml SR Freeness					
Chemical NaOH[b] %	Pressure p.s.i.	Crude %	Screened %	Ash %	Lignin %	Pentosans %	Chlorine Consumption[c]	Bleached Yield[b] %	Initial Freeness SR ml	Beating Time[d] min	Burst Factor (g/cm²)/(g/m²)	Breaking Length m	Tear Factor g/(g/m²)	Folding Endurance Schopper
							Wheat straw							
12	3	62.2	55.5	1.9	7.2	30.0	11.9[e]	48.7	770	15	58	9600	39	800
12	12	59.2	52.6	2.5	5.7	29 6	7.9[e]	47.3	750	15	58	8900	60	1200
12	25	58.5	52.4	2.0	5.1	30.2	7.3[e]	45.3	770	18	58	8900	59	920
14	3	61.3	55.1	2.7	6.7	30 1	10.4[e]	48.5	770	15	57	9600	39	820
							13.8[f]	49.2						
14	12	59.6	54.0	2 8	5.8	27.8	7.8[e]	47.2	740	13	56	9000	44	900
							10.5[f]	50.1						
14	25	57.0	51.7	2.5	4.7	29 3	6.4[e]	43.8	750	15	58	9000	43	1100
							8.4[f]	46.4						
16	3	60.8	55.2	2 8	6.9	28.3	10.2[e]	47.1	750	15	60	10,300	42	860
16	12	58.8	53.5	2.9	5.6	28.5	6.9[e]	46.0	760	15	57	9400	40	800
16	25	56.0	51.7	2.8	4.8	27.8	6.3[e]	46.3	750	15	57	9100	39	1200
							Bagasse							
15[g]	0	75.0	66.1	1.3	6.8	34.2	20.0[f]	55.6	790	35	58	9500	43	740
15[g]	10	73.5	69.0	1.4	5.7	34.3	13.4[f]	60.7	790	37	58	9600	45	840
15[g]	20	70.6	65.9	1.4	4.7	34.0	8.6[f]	61.7	805	34	60	9800	47	1000
15	30	66.6	61.6	1.0	4.4	33.1	7.3[f]	58.6	820	23	58	9700	49	1400

a Liquid : solid, 12:1

b Basis o. d. raw material.

c Basis o. d. pulp,

d Time to beat pulp to 500 ml SR freeness.

e Three-stage bleach.

f Single-stage bleach.

g Liquid : solid, 13.5 : 1.

straw and bagasse fiber at pressures up to 30 p.s.i. (135°C) with 12,14,15 and 16% levels of caustic soda (basis fiber solids). Results of atmospheric pulping with the Hydrapulper were reported previously[5].

Data for straw show that increased pressure (and higher temperature) reduced yields, lignin content and bleach requirements. Increasing the pressure had a greater effect on pulp yield than did increasing the pulping chemical. Pulps prepared near atmospheric pressure (3 p.s.i.) using 12, 14 and 16% chemical required 1.6 times more chlorine for a 70 Hunter brightness than did pulps prepared at 25 p.s.i. At 25 p.s.i., considerable savings can also be made in both pulping and bleachiug chemicals.

Maximum benefits in lignin removal and ash reduction are realized at pressures of about 12 p. s. i. With a further increase in pressure to 25 p.s.i., the efficiency of lignin removal per unit of pressure increase was substantially less than for the lower pressures at corresponding chemical concentrations. However, no significant differences in burst, tensile and tear properties of test are indicated for pressure changes within the range of 3 to 25 p.s i. for all chemical levels.

Lowering residual ash content was a distinct advantage resulting from pulping with a combination of mechanical action, heat and moderate pressure. Earlier in pulping straw at 100 p.s.i. and 170°C[4], residual ash values were 5.2 to 6.3%, whereas in the current study, pulping with caustic soda gave values in a range of 1.9 to 2.9%. Our results agree with those reported in the earlier study of mechano-chemical pulping[5].

In general, similar effects were noted in the pulping of bagasse fiber at moderate pressures up to 30 p.s.i. Screened yields were from 62 to 69%. The screened yields were influenced somewhat by a preliminary fiberizing in a disk mill. At a chemical concentration of 15%, chlorine consumption decreasd as pressure was increased. Both burst and tensile values were essentially the same for straw and bagasse pulps prepared in the Dynopulper.

Apparently the preesure vortex technique is equally adaptable to either straw or bagasse. According to Aronovsky *et al*[6]. the rate of delignification is most rapid during the early phases of the pulping cycle in a mechano-chemical treatment. Delignification is rapid because of the repeated expulsion and reabsorption of pulping liquors by bundles of fibers under the impact action of the pulper's impeller or rotor. With each expulsion of liquor, additional lignin surface is exposed to fresher liquor in succeeding cycles. Pressure and the attendant increase in temperature promote solubility of the lignin in the cooking liquor.

Use of moderate pressures from 10 to 30 p.s.i. with a mechano-chemical-type treatment significantly reduces pulping and bleaching chemical requirements for straw and bagasse. Savings of up to 63% in bleaching chemicals are possible because the pulps contain less lignin. Such pulps contain less ash and greater amounts of pentosan than those described in earler studies of pressure processes. Furthermore, our experimental pulps required less refining or were hydrated more readily for greater strength development. Since the principles involved should be applicable to other mechanical pulpers having proper agitators or impellers and designed for operation under moderate pressure, results should be similar.

Experimental

Raw Materials. The straw, a soft winter wheat (Kawvale) grown in central Illinois, was chopped in an ensilage cutter to lengths of 1 to 3 in., and the fines and dirt were removed on a 20-mesh vibrating screen. The cleaned straw was mixed thoroughly and bagged in weighed units ready for pulping. Bagasse was obtained from Florida. Before pulping, it was depithed by the Hydrapulper-wet screening technique developed at the Northern Laboratory[7].

Chemical composition, determined according to TAPPI. Standard Methods or other appropriate procedures, for the wheat straw and bagasse fiber is given in Table II. Although the lignin and pentosan contents of the raw materials are quite similar, contents of cellulose in the two differ significantly.

Pulping Equipment One of the two commercial laboratory pulpers was a 3-ft diameter stainless-steel Hydrapulper (Black Clawson Co.) designed for use at atmospheric pressure. This unit was equipped with an 18-in. diameter low-vane rotor operated at 800 r.p.m. (peripheral speed of about 3800 f.p.m.). Aronovsky and Lathrop[5] described the effectiveness of the Hydrapulper when they

TABLE II

Proximate Chemical Composition of Wheat Straw and Bagasse Fiber.[a]

Raw Material	Ash %	Lignin %	Pentosans %	Cross and Bevan Cellulose (Ash Free) %	Alpha-Cellulose (Ash and Pentosan Free) %
Wheat straw	5.2	17.3	29.3	48.1	28.8
Bagasse	0.9	18.7	30.7	58.1	39.9

[a] All values on o.d. basis.

prepared straw pulps by their mechano-chemical process.

The second unit, a Dynopulper (Rice Barton Corp.), was designed for pulping at either atmospheric pressure or at moderately low pressures. It consisted of a horizontally mounted cylindrical chamber about 10 in. in diameter and 12 in. long. A 4.5 in. diameter impeller was located in each end to agitate and circulate the contents vigorously. Impellers were driven at about 2000 r.p.m in opposite directions. A quantity of coarse steel granules fused to the working surfaces of the impellers served as a fiberizing medium. Charging and discharging were done through a 6-in. diameter opening on the top side of the cylinder. Allowable internal working pressure was about 40 p.s.i. All parts of the pulper in contact with pulping liquor were stainless steel. Heat was applied to the exterior with a high capacity gas burner.

Atmospheric Pulping--Hydrapulper. From 40 to 50 pounds of air-dry straw or bagasse was added to preheated liquor (95–99°C) in the Hydrapulper with rotor operating. The amounts of NaOH used in pulping were 12 and 15% for dry wheat straw, and 15% for the bagasse. Initial selection of pulping conditions was based on results of earlier mechano-chemical pulping studies[5]. Crude pulps were washed to remove residual chemical and then passed through an 8-cut flat screen. Bagasse pulps were given a preliminary fiberizing treatment in a disk refiner before screening. Yields were determined for both crude and screened pulps and for screening rejects. The quantity of screening rejects, roughly the difference between crude and screened pulps, provided a convenient, ready estimate of of cooking effectiveness. Screened pulps were characterized by chemical composition, by bleachability to 70 Hunter brightness (single stage hypochlorite and three-stage chlorine, caustic soda, hypochlorite) and by standard beater evaluations. Unless indicated to the contrary, pulps and handsheets were tested according to TAPPI Standard Methods (T-200 and T-205).

Super-Atmospheric Pulping-Dynopulper. Of the two mechanical pulpers available, only the Dynopulper could be operated under pressure without modification. The pulper was operated with vent closed and with sufficient heating to create internal pressures up to 30 p.s.i.

Cooking time of 1 hr, used throughout, included 30-min. warm up and 30 min. at maximum pressure. After the cook, the pulper and its contents were cooled by an external shower of tap water. When the pressure had been reduced to atmospheric, the contents were removed and washed to displace spent liquor. Pulps from duplicate runs were combined to provide sufficient material for beater evaluations. Subsequent treatments and evaluation of pulps were the same as for those prepared by cooking at atmospheric pressure.

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