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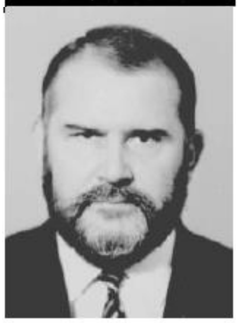

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DEVELOPMENT AND INTRODUCTION OF SEMI-FINISHED PRODUCT COOKING TECHNOLOGY FOR CONTAINERBOARD

A technology has been developed for producing containerboard using modified types of semichemical pulp in composition.

Keywords: pulp, liner, corrugated paper, neutral sulphite semichemical pulp, cooking, degree of substitution, corrugated fibreboard, neutral sulphite liquor, white liquor.

The past has seen both thriving competition among producers of different liner brands and fluting and increased requirements on their quality and stability. The quality of cardboard is an increasingly important factor affecting the choice of supplier. This pushes producers to upgrade cardboard machines, introduce modern technologies, automation equipment and quality control systems.

Arkhangelsk Pulp and Paper Mill is a major producer of cardboard for flat corrugated fibreboard layers (liner and multipurpose cardboard). The plant is equipped with the highest-capacity cardboard machines in Russia and manufactures high-quality products recognised by many consumers.

Yet, owing to the significant difference in colour between sulphate pulp and neutral sulphite semichemical pulp (NSSP) in the production of multipurpose cardboard, the mill has been faced with a persistent problem of product appearance. In multipurpose cardboard produced by cardboard machine No. 2, a lighter main layer is visible through the brown top layer. Most often, this manifests itself as ghost lines. The fibre intake capacity of top-layer headbox is restricted to 10–12% of total cardboard fibre. This has created a need for reduced use of lower-cost raw materials, such as NSSP, in the main cardboard layers and, consequently, boosted the price of the products.

To solve this problem, it has been suggested that the semichemical cooking technology be changed. The purpose of this modification is to change the colour of semichemical pulp in order to improve the appearance of the cardboard and increase the share of semichemical pulp in the composition, while maintaining product quality.

It is known that darker semichemical pulp can be obtained by changing the chromophoric groups in lignin, where the pH of the acid liquor is shifted towards the alkaline region (pH 8.5–9.5), by adding a certain amount of alkaline agent, white liquor, to neutral sulphite liquor [2, 3].

Our main tasks were to obtain the half stuff suitable for use in the liner and corrugated paper composition, where the maximum possible share (up to 100%) of neutral sulphite in cooking liquor will be substituted with white liquor; to assess the impact of factors of liquor mix cooking on the physical and mechanical properties of semichemical pulp.

Cooking was performed periodically in the laboratory at Arkhangelsk State Technical University using raw materials and pulping agents selected at the mill.

The experiment was conducted using second-order rotatable composite uniform design. The duration of stay at terminal temperatures and the ratio of substitution of neutral sulphite liquor by white liquor (WL) were accepted as variables. The full description of the variables is shown in table 1.

Constant cooking conditions: water ratio — 4.5, sodium monosulphite/water ratio — 5:1, initial cooking temperature — 150 °C, maximum cooking temperature —175 °C, total alkali consumption per cooking procedure — 20% (in Na_2CO_3 units), duration of increase in temperature to maximum point — 45 min.

Table 1

Variant	Variables		White liquor composition, g/l (in Na_2CO_3 units)		Neutral sulphite liquor composition, g/l (in Na_2CO_3 units)		Yield, %	Kappa number	Milling duration up to 30 °SR, min.
	Substitution with WL,%	Duration of stay, min.	A	Na_2S	Na_2SO_3/Na_2CO_3	Na_2CO_3 total			
1	57.3	30	104.5	32.2	88.5/17.5	106	86	118	22.0
2	57.3	60	104.5	32.2	88.5/17.5	106	80	154	22.0
3	92.6	30	106.0	32.6	87.5/18.6	106	76	134	22.0
4	92.6	60	106.0	32.6	87.5/18.7	106	88	120	22.0
5	75.0	24	111.0	32.2	91.2/19.1	110	76	84	21.5
6	75.0	66	111.0	32.2	91.2/19.2	110	83	80	22.0
7	50.0	45	112.5	32.6	94.9/19.1	114	67	110	22.0
8	100.0	45	102.6	29.8	–	–	91	184	30.0
9	75.0	45	114.7	33.8	90.6/17.0	108	85	132	22.5
10	75.0	45	114.7	33.8	90.6/17.1	108	88	127	22.0
11	75.0	45	112.5	32.6	94.9/19.1	114	89	110	17.0
12	75.0	45	112.5	32.6	94.9/19.2	114	87	125	23.0
13	75.0	45	112.5	32.6	94.9/19.3	114	86	108	17.0

The properties of semichemical pulp were assessed on the basis of yield, the kappa number and a set of physical and mechanical values, such as the standard physical and mechanical characteristics of strength and hardness (breaking length L, bursting strength Π, flat crush resistance CMT, ring crush resistance RCT, short-span compression test *SCT*), stress-related properties (flexural rigidity *EI*, initial elastic modulus E_1, tensile energy absorption TEA, breaking strength ε_p, tensile rigidity S_t, fracture toughness index J_{IC}, bonding force according to Ivanov F_{bond}, density ρ, fibre strength L_0).

Half stuff samples where 1 m^2 of sample weighs 125 g, the freeness is 30 °SR, the yield is 67–91%, and the cooking degree is 80–184 kappa, were obtained as a result of the experiment. These values correspond to extreme, boundary conditions. The average varying range is much smaller: the yield is 80–88%, the cooking degree is 110–135 kappa. Virtually all the samples are deep brown in colour. It is noteworthy that milling duration increased slightly to reach 30 °SR (per 5–6 min., on average) compared to traditional neutral sulphite cooking. The properties of half stuff are shown in table 1.

The results of assessment of the standard physical and mechanical characteristics of semichemical pulp are shown in table 2. The data show that, in all the variants studied, the main indicator values exceed the requirements of the existing NSSP process procedure.

Table 2

Variant	Variables		Physical and mechanical characteristics				
	Substitution with WL,%	Duration of stay, min.	*L*, m	*П*, kPa	CMT_{30}, N	RCT, N	SCT, kN·m
1	57.3	30	9,850	710	300	330	5.9
2	57.3	60	10,100	725	310	360	5.9
3	92.6	30	9,500	775	285	350	6.0
4	92.6	60	10,800	740	300	340	5.6
5	75.0	24	9,650	780	315	345	6.0
6	75.0	66	9,500	760	260	295	5.3
7	50.0	45	9,800	700	280	320	5.5
8	100.0	45	8,500	610	280	280	5.3
9	75.0	45	9,900	700	310	325	5.6
10	75.0	45	9,600	690	255	305	5.4
11	75.0	45	9,950	755	275	310	5.7
12	75.0	45	10,650	750	285	320	5.7
13	75.0	45	11,300	735	235	305	5.2

Table 3

Variant	Substitution with WL,%	Duration of stay, min.	ρ, g/cm^3	F_{bond}, MPa	L_0, m	*EI*, mN·cm^2	E_1, MPa	TEA, J/m^2	ε_p, %	J_{IC}, kJ	S_t, N/mm
1	57.3	30.0	0.87	1.264	9,000	502	7,068	185	2.43	601	1,010
2	57.3	60.0	0.92	1.273	8,100	527	6,274	217	2.69	709	917
3	92.6	30.0	0.85	0.928	9,550	661	6,590	239	2.88	753	1,046
4	92.6	60.0	0.88	1.301	9,150	508	6,599	255	2.94	783	953
5	75.0	23.8	0.94	1.209	8,500	322	6,972	161	2.46	603	854
6	75.0	66.2	0.85	1.163	9,350	445	6,619	204	2.77	839	945
7	50.0	45.0	0.79	0.760	7,600	548	7,087	222	2.78	766	1,008
8	100.0	45.0	0.90	1.001	8,000	536	6,475	160	2.27	676	974
9	75.0	45.0	0.88	1.316	8,500	546	6,306	221	2.73	683	937
10	75.0	45.0	0.91	1.429	9,000	570	6,298	217	2.73	–	920
11	75.0	45.0	0.91	1.423	8,750	519	6,106	223	2.76	812	897
12	75.0	45.0	0.93	0.885	8,550	522	6,316	277	3.21	782	915
13	75.0	45.0	0.88	1.311	8,900	349	6,926	247	3.05	770	911

As follows from table 3, the semichemical pulp is comparable with hardwood sulphate pulp in terms of stress-related properties.

The mathematical model for implementation of the two-factor, second-order, rotatable, composite, uniform design is as follows:

$$y = b_0 + b_1x_1 + b_2x_2 + b_{12}x_1x_2 + b_{11}x_1^2 + b_{22}x_2^2.$$

The values of the ratios in the regression equation of polynomial approximant adequately describing the process ($F_{calc} < F_{tabl}$) for the standard and stress-related properties of semichemical pulp are shown in tables 4 and 5.

Table 4

Ratios	Values of ratios in the equation for standard properties of semichemical pulp						
	High-yield pulp yield	Kappa number	L, m	$П$, kPa	RCT, N	CMT, N	SCT, kN·m
b_0	87.00	120.0	10,300	726.00	313.10	272.07	5.52
b_1	1.99	2.0	166	-6.04	-6.34	-6.60	-0.17
b_2	3.99	10.8	-201	-5.91	-7.10	-3.12	-0.06
b_{12}	4.50	-12.5	260	-12.50	-10.00	1.25	-0.10
b_{11}	-2.88	-14.9	-176	28.70	12.45	11.67	0.15
b_{22}	-3.14	17.6	-372	-28.80	2.45	7.93	0.03
Statistical indicators							
R_{mult}	0.33	0.94	0.99	0.85	0.79	0.75	–
F_{tabl}	6.59	6.59	6.59	6.59	6.59	6.59	6.59
F_{calc}	12.31	3.69	0.68	1.28	7.84	0.38	0.91

Table 5

Ratios	Values of ratios in the equation for stress-related properties of semichemical pulp								
	ρ, g/cm^3	F_{bond}	EI	E_1	TEA	ε_p	J_{IC}	S_t	L_0
b_0	0.903	1.270	501.21	6,392	236.8	2.900	609.5	916.03	8,745.0
b_1	-0.003	0.040	5.6372	-160	13.6	0.100	59.1	-7.18	-10.3
b_2	0.012	0.004	15.50	-127	0.4	-0.003	12.2	3.40	276.0
b_{12}	-0.005	0.090	-44.75	201	-4.3	-0.050	-19.4	-0.20	126.0
b_{11}	-0.001	-0.003	-36.84	168	-17.6	-0.100	54.0	1.47	247.4
b_{22}	-0.026	-0.160	42.41	160	-13.5	-0.140	53.9	47.08	-321.0
Statistical indicators									
R_{mult}	–	–	0.97	0.98	0.95	–	0.95	0.91	0.99
F_{tabl}	6.59	6.59	6.59	6.59	6.59	6.59	6.59	6.59	6.59
F_{calc}	4.55	0.42	0.64	0.21	1.80	1.05	6.11	13.34	5.45

The high numerical values of the multiple correlation coefficient R_{mult} suggest that the approximation is quite accurate.

For hardness, the quadric effect ratios are positive; for strength, they are negative. This suggests that there is a minimum or a maximum, i.e., this confirms the well-known fact that an excessive increase in cooking duration and white liquor content is undesirable. An optimal variant should be used.

Increased cooking intensiveness slightly reduces the strength (L, $П$) and hardness indicators (CMT, SCT), which do not exceed the limits established for traditional neutral sulphite cooking.

Increased values of the variables negatively affect tensile and flexural rigidity (S_t, EI). Increased cooking duration leads to an increase in the indicators describing the elasticity of the material (ε_p, TEA). At the same time, variations in the degree of substitution of sodium monosulphite with white liquor have little, if any, effect on the elasticity of semichemical pulp samples.

For ρ and $F_{св}$, the x_{11}^2 ratios have low values, this predetermining the linear character of the dependence.

Thus, in terms of yield, laboratory samples are comparable with traditional NSSP, while their physical and mechanical properties are not inferior to those of semichemical pulp obtained in real plant conditions.

Another focus of this study is industrial cooking of modified semichemical pulp in cardboard production at OAO Arkhangelsk Pulp and Paper Mill.

The first stage of the field tests was completed in March 2001. A modified mode was launched at one of the two semichemical pulp production lines using Pandia machines; the second line worked in normal mode.

The yield on both lines was the same and made 26.0 kg per each rotation of the meter. After the monosulphite-based cooking liquor was substituted with a mix of strong and weak white liquor, where the volume-to-volume ratio of 1:2 and the pH of 8.6–8.8 were preserved, the volume of the liquid fed into the cooker on the first line went up by 0.5 m^3/t. The characteristics of the liquors used on both lines were virtually constant during the tests. The cooking temperature on the lines changed within the interval of 177–180 °C, the average value for both lines being 178 °C. The mechanical strength of the modified half stuff slightly decreased (by 3–6%) compared to traditional semichemical pulp.

The results achieved in the first stage of the modified NSSP cooking field tests proved the possibility of darkening the pulp using the suggested method without changing the mechanical characteristics of the semichemical pulp.

In May 2001 (when multipurpose cardboard was produced by cardboard machine No. 2), repeated production of semichemical pulp on the two production lines was planned in order to conduct a final assessment of the quality of the semichemical pulp and cardboard. A solution where 50% of sodium monosulphite was substituted with a mix of strong and weak white liquor was used in this process. The results of the assessment of the physical and mechanical and stress-related properties of the cardboard are shown in table 6. Analysis of the properties of the semichemical pulp demonstrated that the degree of undercooking after the hot refining system on both production lines was virtually the same, the kappa numbers being close. The chemical consumption on both production lines was virtually the same, namely: sodium monosulphite — 0.51 m^3/t, strong white liquor — 0.18 m^3/t, weak white liquor — 0.48 m^3/t. The mechanical strength of the semichemical pulp produced using the modified cooking method decreased only slightly while, by the end of the production period, it even increased: breaking length — 7,750 m (as compared to 7,300 m in traditional pulp), bursting strength — 490 kPa (445 kPa), CMT — 325 N (290 N), tearing strength — 860 mN (810 mN).

Table 6

Characteristic	Characteristic value for different sampling periods				
	5/14	5/15	5/16	5/17	production average
Weight of 1 m^2, g	148	150	146	145	147
NSSP content,%	60.7	63.0	70.0	75.4	67.3
П, kPa	560	580	540	530	550
RCT, N	252	286	257	242	259
L, m	9,630 / 3,880	9,870 / 4,190	10,000 / 4,030	9,390 / 3,960	9,720 / 4,015
E_1, MPa	3,313 / 1,804	4,302 / 1,959	4,329 / 1,945	4,606 / 1,946	4,138 / 1,914
S_t, N/m	1,034 / 442	1,047 / 477	1,002 / 448	959 / 409	1,011 / 444
EI, mN·cm^2	863 / 296	836 / 353	679 / 298	509 / 192	722 / 285
ε_p,%	2.15 / 3.31	2.20 / 3.25	2.23 / 3.19	1.95 / 3.09	2.13 / 3.21

Note. The numerator contains data for samples tested in machine direction; the denominator contains data for samples tested in cross-machine direction.

As the degree of substitution of sodium monosulphite with white liquor was increased further (up to 75%), the pulp became even darker and the mechanical properties of cardboard weighing 160 g/m^2 with the pulp content of 55–56% improved. Yet cooking with sodium monosulphite substitution by 75% was accompanied by an increase in emissions of volatile sulphur compounds, which was only reduced with the help of engineering measures. It was also noted that the alkaline balance decreased owing to the reduction in sodium carbonate consumption during the cooking of semichemical pulp.

Since September 2001, cooking with sodium monosulphite substitution with a mix of weak and strong white liquor by 50–60% has been used constantly on the two Pandia machines.

In pilot production, the main goal of modifying the cooking of semichemical pulp was thus achieved: the pulp became darker when at least 50% of sodium monosulphite was substituted with a mix of strong and weak white liquor, without a significant change in the characteristics of the semichemical pulp or deterioration in the physical and mechanical properties of multipurpose cardboard and corrugated paper.

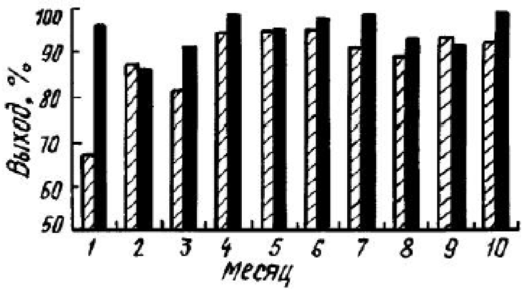

Fig. 1	
Выход,%	Yield,%
Месяц	Month

Fig. 1. Changes in B-0 corrugated paper quality before (□) and after (□) cooking modification (figures from 1 to 10 indicate months, from June to March)

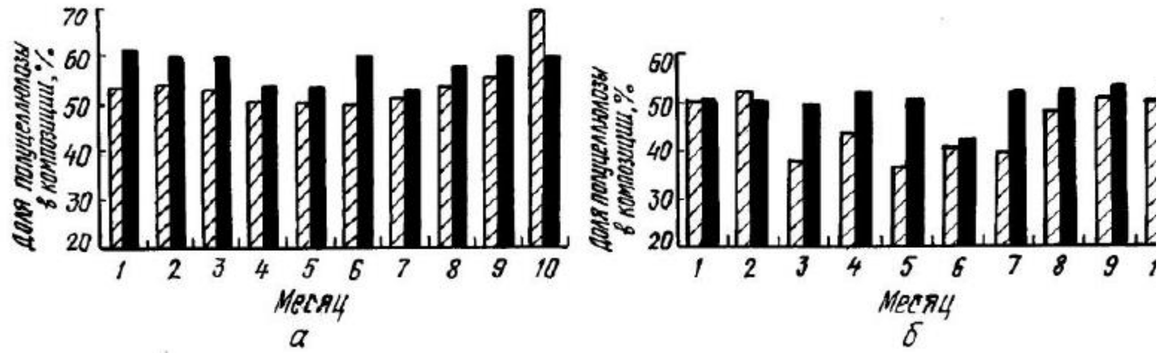

Fig. 2	
Доля полуцеллюлозы в композиции,%	Share of semichemical pulp in the composition,%
Месяц	Month

Fig. 2. Use of semichemical pulp in the corrugated paper (*a*) and multipurpose cardboard (*б*) composition (see the marks in Fig. 1)

In addition, the output of B-0 corrugated paper went up from 88.9% to 95.1%, on average (fig. 1). The quantity of product rejected for failing to meet the flat crush test requirements and because of ghost lines fell several-fold. The pulp yield remained virtually unchanged, averaging 78%.

On average, the content of semichemical pulp in the composition of corrugated paper went up from 52.3% to 57.6% and of multipurpose cardboard — from 44.2% to 50.2% (fig. 2). Darkening of the semichemical pulp made it possible to increase its share in the cardboard composition on cardboard machine No. 1, without affecting its physical appearance.

Consequently, when used for producing corrugated fibreboard and packaging, cardboard and corrugated paper containing up to 55–60% of modified half stuff in their composition do not affect the quality of the products.

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Development and Introduction of Semi-finished Product Cooking Technology for Containerboard

A technology was developed for producing containerboard using modified types of semichemical pulp in composition.