The H factor for Bamboo Sulphate Pulping : A device to control pulp mill operation

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The sulphate pulping of bamboo (Dendrocalamus strictus) was studied from beginning to the end of cook, applying the concept of representing the times and temperatures of the cooking cycle by a single numerical value referred to as Vroom' H factor. The experimental results showed that the H factor can be employed as a means of predicting compensating adjustments of cooking times and temperatures to give the same yield of pulp, kappa number and lignin content wiih varying cooking cycles. This indicated that the concept of H factor can suitably be applied as a guide for controlling sulphate pulping process of bamboo in mills by predicting times for a variety of temperatures or vice-versa to make necesssary adjustments in the cooking cycle, (whenever there is any deviation in standard cooking cycle due to operational difficulties) so as to get equivalent pulp yield. For the experimental standard cooking cycle employed in this investigation (90 min. from 80°C to 170°C and 90 min. at 170°C) the H factor was found to be 91982.

Introduction

In a chemical pulping process there are two portions of the cooking cycles : (i) the portion in which the temperature of the contents of the digester is raised gradually to a constant temperature leval i. e. rise-to-temperature portion and (ii) the portion in which the contents of the digester after being raised to a constant temperature level are held at that temperature for a certain interval of time i.e. at-temperature portion. Thus under otherwise constant conditions of pulping the degree of delignification in any cooking cycle is a function of time and temperature. These variables are generally represented by a time-temperature profile. However, it is inadequate to have two variables at a time to allude the degree of delignification accomplished at any moment. Therefore, to improve upon the efficiency of experiments in the field of chemical pulping, to have a ready guide for adjusting times for a variety of pulping temperatures (when it is necessary to compare the effects of temperatures on pulps ccoked to the same degree) and to rationalize the degree of cookIng accomplished in a cooking cycle, time and temperature should be combined and represented as one numerical factor.

A few methods of expressing time temperature profile as a single numerical factor have been reported in literature. The development of single numerical factor has been on the basis of assuming the dependence of rate of delignification with temperature and time and calculating relative reaction rate values. Vroom[1] assumed that the Arrhenius equation of dependence of rate of reaction with temperature will satisfactorily describe the relationship between rate of delignification and temperature in sulphate pulping process and calculated the relative reaction rate values for a range of temperature levels to develop a single numerical factor called 'the H factor' for representing times and temperatures by one numerical value. He defined the H factor as the area under a relative reaction rate versus time curve.

Determination of the H factor

As stated above, for the determination of the H factor relative

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reaction rate values for a range of temperature are calculated employing the Arrhenius equation $(k=B_{\bullet}{}^{-A/RT})$. Vrcom employed the Arrhenius equation in the form of

$$\ln k = B - A/T \qquad (1)$$

(where k is the rate of delignification, A and B are constants and T is temperature in Kelvin scale) and arbitrarily assumed that the rate of delignification at 100°C in sulphate pulping is unity. A value for, A of 16113 reported by Larocque and Mass[1] was selected by him and the rates of delignification reaction at other temperatures being scaled to this standard. The equation (1) at 100°C becomes

$(0)=B-16113/T$ giving $B=43.20$. Thus, the relative rate values of delignification at any temperature is given by

$$k = \ln^{-1}(43.20 - 16113/T) \qquad (2)$$

From the equation (2) the value of k, can be calculated for any temperature level. The value of, k, for various temperature levels in centigrade scale are reported in Table-I. The H factor thus can be determined by plotting relative reaction rate values against time or temperature and finding out the area under the curve obtained.

Another method for calculating the H factor for any cooking cycle is demonstrated in Table-II, taking the standard cooking cycle of 90 minutes to 170°C from 50°C and 90 minutes at 170°C employed in this investigation as an example.

Table—I

Relative rate values for the H factor in Sulphate Pulping

Temperature °C	Relative rate	Temperature °C	Relative rate	Temperature °C	Relative rate
100	1	130	25	160	401
101	1	131	28	161	435
102	1	132	32	162	471
103	1	133	34	163	511
104	2	134	37	164	568
105	2	135	41	165	610
106	2	136	46	166	661
107	2	137	49	167	716
108	2	138	54	168	777
109	3	139	60	169	855
110	3	140	66	170	927
111	3	141	73	171	1005
112	4	142	79	172	1089
113	4	143	87	173	1180
114	5	144	96	174	1279
115	5	145	105	175	1387
116	6	146	114	176	1503
117	7	147	126	177	1629
118	7	148	138	178	1786
119	8	149	150	179	1714
120	9	150	165	180	2042
121	10	151	182	181	2213
122	11	152	197	182	2398
123	12	153	217	183	2600
124	14	154	236	184	2818
125	15	155	260	185	3054
126	17	156	281	186	3258
127	18	157	305	187	3531
128	20	158	336	188	3827
129	22	159	364	189	4032

Table—II

Calulation of H Factor employing standard cooking cycle

Time from start, minutes	Temperature °C	Relative Rate from Table-I	Average rate (R)	Time interval (t) minutes	H*=Rxt
0.0	50	0	0.0	0	0
30.0	90	0	0.0	30	0
37.5	100	1	0.5	7.5	4
45.0	110	3	2.0	7.5	155
52.5	120	9	6.0	7.5	48
60.0	130	25	17.0	7.5	121
67.5	140	66	45.5	7.5	346
75.0	150	165	115.5	7.5	863
82.5	160	401	283 0	7.5	2120
90.0	170	927	664.0	7.5	4980
...	...	...	...		8343
90.0	170	927	927	90.0	
				Total	91932

*Calulated to the nearest whole number

Importance of the H factor

The H factor as a means of expressing cooking times and temperatures is very useful and of great importance in the field of sulphate pulping. In mill operations it is of great value in predicting necessary adjustments to be made in either cooking time or temperature to produce equivalent pulp yield (when any deviation from the standard cycle becomes necessary). The suitability and application of the H factor have largely been tested for sulphate pulping of hardwoods and softwoods.[1] Most of the mills in India employ sulphate pulping process for production of pulp and use bamboo as a major raw material. There has been no attempt. so far, to study the sulphate pulping of bamboo from the beginning to the end of cook. so as to provide guidelines, such as the H factor to facilitate the process control of pulp mill operations. Therefore sulphate pulping of bamboo (*Dendrocalamus strictus*) has been studied from beginning to the and of the cook and the present paper deals with the determinatlon of the H factor and examination of its suitability

Experimental

Standard cooking cycle :

The sulphate pulping of bamboo was carried out choosing a standard cycle of 3 hours for a maximum temperature of 170°C. A series of experiments was carried out by digesting bamboo chips (500 g.) for different intervals of time of cooking at 170°C (ranging from 0 to 90 min.) in an electrically regulated rotary autoclave, employing the following constant conditions:—

Active aikalie	—15% as Na_2O o.d. chips
Sulphidity	—25%
Material to liquor ratio	—1:4
Initial temperature	-50°C
Time of raise 170°	-90 minutes
Rate of rise of temperature	—4°/3 minutes

In another series of experiments under otherwise constant conditions, bamboo chips (500 g) were digested at temperature ranging from 100 to 190°C. The time required to reach the desired maximum temperature from initial temperature was carefully noted. The digester was blown at maximum temperature immediately without holding the contents for any time and contents removed. The at-temperature portion in this series was eliminated. The semi-cooked material was refined in laboratory disc refiner.

Prediced cooking cycle

Pulping of bamboo chips (500 g.) was carried, under otherwise constant conditions of cooking, at four at-temperature levels (160, 165 175 and 180°C) for a period of predicted time (229, 181, 66 and 45 minutes) for respective at-temperature level after raising the temperature of the contents of digester from 80°C to maximum at-temperature level in 90 minntes.

Analysis of pulps

The yield of pulps, Kappa number and lignin content were determined. Tappi standard methods were employed to determine the lignin in pulp and kappa number of pulp.

Results and discussion

The results of both the series of experiments carried out with standard in Table III. The results of experiments employing predicted cooking cycles for 4 at-temperature levels are recorded in Table IV.

The values of ,k, for the temperature range of 100-170°C when

Table—III

Variation in Yield with Time and Temperature and H factor

Time minutes	Blow Temperature °C	Total Yield %	H factor = Rxt
180	170	43.6	9270
170	170	44.4	9270
160	170	45.4	9270
150	170	46.0	9270
140	170	47.6	9270
130	170	48.4	9270
120	170	48.9	9270
110	170	49.4	9270
100	170	49.8	9270
90	170	50.0	4980
82.5	160	56.3	2128
75.0	150	57.6	866
67.5	140	62.0	341
60.0	130	68 0	128
52.5	120	70.0	45
45.0	110	75.0	15
37.5	100	81.2	4

Table—IV

Comparison of Yield and Lignin content of the pulps procured applying predicted time values with those obtained with standard cycle

Cooking temperature °C	Predicted time at-temperature minutes	Yield %	Lignin %	Kappa Number
160	229	44.0	2.6	26.3
165	161	44.4	2.8	26.5
175	66	43.6	2.9	27.0
180	45	43.0	2.6	26.0
170*	90*	43.6*	2.6*	26.0^{x}

*Results with standard cycle.

plotted against time required to reach that tempereture from 50°C gave a curve as shown in Fig. 1. The area under the curve represented by oblique lines gave the value 91, 982. This numerical valus represents the H factor for the particular standard cycle of sulphate pulping of bamboo employed in this investigation. Likewise the A factor for any cooking cycle can be determined.

The application of another method of the H factor determinetion as demonstrated in Table II for the standard cooking cycle employed in this investigation also gave an approximately the same value as obtained by finding the area under the curve in Fig. 1. This shows that this method can also be employed for easier calculation of approximate value of the H factor. For accuracy in predicting time values, the time interval between two temperature levels is represented in minutes.

Suitability of the H factor

To test the suitability of the H factor for bamboo sulphate pulping, the required cooking times at other 4 at-temperature levels (160, 166, 175 and 180°) were predicted with the aid of the H factor value of 91,982. As indicated in Table-II, H=R.t; where R=relative reaction rate and t is time interval at-temperatnre level The values of R are known from Table-I for various temperature levels. Thus substituting for R from Table-I values of time. t, can be calculated for various at-temperature levels. The values obtained for 160, 165, 175 and 180°C were 229, 151, 66 and 45 minutes respectioely. The pulping of bamboo chips (500 g.) under otherwise constant conditions at above mentioned 4 at-temperature levels for a period of predicted time for respective at-temperature level, after raising the temperature of the contents of the digester from 50°C to maximum temperature level in 90 minutes, gave the pulps of the analysis as recorded in Table-IV. A perusal of the data on yield, lignin contents and Kappa number of pulps recorded in Table-IV shows that these are practically the same as obtained with the pulp prepared at 170°C with standard cooking cycle employed. This indicates that the use of the H factor as a means of expressing cooking times and temperatures as a single variable in sulphate pulping of bamboo has been found quite satisfactory. In other words, regardless of cooking temperature, equal areas under the rate versus time curves-that is, equal H factors produced pulps of equivalent Kappa number and lignin content.

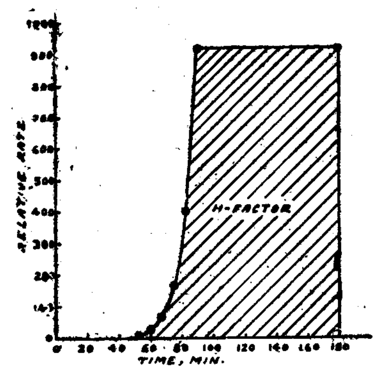

FIG. 1. 'H'-FACTOR FOR THE COOKING CYCLE.

Uses of H factor

Its major use is visualized as a means of predicting the required change in cooking time to compensate for some changes in temperature during cooking. In mill operation on occassions, it may be necessary to shorten the cooking time, perhaps due to operational difficulties delaying the start-up of a digester. The H factor provides a suitable means of predicting the increase in maximum temperature which will be required to enable a normal pulp to be preduced in the shortened time.

Reference

1. Vroom, K.B., *Pulp Paper Mag. Can.*, 58, No. 3, 228 (1957).