Improved Process Control Strategy for Liquid Phase Kraft Pulping of Bamboo (D. Strictus)

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ABSTRACT

Conventional liquid phase kraft pulping of Bamboo has been studied in detail to develop an improved process control strategy so as to produce pulp of more uniform quality. Results of test experiments, wherein EA_{165} was used to decide H—factor to be applied for obtaining desired degree of delignification, indicated that using the control strategy, target kapppa number of pulp could be con rolled within $\pm$? units under varying operational conditions in raw material quality charging conditions, & liquor composition etc.

INTRODUCTION :

Most of the troubles faced in pulp mills & paper machines can be traced back to the digester house. Lack of appropriate digester control facilities produce pulp of inconsistant quality which cause severe disturbances in subsequent washing, screening & bleaching, in the recovery system & steam generating plants, as well as in paper making.

A survey (1) of pulping practices carried out in India reveals that almost all pulp manufacturing units use manual feedback-control strategy (fig.1) for the operational control of digesters. This is done by determining kappa number of unbleached washed pulp at the end of each batch cook or at regular intervals from brown-stock-washers. The result is then compared with the target kappa number and suitable adjustments in one or more of the manipulated variables, e. g. alkali charge, cooking time or temperature, are made so as to bring the pulp kappa number closer to its target value. Such practice gives only an empirical judgement more by experience than by some rational control technique.

With existing pulping process control strategy, it is rather difficult to achieve the target kappa number to obtain pulp of uniform quality. Feed-back control system is unsatisfactory because of long time delay between control action and the ability to sense the resulting output (2). It does not give a stable and dependable tool to fathom the cooking reactions in the digester.

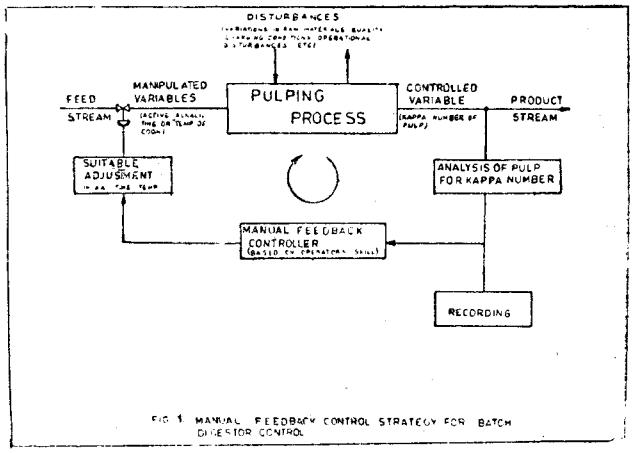

FIG. 1. MANUAL FEEDBACK CONTROL STRATEGY FOR BATCH DIGESTOR CONTROL

since it is not possible to measure the degree of delignification every moment during the cook.

The problem may be solved by adopting a "feed-forward-control strategy". which consists of measuring the input conditions like quality and quantity of raw material and cooking media, besides the total energy input and its nature of distribution during delignification. Based on the detailed study of pulping variables, a suitable combination of H-factor and effective alkali can be chosen to produce pulp of the target kappa number. Once the chips & liquor are charged into the digester, H-factor only remains to be monitored during the cook and as soon as the integrated value of H-factor reaches the desired value, digester is blown.

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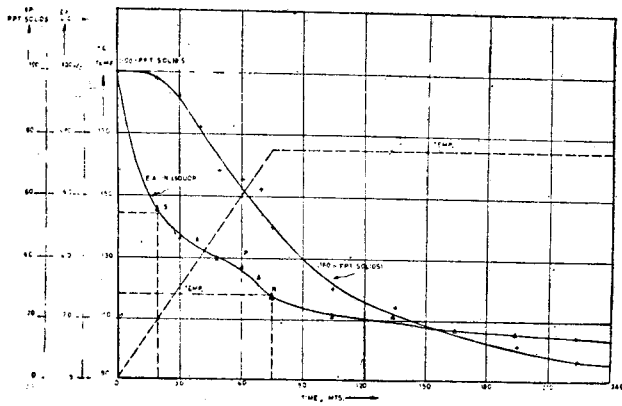
However, this needs successful determination of a number of input variables including exact quantity & quality of the chips charged. Quality of raw materials fluctuates widely because they grow in natural forests where there is seldom any silvicultural control. It also changes due to variations in raw material supply, degree of decay from lot to lot, bark & knot contents and the process variations in the chipper house. Quantity of charge shall vary with chip size and packing density. Effective alkali concentration in white liquor although can be accurately determined but the effective alkali applied shall vary with the varying quantity of chips charged to the digester. Thus, it seems to be rather difficult and costly to accurately measure all these input conditions This variability in raw material supply and possible inaccuracy in digester charging is expected to result in pronounced variation in chemical demand and ultimately the degree of deligni- fication.

Raw material supyly variations can be reduced by installing sophisticated chips handling systems with sorting equipments, several chip piles and blending equipments, weightometers, chip moisture and bulk density meters etc. Obviously, all this is costly and demand maintenance and still the variation in chip quality could not be perfectly eliminated.

Consequently, an improved and simple control strategy is required to be developed to improve the uniformity in output quality under varying input conditions. The feed-forward control strategy as developed by the author provides a strong tool in the hands of pulp technologists to produce pulp of desired uniformity and quality.

DEVELOPMENT OF THE CONTROL STRATEGY :

In conventional kraft pulping. more than 50-70% of the total effective alkali cansumed during a cook is used up in dissolving carbohydrates of lower molecular weight during rise to temperature period (4). The same was confirmed during an experimental cook in which the concentration of organic solids and EA were followed throughout the cook (fig—2). The rather sharp decline in effective alkali concentration during early part of the cook may be attributed to the neutralization of acidic constituents in the raw material, the diffusion of chemicals into the chips and the dissolution of certain lower carbohydrates (3). The inflection point P on fig- corresponding to temperature of 150—155°C indicate the point where bulk delignification begins after the completion of initial neutralization, and carbohydrate dissolution. This is also supported by the results of kinetic study of bamboo pulping (7) plotted on the Ross diagram and yield vs time/temperature curve.



Any variation in quality of raw material affects almost exclusively the initial consumption of alkali. Thus, a varilable amount of alkali is left behind in the process for bulk delignification, resulting in variations in the pulp quality. As can be seen from table I, wherein the EA concentration in liquor samples drawn at 165°C, EA_{165}, is different for different lot of chips with varying quality for the same initial effective alkali. Consequently, effective alkali value after the initial drop is more meaningful in relation to the rate of bulk delignification. The effective alkali in the liquor sample drawn after this initial drop, if correlated with thekappa number of the pulp, and used for feed forward controls can effect closer control of the target kappa number of the pulp.

Table—I : EA Consumption During Heatup Period For Chips from Different Lots

S.NO.	$EA_{appl.}$ gpl	EA_{165} gpl	RATE OF TEMP. RISE °C/min.
1	40	11.23	1
2	40	14.80	1
3	40	13.99	1
4	40	13.12	2
5	40	11.36	2
6	30	6.95	2
7	30	7.86	2
8	30	9.25	1
9	30	9.32	1
10	30	8.51	1

EXPERIMENTAL DESIGN AND OBSERVATIONS :

Cooking experiments were carried out in an electrically heated 2.5 litrer stationary digester equipped with auto-transformer. to regulate the rate of heat input, sampling system and necessary instrumentation.

Bamboo chips were collected from mills chipper house and used for experiments. Pulping liquor from mills white liquor preparation plant was analyzed adjusted for composition and used.

The cooked chips were distintegrated and washed by water over an 80-mesh screen. Pulp yield was calculated based on the OD weight of chips cooked.

Kappa number of pulp was determined using TAPPI std. method T 236 os-76 Effective alkali in liquor was tested by electrometric titration to an end point of 9.5-9.0pH.

The experiments were designed to develop model equations for kraft pulping of bamboo such that these equations correlate the dependent variables - kappa number K and pulp yield Y, with the independent variables-effective alkali EA and Hfactor. Process conditions were so selected that bleachable grade kraft pulp was produccd.

Samples of liquor were drawn at 110°C (when the initial reactions are still in progress) & at 165°C (when these reactions are over) and tested for EA concentration.

The results are tabulted in table 2.

DEVELOPMENT OF PROCESS MODELS:

The linear expression

$$(K,Y) = A + B.\ (\ln H).\ (EA)^n$$

as proposed by Hatton (6) was used to analyze the data.

The constants A and B were determined for each data by means of a stepwise multiple regression analysis. Determination of the value of n required making series

TABLE-2: DEVELOPMENT OF MODEL FOR FEED FORWARD CONTROL AND VALIDITY OF H-FACTOR IN CONVENTIONAL LIQUID PHASE KRAFT PULPING

Bamboo chips lot: "A"; L:W = 4:1; Sulfidity of white liquor: 20±0.5% ; Rate of Temperature rise: 1°C/min.

COOK NO.	MAX. TEMP.	$EA_{appl.}$	TIME AT MAX. TEMP.	H-FACTOR	EA_{110}	EA_{165}	PULP YIELD			KAPPA NUMBER	$EA_{res.}$	
							Total	Rejects	Screened			
	°C	% od Chips gpl	min..		gpl	gpl	%	%	%		gpl	(% od chips)
BKL 1	165	15% 38.57	-	410	24.51	12.73	49.50	1.40	43.10	31.8	10.00	3.89
BKL 2		"		750	24.00	12.60	43.00	0.62	42.38	24.5	8.55	3.33
BKL 3		"		1045	24.32	12.67	40.50	0.20	40.30	21.6	7.69	2.99
BKL 4		"		1340	24.83	12.81	39.05	-	39.05	18.8	7.09	2.76
BKL 5	165	14% 36.00	-	420	20.87	11.48	51.55	1.93	49.62	37.0	9.02	3.51
BKL 6		"		710	20.15	11.68	46.50	1.30	45.20	30.1	7.92	3.08
BKL 7		"		1000	19.95	11.35	44.90	1.05	43.85	26.7	6.88	2.68
BKL 8		"		1340	20.70	11.30	43.15	0.90	42.25	24.5	6.26	2.44
BKL 9	165	13% 33.43	-	420	17.22	9.93	54.85	2.50	52.35	42.2	8.35	3.25
BKL10		"		730	17.46	10.00	50.50	1.60	48.90	35.0	6.78	2.64
BKL11		"		1040	18.00	10.00	47.50	1.15	46.35	30.7	6.05	2.35
BKL12		"		1330	17.90	9.81	46.00	1.20	44.80	28.8	5.43	2.11
BKL13	165	12% 30.86	-	420	15.60	8.76	58.10	3.60	54.50	47.0	6.88	2.68
BKL14		"		750	14.88	8.68	54.30	3.17	51.13	40.3	5.89	2.29
BKL15		"		1040	15.30	8.27	51.45	1.85	49.60	36.5	5.00	1.95
BKL16		"		1350	14.95	8.47	49.80	1.55	48.25	33.5	4.69	1.82
BKL17	175	13% 33.43	9.0	500	-	-	53.20	2.55	50.65	39.6	7.85	3.05
BKL18		"	17,5	700	-	-	51.15	1.50	49.65	36.0	7.00	2.72
BKL19		"	26.5	900	-	-	48.50	1.30	47.20	32.6	6.80	2.65
BKL20		"	35.0	1100	-	-	47.10	1.00	46.10	30.0	5.55	2.16
BKL21	185	13% 33.43	3.0	800	-	-	49.25	1.00	48.25	34.0	6.50	2.53
BKL22		"	7.0	1000	-	-	48.00	1.00	47.00	30.8	6.10	2.37
BKL23		"	11.0	1200	-	-	45.90	0.92	44.98	29.2	5.90	2.30
BKL24		"	16.5	1500	-	-	44.95	0.20	44.75	28.0	3.01	1.17
BKL25	155	13% "	57.0	300	-	-	59.15	3.95	55.20	47.2	8.95	3.48
BKL26		"	80.5	400	-	-	55.50	2.55	52.95	42.3	8.95	3.48
BKL27		"	103.5	500	-	-	53.95	3.11	50.84	40.1	7.50	2.92
BKL28		"	127.0	600	-	-	52.00	1.85	50.15	37.3	7.00	2.72
BKL29		"	173.5	800		-	50.05	1.62	48.43	34.3	6.45	2.51

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of calculations using a different value each time between 0.1 to 1.0. The combination of A, B & n giving the least value of the sample standard deviation σ_{n-1} was taken to be as correct representation of the data.

The three pairs of model equations developed based on $EA_{appl.}$, EA_{110} & EA_{165} are as follows:

$$K = 111.9038 - 1.4926\ (\ln H)\ (EA_{appl.})^{0.8}; \quad \sigma_{n-1} = 0.8300 \quad ...(1)$$

$$Y = 103.4675 - 1.0306\ (\ln H)\ (EA_{appl.})^{0.8}; \quad \sigma_{n-1} = 0.5680 \quad ...(2)$$

$$K = 108.4365 - 3.5084\ (\ln H)\ (EA_{110})^{0.4}; \quad \sigma_{n-1} = 1.0746 \quad ...(3)$$

$$Y = 98.2048 - 2.0353\ (\ln H)\ (EA_{110})^{0.44}; \quad \sigma_{n-1} = 0.9685 \quad ...(4)$$

$$K = 108.2661 - 3.5093\ (\ln H)\ (EA_{165})^{0.5}; \quad \sigma_{n-1} = 0.9447 \quad ...5)$$

$$Y = 97.9724 - 2.0313\ (\ln H)\ (EA_{165})^{0.55}; \quad \sigma_{n-1} = 0.6711 \quad ..(6)$$

Since 95% of the observations will lie within $\pm 2\sigma_{n-1}$ limits, we can control K in the range of $K_{target} \pm 2$ using any of these equations, provided the inputs are accurately measured

PROCESS-MODEL TESTING :

To establish the applicability of the process model-equations 1 to 6 under mill process variability, a series of model-test cooks were conducted to cover the practical range of operating conditions. The process conditions are described in the following lines & the results are given in table—3.

i) mill run chips of bamboo collected from different lots x, y, z etc.

ii) chips size $-\frac{3}{4}'' + \frac{1}{4}''$

iii) Effective alkali (% on chips) : Varying

iv) Sulfidity of white liquor : 15 to 25%

v) L/W ratio 3.2 to 4.2 on gross weight of chips, since moisture is not known

vi) varying time from digester charging to the temperature of 100°C—such condition sometimes arises in mill practice, when loaded digester is to wait for steam, power etc.

TABLE- 3 : TESTING OF MODEL EQUATIONS DEVELOPED BASED ON $EA_{appl.}$, EA_{110} & EA_{165} USING H-FACTOR CONCEPT FOR CONVENTIONAL LIQUID PHASE KRAFT PULPING

COOK NO.	FEED FORWARD CONTROL THROUGH	MOISTURE (PRESUMED) (%)	L:W (GROSS) (cc/g)	$EA_{appl.}$ (% on gross wt.of chips)	$EA_{appl.}$ (% on od chips)	SULFIDITY OF WL (%)	TIME TO 100°C (min.)	TIME FROM 100 to 165°C (min.)	EA_{110} (gpl)	EA_{165} (gpl)	REQUIRED H-FACTOR (CALCULATED)	$K_{obs.}$	$(K_{obs} - K_{control})$
T-1	$EA_{appl.}$	8%	3.6	13.8	15.00	24.6	30	80		11.75	540	33.4	+3.4
T-2	"	8%	[illegible]	10.5	11.42	15.0	60	66	14.50	8.55	2490	28.1	-1.9
T-3	"	8%	4.0	12.0	13.04	20.0	100	65	16.30	9.30	1135	32.5	+2.5
T-4	EA_{110}	-	3.3	14.0	-	16.0	[illegible]	51	26.15	13.65	430	30.5	+0.5
T-5	"	-	3.6	13.0	-	18.0	200	60	16.50	9.20	1455	31.0	+1.0
T-6	"	-	[illegible]	12.5	-	18.5	180	75	17.65	9.75	1200	29.0	-1.0
T-7	"	-	4.0	12.9	-	22.0	30	80	17.90	10.00	1155	28.5	-1.5
T-8	"	-	3.5	14.0	-	24.5	50	5[illegible]	25.50	12.65	455	31.2	+1.2
T-9	EA_{165}	-	3.6	14.5	-	17.0	50	65	-	11.50	720	31.0	+1.0
T-10	"	-	3.5	13.0	-	18.0	55	66	-	9.20	1560	29.5	-0.5
T-11	"	-	4.0	12.5	-	18.0	60	85	-	9.45	2150	29.3	-0.8
T-12	"	-	[illegible]	12.8	-	[illegible]5	180	5[illegible]	-	10.60	945	30.6	+0.6
T-13	"	-	4.1	13.5	-	[illegible]0	120	55	-	11.80	660	30.2	+0.2
T-14	"	-	4.0	14.0	-	20.0	15	82	-	13.30	455	30.9	+0.9
T-15	"	-	3.4	11.0	-	22.0	15	71	-	11.50	720	31.0	+1.0
T-16	"	-	3.6	12.8	-	23.5	15	83	-	11.40	740	28.9	-1[illegible]

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vii) Rate of temperature rise 0.8° C/min to 1.2°C/min

viii) Temperature of cooking up to 170°C

ix) In the experiment no. T–1 to T–3, where EA applied is used for control purpose, the chip moisture was presumed to be 8% for calculating the alkali to be charged to the digester

x) Target kappa number : 30

Considerations were given to EAappl., EA_{110}, EA_{165} separately and individual model equations were used to estimate H-factor required to achieve the target kappa number of 30. As is seen from table–3, the deviation of kappa number of the pulp from its target value was the least, when model based on EA_{165} was used for control purposes, under varying raw material quality & charging conditions.

The rather complex problem of accurately measuring the charge weight of the chips, nature, white and black liquor strengths and volumes, raw material quality etc. to obtain pulp of desired uniform quality is thus reduced to simply an accurate measurement of effective alkali concentration in a liquor sample drawn at 155°C.

Thus, for improved process control and output of more uniform quality "once the digester is charged with chips and alkali and the cook is started, a liquor sample is drawn when the temperature reaches 165° & tested for EA concentration Based on the correlations developed, suitable adjustment in the value of H-factor to be applied. is made. As soon as the integrated value of H-factor corresponds to this adjusted value, the digester is blown".

APPLICATION OF THE DEVELOPED CONTROL STRATEGY :

1) Evaluation Of The Existing Operations :

Prior to implementation of the new control system a base line evaluation is to be made on the digester operations to determine the average permanagnate-number/kappa number and calculate the standard deviation. This will require installation of blow line sampling system where the samples of pulp can be collected at periodic intervals during the blow for each of these cooks. Statistical analysis on these random samples could give the pooled estimate of variance of P or K number within each cook σ^2 and between cooks σ^2. The variability within the cook should be low enough to proceed with K number controls between cooks, otherwise suggestions of Bailey & Yawn (5) may be implemented first. The variance σ^2 could be used for purposes of comparison after implementation of the new system.

During the evaluation, data on process variables including EA_{165} & H—factor for each cook should also be separately recorded to either confirm or modify, if necessary the model equation developed on the laboratory investigations.

2) CONTROL SYSTEM COMPONENTS :

i) the liquor sampling system : This may consist of a sample probe, the sampling valves, liquor cooler, a high pressure back flush system, and inter connecting piping- The details may vary from installation to installation and are dependent upon digester type, configuration and plant layout.

ii) the temperature measuring system : This consists of temperature probes, indicator & recorder and the H-factor meter (integrator).

iii) the liquor analyzer: Which has a precision of ± 0.3 gpl in determining EA concentration in the liquor system. An automatic liquor sampling and analysis system may be installed to give directly EA_{165} (gpl).

iv) the steam flow control system : Based on the maximum steam flow restraint. The steam is introduced to capped digesters in queue.

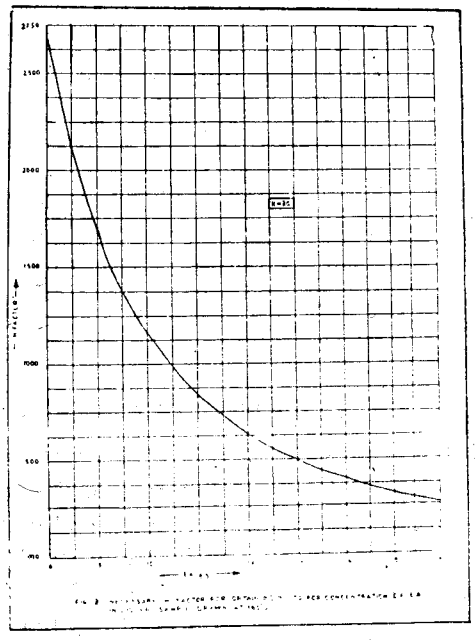
v) the cooking temperature and blow line control system. This may operate on the basis of production constraint. It includes temperature controller buzzer connected to H-factor meter & blow valve switch etc.

vi) the curve of EA vs H-factor for the target kappa number control : This may be based on the process model used for determining H-factor for the analyzed EA_{165} (gpl) similar to fig-3.

3) SYSTEM OPERATION :

Fig-4 is a block diagram of the improved feed forward control loop. The manual system could work as follows :

After the digester is charged with chips, white liquor and black liquor and the lid is closed, available



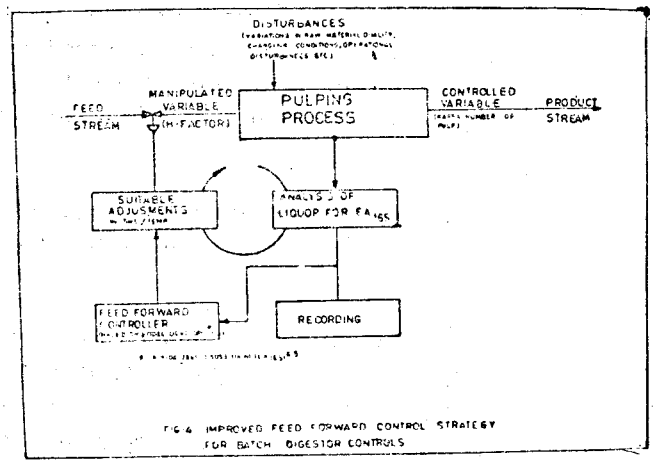
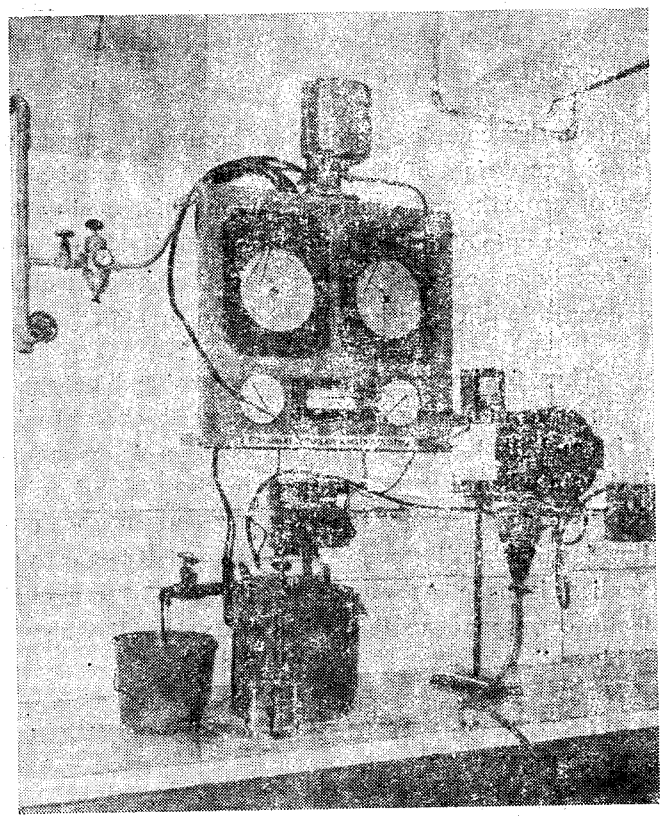


FIG 4 IMPROVED FEED FORWARD CONTROL STRATEGY FOR BATCH DIGESTOR CONTROLS

steam subject to the maximum steam flow restraint is allowed to flow into the digester. The H—factor meter, then starts integrating the value of H. When the temperature reaches 165°C, a liquor sample is withdrawn and tested using electrometric titration to give EA concentration (gpl) of the sample. EA_{165} is then used along with the process—model to compute the H – factor required to achieve the target kappa number. Time–temperature schedule is then decided based on the production restraints. The H–factor meter continues to integrate H–factor value, till the end of the cook. It is preferable to have an arrangement for a buzzer, which sounds about 5 – 10 minutes prior to the blow time for alerting the operator. Once the final H–factor is reached, a second alarm may instruct the operator to operate the blow valve. The counter is then manually reset to zero to start the new cook.

If the system is equipped with computer directed controls with the production and steam flow control feature, then the time–of–start steaming rate, top temperature, and the total H–factor to be applied all can be directed by the computer. In this case, the steaming profiles may vary to fit the production constraint entered by the operator.



Conclusions :

A simple feed forward control strategy for the control of industrial batch digester cooking of Bamboo have been developed. The implementation of such a control system makes it possible to produce pulp with a predetermined kappa number with extremely good accuracy without a sytem of measuring & blending equipments except for an addition liquor sample tasting facility. No extra

care is needed in charging, and the system can handle a great variety of pulping schedules.

The method is basically simple and require only the measurement of EA concentration in either one or two samples of pulping liquor drawn from the digester at specified time. Itcan be adopted to either manual, semiautomatic or automatic control of batch digester cooking.

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