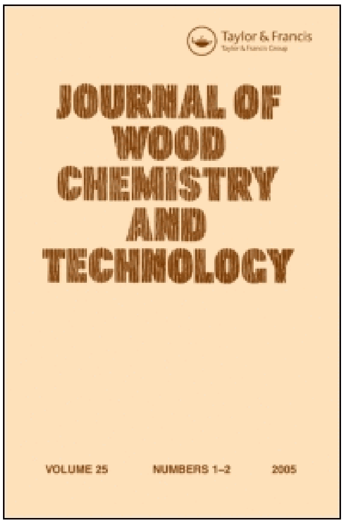

Journal of Wood Chemistry and Technology
Publication details, including instructions for authors and subscription information:
http://www.informaworld.com/smpp/title~content=t713597282

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To cite this Article Twimasi, Kwasi Antwi(1997) 'The Kinetics of the Sulphate Pulping of *Gmelina arborea* From Ghana', Journal of Wood Chemistry and Technology, 17: 1, 179 — 185

To link to this Article: DOI: 10.1080/02773819708003126

URL: http://dx.doi.org/10.1080/02773819708003126

JOURNAL OF WOOD CHEMISTRY AND TECHNOLOGY, 17(1&2), 179-185 (1997)

THE KINETICS OF THE SULPHATE PULPING OF Gmelina arborea FROM GHANA

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ABSTRACT

Investigations concerning the behaviour of Gmelina arborea wood growing in a plantation in Ghana by the Kraft delignification process were carried out in the St. Petersburg (formerly Leningrad) Academy of Forest Technology and Engineering in the Commonwealth of Independent States (Russia).

The basic kinetic data such as the rate constant, order of reaction, temperature dependence and the energy of activation were calculated. The kinetic data obtained indicate that the dielignification of G. arborea is by a process similar to that of diffusion as occurs during chemical reactions. Consequently, the delignification process at temperature which was carried out at selected cooking conditions is not solely controlled by kinetic processes.

Keywords

Sulphate pulping, kinetics, rate constant, activation energy, morphological characteristics, chemical properties, pulp properties.

INTRODUCTION

The Republic of Ghana spends a significant portion of her hard to come by foreign exchange on the importation of paper, board and allied products. It is not only Ghana which is in such a peculiar position but also many other developing countries on the African continent.

One of the basic criteria for assessing the level of development of any given country is the consumption of paper and board per capita per annum. It is crucially important to intimate that the consumption of paper and board per capita per annum for Africa is the lowest in the world, about 5.2 kg (1). This is as a result of the inability of some African countries which lack adequate foreign exchange and which almost invariably do not have pulp and paper mills to import paper and board to enhance socio-economic development. There is no doubt that the consumption of paper and board will show a tremendous increase if and when paper products become available and cheap in the future.

Gmelina arborea, which is a hardwood, is native to Asia but has been successfully cultivated in various tropical countries including Ghana, as a potential source of fibrous raw material for the pulp and paper industry since under tropical climatic conditions it is a fast-growing tree.

The morphological characteristics, physical and chemical properties of G. arborea have been reported earlier in the literature by Twimasi et. al.(2). The same author, has also reported work on bleached pulp characteristics of Gmelina arborea and other species elsewhere (3) whereas the work of Palmer on G. arborea has also been recorded in the literature (4).

EXPERIMENTAL

In carrying out this pioneer investigation, logs of G. arborea aged 8 years, were supplied by the Forestry Research Institute of Ghana in Kumasi, from a plantation. The wood was chipped by hand and chips of dimensions - 20 x 20 x 2mm were utilized for the study.

Cooking was effected in 0.5 litre stainless steel bombs placed in preheated (up to 70°C) glycerine bath equipped with a mixer and controlled thermostatically. Three cooking temperatures - 160, 165 and 170°C were selected for the work.

Thus, the influence of temperature in the chosen range, time, yield and the quantity of residual lignin at constant chemical digestion conditions of active alkali 15% as Na_2O on oven dry wood and a sulphidity of 25% were investigated.

Since during all chemical reactions with the exception of zero order and autocatalystic reactions the velocity of the process decreases with an increase in the degree of conversion of the reacting substances, the bombs were removed consecutively from the glycerine bath at increasing time intervals and the reaction was curtailed by quenching the bombs in a running cold water tub. This was done in order that the variation in the degree of conversion at each stage was ideally the same. Subsequently, the chips were thoroughly washed, dewatered and then air-dried.

Analysis carried out involved the determination of yield, residual lignin and Kappa number. Using the data obtained, curves for the dissolution of lignin i.e. kinetic curves were plotted.

CALCULATION PROCEDURE

A differential method embodying the logartithm of a differential equation and the construction of a logarithm curve was done according to well-known principles (5,6,7,8).

The rate of dilignification, 'V' in each pulping phase could be expressed with respect to the lignin content of the wood residue by the differential equation

$$-dc/dx = KC^n, \qquad [1]$$

where:

K-the observed rate constant.

The values of log V and log C were determined and a curve of log V versus log C was constructed. Since $V=KC^n$, and in logarithm form $\log V=\log K + n \log C$, the average order of reaction 'n' is easily determined as the tangent of the inclined angle of the straight line in the co-ordinates of log V against log C. Similarly, the values of the observed rate

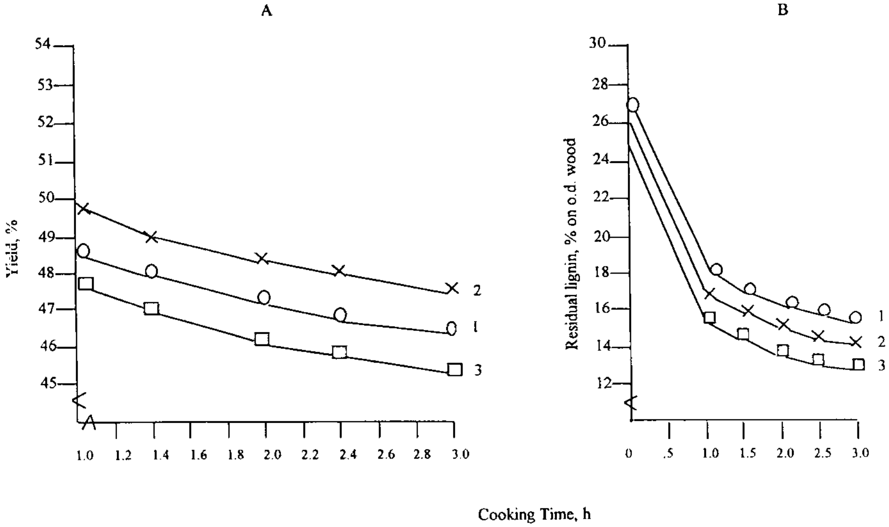

Fig.1 The dependence of Yield (A) and dissolution of lignin (B) during the sulphate pulping of G arborea on cooking time and temperature.
1 - 160°C; 2 - 165°C; 3 - 170°C; Active alkali concentration - 15% as Na_20 on o.d. wood.

constant 'K' at the particular temperature and effective alkali concentration can be calculated from the slope of the straight line.

The temperature dependence of the rate constant is characterised by the value of the energy of activation, 'E' (9). The energy of activation was graphically elucidated from the rate constants at different temperatures by means of the Arrhenius equation:

$$K = Ko.exp(-E/RT), \qquad [2]$$

where, 'K' is the rate constant; 'Ko' is the exponential constant; 'E' is the activation energy; 'R' is the general gas constant and 'T' is the absolute temperature.

The Arrhenius equation could also be expressed as:

$$lnK = lnKo - E/RT \qquad [3]$$

RESULTS AND DISCUSSION

The influence of temperature and cooking time on the yield and residual lignin at a instant active alkali concentration of 15% as Na_20 on o.d. wood is given in Figure 1. Correspondingly, Figure 1 and Figure 2 illustrate the influence of temperature on the pulp yield and residual lignin respectively. The relationship of log V 'versus' log C has been graphically shown in Figure 3.

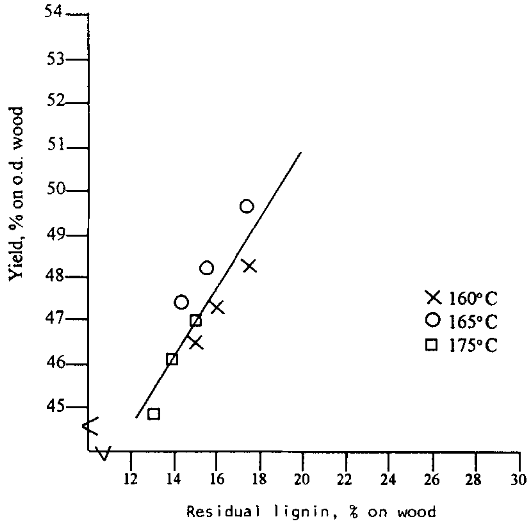

Fig.2 The relationship between lignin content and pulp yield at various cooking temperatures.

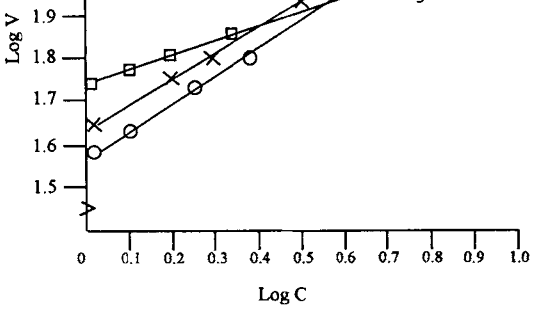

Fig.3 Determination of the reaction rate of delignification by the relationship. log V <u>versus</u> log C; 1 - 160°C; 2 - 165°C; 3 - 170°C

TABLE
Kinetic parameters for delignification of Gmelina arborea from Ghana.

Cooking temp- erature, ^{0}C	Reciprocal of the absolute temp- erature 'K', $I/T \cdot 10^{3}$	Rate Constant h^{-1}	Temp erature depen- dence	Reaction Order, n	Average Tempe- erature depen- dence	Average activation energy kJ/mole
160	2.31	1.57	1.1	1.56	-	-
165	2.28	1.64	1.1	1.50	1.1	67
170	2.28	1.71	1.1	1.38	-	-

As could be inferred from Figure 2, the final cooking temperature (delignification at temperature) within the interval 160-170°C practically does not influence the quantity of lignin in the wood. In other words, the experimental points pertaining to the results obtained at the different temperatures all lie in a straight line. This could be explained probably by the fact that at the final cooking phase at the selected temperatures lignin dissolution is retarded owing to condensation which has occurred and coupled with the inacessibility of the remaining lignin in the wood chips.

Therefore, pulping to the same degree of delignification results in getting the same yield or cooking to the same level of pulp yield gives an identical quantity of residual lignin.

Generally, cooking up to a residual lignin of about 2% on wood basis, the relationship is characterised by a straight line and later as afore-mentioned, lignin dissolution is retarded and as a consequence the pulp yield is reduced.

It has been observed by other investigators also (10,11) that an increase in the temperature at cooking from 160 to 170°C does not reduce pulp yield or result in obtaining pulp of poor quality. The rate constants, order of reaction and the temperature dependence together with other data are found in the Table.

The activation energy, 'E' is determined from the slope of the straight line when InK is plotted against the reciprocal of the absolute temperature, I/T, - Figure 4.

It is evident from the data in the Table that in the main, the rate constant increases with an increase in temperature within the range 160 to 170°C and which observation was not unexpected.

The value of the activation energy which is dependent on the morphological characteristics, chemical properties and on the process of delignification was found to be 67 kJ/mole.

The results of the investigation confirm the conclusions made by other researchers (11,12,13) about the fact that under identical conditions hardwoods could be pulped at a shorter time than softwoods.

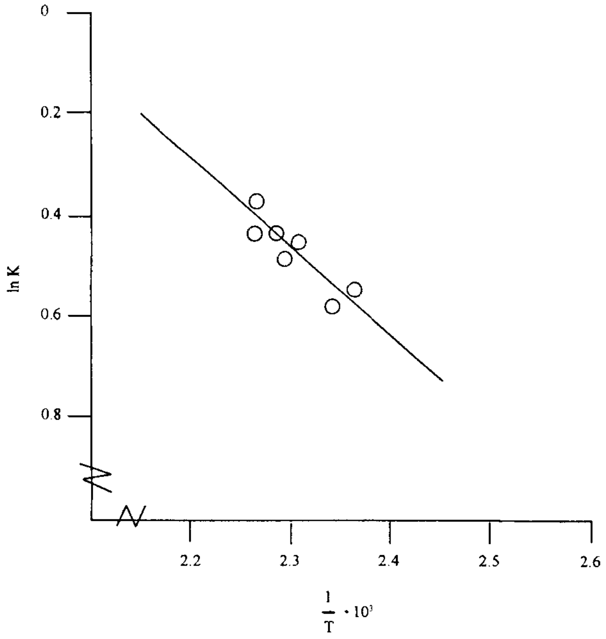

Fig.4 Graphical representation of the activation energy during the delignification process of G. Arborea.
Logarithm of the rate constant versus the reciprocal of the absolute temperature.

Moreover, the value of the activation energy, reaction order and the temperature dependence depict that under the cooking conditions selected, the process of delignification at temperature is not solely dependent on the kinetic processes only, but also on diffusion.

CONCLUSION

The kinetic data for the sulphate cooking of G. arborea growing in a tropical country, Ghana, confirm that the processes occurring during delignification is a heterogeneous one involving not only kinetic phenomenon, but also diffusion as well.

The cooking conditions for Gmelina arborea with an appreciable pulp yield which guarantees the possibility of utilizing the product in various furnishes have been determined as follows: temperature - 165°C, active alkali concentration, 15.0 - 15.8%, as Na_2O, cooking time at temperature, 2h (excluding 1 h time to temperature) and sulphidity, 25%.

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