Geliş Tarihi: 03.11.2007

“G-factor” Calculations and Applications for Kraft Pulping

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ABSTRACT

A “G-factor” is proposed to combine cooking time and temperature into a single variable, similar in concept to Vroom’s H-factor, for calculating the effect on pulp viscosity of widely varying cooking cycles.

In this study, after giving some explanatory information about calculation and application of G-factor, the effects of increasing alkali concentration on viscosity were investigated for the same G-factor. For Anatolian Black Pine kraft pulping trials, increasing alkali charge causes viscosity decrease at the same G-factor level. Since viscosity loss has higher activation energy than delignification, higher pulping temperatures always lead to lower viscosities.

Keywords: G-factor, Kraft pulping, Anatolian black pine

“G-Faktörü” Hesaplamaları ve Kraft Pişirmeleri İçin Uygulamalar

ÖZET

“G-faktörü” Vroom’un H-faktörüne benzer bir şekilde, kâğıt hamuru viskozitesi üzerine etki eden pişirme süresi ve sıcaklığının kombine edildiği tek bir değişken olarak tanımlanır.

Bu çalışmada, G-faktörünün hesaplanması ve uygulanması konusunda bazı bilgiler verildikten sonra aynı G-faktörü değeri için artan alkali konsantrasyonunun Anadolu Karaçamı kraft hamurlarının viskoziteleri üzerine etkileri araştırılmıştır. Anadolu Karaçamı kraft pişirmeleri için aynı G-faktörü düzeyinde artan aktif alkali yükünün viskozite azalmasına sebep olmuştur. Viskozite kaybı delignifikasyona oranla daha fazla aktivasyon enerjisine sahip olduğundan, yüksek pişirme sıcaklıkları daima daha düşük viskoziteye sahip hamurlar elde edilmesine neden olur.

Anahtar Kelimeler: G-faktörü, Kraft pişirmesi, Anadolu karaçamı

1. INTRODUCTION

During delignification, there is a corresponding reduction in pulp viscosity (a measure of cellulose weighed-average molecular weight). If pulp viscosity is allowed to fall below a critical level, the pulp strength drops dramatically. Maintenance of pulp viscosity is the principal reason that the kraft cook must be terminated at a point where a substantial level of residual lignin remains with the fibers.

A derivation termed the G-factor can be applied for the viscosity reduction. Pulp viscosity is a unique function of G-factor i.e. combinations of time and temperature that give the same G-factor can be expected to produce pulp with the same viscosity. Because the G-factor increases more rapidly with temperature than the H-factor, it follows that higher pulping temperature has a proportionally greater effect on viscosity reduction. This is the principal reason why the pulping temperatures above 180 ^{o}C are avoided (SMOOK 1992).

G-factor relates to viscosity in the same manner as H-factor relates to kappa number. If this proves to be a generally applicable concept, it will be a useful means of incorporation considerations of pulp quality into the criteria for choosing digester operating conditions (KOCUREK 1989).

H-factor successfully predicts both lignin content and yield, but the same is not true for viscosity of pulp. Because, the activation energy of the cellulose chain cleavage reaction is not the same as that of delignification (KOCUREK 1989).

The aim of this study is to give information about how to calculate G-factor after giving explanatory information and determine the effects of the alkali charge on viscosity and G-factor for Anatolian Black Pine (*Pinus nigra* subsp. *Pallassiana*) kraft pulps.

2. EXPERIMENTAL

2.1. Raw Material

Air-dried Crimean Pine woods were (*Pinus nigra* Arnold sbsp. *pallassiana*) obtained from West Black sea region of Turkey

2.2. Pulping and Pulp Analyses

Pulping trials were carried out in a 15 L. batch cylindrical reactor which was heated electrically. Temperature was controlled by Omron E5CK type digital controller unit in the range of ±0.2 ºC, cooked material was disintegrated by a laboratory type 2 L. pulp mixer for 10 minute at 2% consistency. Then, the pulp screened on a Noram type laboratory type pulp screen with 0.15 mm slots. In order to perform uniform pulping conditions the starting materials were chipped as 20 x 20 x (2-4) mm air-dried and used for pulping. SCAN-cm 15:88 standard method was used for determination of the pulp viscosities.

2.3. Calculating of G-Factor

As derived for application to the kinetics of delignification, Vroom's H-factor (VROOM 1957) can be defined according to Eq. 1, where $K_{lig(373)}$ is the delignification rate at 100 ^{o}C (373 K). Now by analog with the H-factor, we can define the G-factor for viscosity loss as a means of expressing the effect of pulping time and temperature in a single variable (Eq. 2)

$$H = 1 / (K_{lig(373)}) \int_0^t klig(T)dt \quad (1)$$

$$G = 1 / (Kvis_{(373)}) \int_0^t kvis(T)dt \quad (2)$$

Kubes at al (1983) presents the kraft data in Figure 1 that, at constant alkali charge, straight-line plots of viscosity^{-1} versus time were obtained, with a different slope for each cooking temperature.

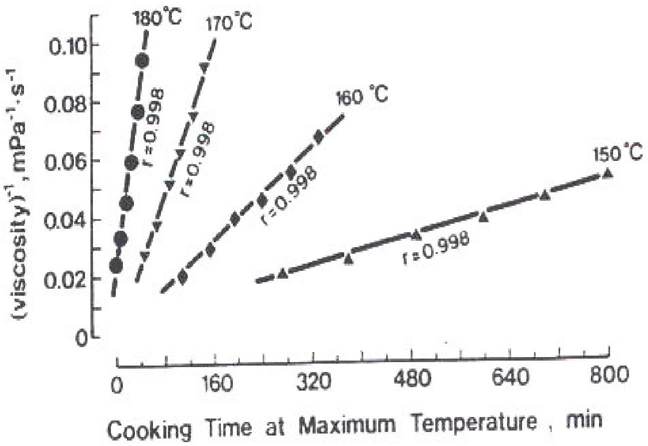

Figure 1. Reciprocal viscosities of unbleached black spruce are plotted against time at for different maximum temperature

The slopes represent the specific rates, k_{vis}, of the chain cleavage reaction, and their significance derives from the Arrhenius equation (Eq. 3) which relates a reaction rate, k, to the absolute temperature, T, and the activation energy, E_a, of the reaction; A and R are constant.

$$k = A \cdot e^{-\frac{E_a}{RT}} \qquad 3$$

$$k_{vis} = A_{vis}\, e^{-\frac{E_{a\,vis}}{RT}} \qquad 4$$

For viscosity loss as a function of temperature, the Arrhenius Equation can be rewritten as Eq. 4, where the k_{vis} values are the slopes of the lines in Figure1, and $E_{a,vis}$ represents the activation energy for viscosity loss. After co-variance analyses of the soda-AQ and kraft data points of the Arrhenius equation plot, there were not seen any difference between two pulping results and activation energy of 179±4 kJ/mol for viscosity loss was obtained by Kubes et al. (1983).

Table 1. Calculation of the G-factor (initial digestion at 170 ^{o}C)

Time from start (h)	Temp. (^{o}C)	Relative reaction rate	Av. Rate	x	Time interval (h)	=	G-Factor
0.00	20.0	0					
0.25	45.0	0					
0.50	71.0	0					
0.75	96.5	0					
1.00	122.0	25	12.5	x	0.25	=	3
1.25	147.0	718	371.5	x	0.25	=	93
1.50	170.0	9100	4910	x	0.25	=	1228
3.16	170.0	9100	4910	x	0.25	=	15200
	Total G-factor = 16524						

The G-factor is usually calculated by a numerical procedure that is equivalent to plotting the relative rate constant vs. pulping time and evaluating the area under the curve (KUBES ve ark. 1983; LI ve ark. 2000). An example is given in Table 1. In the rise to temperature portion it is usually accurate to average the relative rate constant over 0.25 h periods. The curve temperature vs. time, with its corresponding curve of relative rate constant vs. time is shown in Figure2. The G-factor, i.e., the area under the rate curve, is given by the total value in column 6 of Table 1, obtained by adding the products of average relative rate constants and the corresponding time intervals over which the respective average rates pertain.

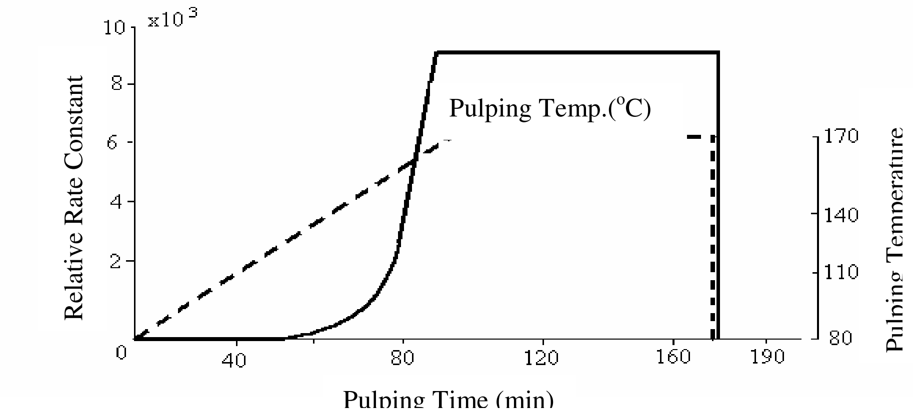

Figure 2. Temperature and relative reaction rate of kraft pulping vs. pulping time (AUREL/HARTLER 1965)

3. RESULTS and DISCUSSIONS

Pulping trials were conducted under the operating conditions varied over the following ranges: 7600, 15500 and 23400 G-factor level, 14%, 18% and 22% active alkali charge and 15%, 30% and 45% sulphidity charge. 27 pulping trials were conducted according to 3x3x3 experimental factorial design and each experiment was duplicated. Viscosity values belong to each pulp sample were presented in Table 2.

As can be seen in Fig 3., while increasing sulphidity rate, viscosity of the pulp samples are increasing too. On the other hand, Gullichsen and Paulapuro 1999 and Smook 1992 were stated that, increasing sulfidity from zero to forty percent increases average fiber length and strength properties.

Table 2. Pulping of Anatolian Black Pine with various pulping conditions

Pulping No	Sulphidity. Rate (%)	G-factor.	Active Alkali Rate (%)	First Experiment group	Second Experiment group
				Viscosity (cm^3/g)	Viscosity (cm^3/g)
1	15	7600	14	981	985
2	15	7600	18	888	938
3	15	7600	22	782	820
4	15	15500	14	1064	1029
5	15	15500	18	760	742
6	15	15500	22	527	553
7	15	23400	14	940	963
8	15	23400	18	637	669
9	15	23400	22	390	415
10	30	7600	14	1057	1157
11	30	7600	18	947	978
12	30	7600	22	808	773
13	30	15500	14	977	1184
14	30	15500	18	829	795
15	30	15500	22	525	593
16	30	23400	14	1083	1075
17	30	23400	18	674	721
18	30	23400	22	505	511
19	45	7600	14	1238	1268
20	45	7600	18	1052	1096
21	45	7600	22	917	903
22	45	15500	14	1211	1180
23	45	15500	18	1002	1015
24	45	15500	22	555	715
25	45	23400	14	1164	1083
26	45	23400	18	856	898
27	45	23400	22	513	641

Active alkali concentration is the most important factor on the viscosity. Increasing alkali charge decreases viscosity values and the most important reactions of increasing alkali concentration in kraft white liquor are alkalen peeling and alkalen hydrolyze on carbohydrate polymers (FENGEL 1989; RYDHOLM 1965). It has been corrected again in this study that, increasing active alkali charge as 14 %, 18% and 22%, viscosity is become less 25% on each stage (Figure 3).

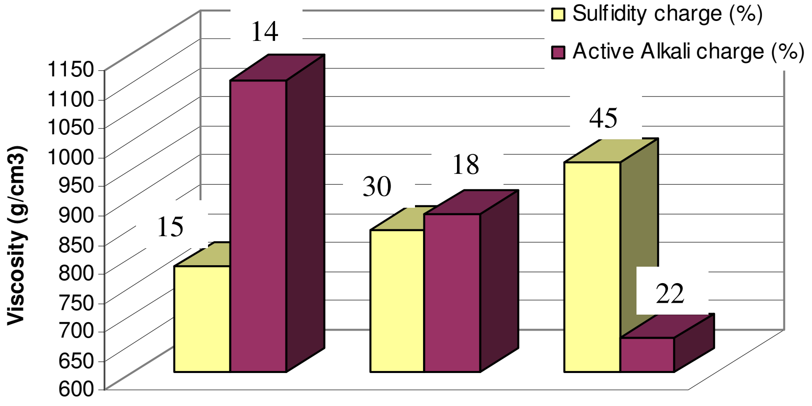

Figure 3. Effects of sulphidity active alkali charge on pulp viscosity during kraft pulping

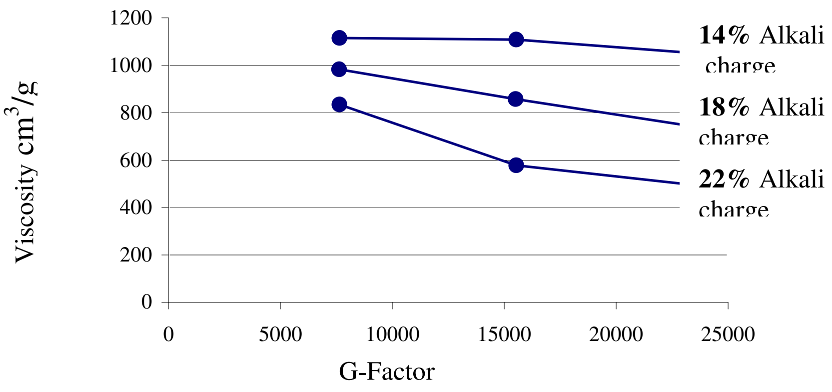

Figure 4. Effect of G-factor and active alkali charge on viscosity

Changing on viscosity values according to G-factor and alkali charge for Anatolian Black Pine was showed in Figure4. Increasing active alkali concentration slowly decreases the viscosity, as described in the literature (KOCUREK 1989; SMOOK 2000). At the same G-factor level, increasing alkali charge causes viscosity decrease for Anatolian Black Pine kraft pulps.

4. CONCLUSIONS

Under the same restrictions required for the H-factor (constant wood species and alkali charge), pulping at constant G-factor produced pulps of equal viscosity. Once a G-factor versus viscosity plot has been established for a given alkali charge and concentration, pulp viscosities can be predicted for a variety of times and temperatures. Since viscosity loss has higher activation energy than delignification, higher pulping temperatures always lead to lower viscosities.

REFERENCES

Aurell, R., Hartler, N., 1965. Svensk Papperstid. 68 (4):97.

Fengel, D., Wegener, G., 1989. Wood, Chemistry, Ultrastructure, Reactions, Walter de Gruyter, Berlin-New York.

Gullichsen, J., Paulapuro H., 1999. Pulp and paper Testing, Tappi Press, Atlanta.

Kocurek, M.A., 1989. Alkaline Pulping, Tappi Press, Atlanta, USA.

Kubes, G., Fleming, B.I., MacLeod, J.M., Bolker, H.I., 1983. Viscosities of Unbleached Alkaline Pulps. II. The G-Factor, Journal of Wood Chemistry and Techbology, 3 (3), 313-333.

Li, J., Moeser, G., Rosen, L., 2000. Nonuniformity of Carbonhydrate Degradation During Kraft Pulping-Measurement and Modeling Using a Modified G-Factor, Industrial and Engineering Chemistry Research, V:39, No:4, p. 916-921.

Ryhdolm, R.A., 1965. Pulping Processes, Interscience Publishers, London, UK.

Smook, G.A., 2000. Handbook for Pulp and Paper Technologists, Angulus Wilde Publications, Vancouver, Bellingham.

Vroom, K.E., 1957. Computing of H-Factor, Pulp and Paper Magazine of Canada, 58:228-231.