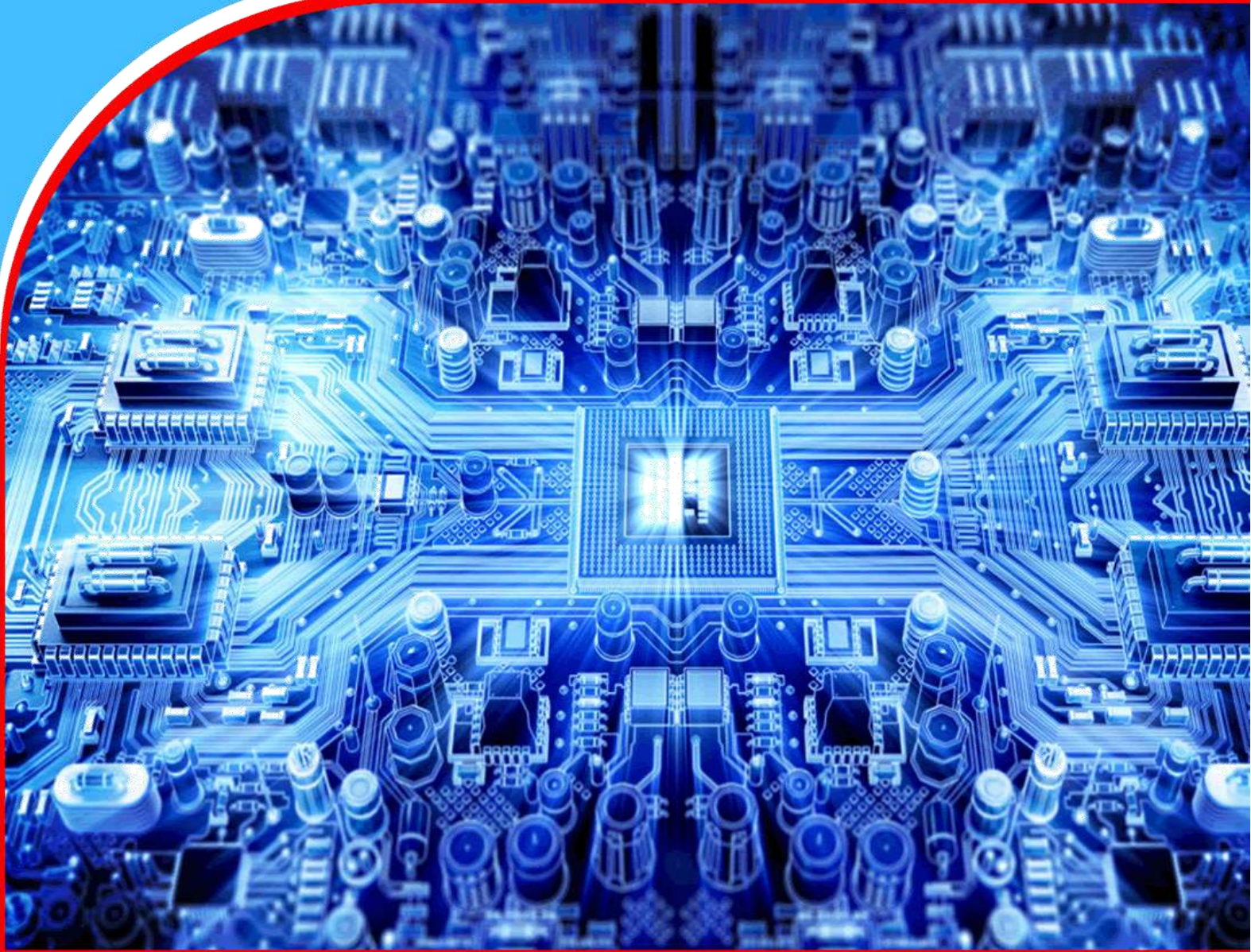


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Kinetic Modeling of Pulp Production from Plantain Trunk.

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Abstract

Plantain pseudostem has high content of lignocellulose used for production of pulp. But ironically, this resource is unexploited, with plantain stem becoming a common domestic waste in many parts of the world. The present work provides a kinetic model based on the kraft process from experimental determination of the rate of delignification reaction of plantain stem aimed at its application for pulp making and eventual paper production. Objectives of the work are twofold: firstly, to create an alternative raw material to wood for pulp production given the dwindling wood resources world – over and secondly, as a means of environmental waste management and control. The Arrhenius kinetic model was used to find the rate constant for the process with precise determination of its activation energy and pre – exponential factor. Results of study showed that Plantain (*musa acuminata*) is similar in chemical composition and morphology, but has higher amounts of cellulose (which is the major substance in pulping) than banana (*musa paradisiaca*). Plantain pseudostem is therefore highly recommended as an alternative source of raw material to wood for pulping production.

Key words: *Kinetic, Modeling, Pulp, Plantain Trunk*

1.0 Introduction:

Pulp is a lignocellulose fibre prepared by separating cellulose fibre from wood, fibre crops, waste paper, etc using chemical or mechanical methods. Different kinds of paper are made from wood with nothing else, mixed with it. Plantain plant (*Musa acuminata*) which grows easily and is thus found in different environments, not only gives the delicious fruit but also provides fibre (Chamorro et al., 2017). All varieties of plantain plant have abundance of fibre. The trunk (*Pseudostem*) is however thrown away as agricultural waste usually after harvest of the fruit thereby constituting disposal and pollution problems. This lignocellulose agricultural waste can be utilized by the paper industry due to its fibre content (Ververis et al., 2004). Paper sheets from Plantain pulp showed high material for pulp and paper industry with species having medium to long fiber lengths (Sankia et al; 1997).

Plantain fruit has low lignin content often difficult to remove, however some authors think that plantain stem can give high quality fiber with high yield by adequate preparation of the material. Heikal et al. (1976) compared the kraft nitric acid pulping of retted and unretted banana chips and concluded that pulping of retted samples gave pulps with better chemical and mechanical properties than that of unretted samples. Wastepaper is a source of pulp but the expansion of this resource is highly complex due to difficulties in gathering it from scattered places, sorting mixed papers and recovering the fiber from many types of coated and treated papers (Britt. K.W, 1986). Today, there is greater advocacy for use of field crop fiber or agricultural residues as being more sustainable for pulping instead of wood fiber (Arsene and Bilba, 2007).

There are a number of different processes which can be used to separate the wood fiber in pulping:

- i. Mechanical pulping uses manufactured grindstones with embedded silicon carbide or aluminium oxide to grind small wood logs called 'bolt' to make stone pulp (Herbert, 2006).
- ii. Therm-mechanical Pulp processes wood chips using heat and a mechanical refining movement (Herbert, 2006).
- iii. Chemothermechanical pulping which is the combination of chemical, thermal and mechanical process in pulping (Husaini, 2011).
- iv. Organosolve Pulping which uses organic solvents at temperatures above 140°C to break down lignin and hemicellulose into soluble fragments. The pulping liquor is easily recovered by distillation. Most commonly used solvents are methanol, ethanol, formic acid and acetic acid often in combination with water (Husaini, 2011)..
- v. **Chemical Pulping** is a process of combining wood chips and chemicals in large vessels called digesters where delignification occurs (Herbert, 2006).
- vi. Kraft pulping is currently the dominant pulping process, constituting about 90% of the world's production of virgin chemical pulp.

The main advantages of kraft pulping over other pulping processes are two - fold: the ease with which the different wood raw materials can be handled, and the superior material strength it produces. This pulping process operates in the alkaline pH region of around 12, at a cooking temperature of around 140-175°C, and uses sodium hydroxide (NaOH) and sodium sulfide (Na₂S) as the main cooking chemicals (Gellerstedt and Lindfors, 1991). In the last half century, many studies on the kinetics and transport behavior of the kraft pulping process from wood and even

Bananas (*musa paradisiaca*) have been conducted, and models with various complexities describing the delignification kinetics have been developed for design purposes (Gierer, 1985).

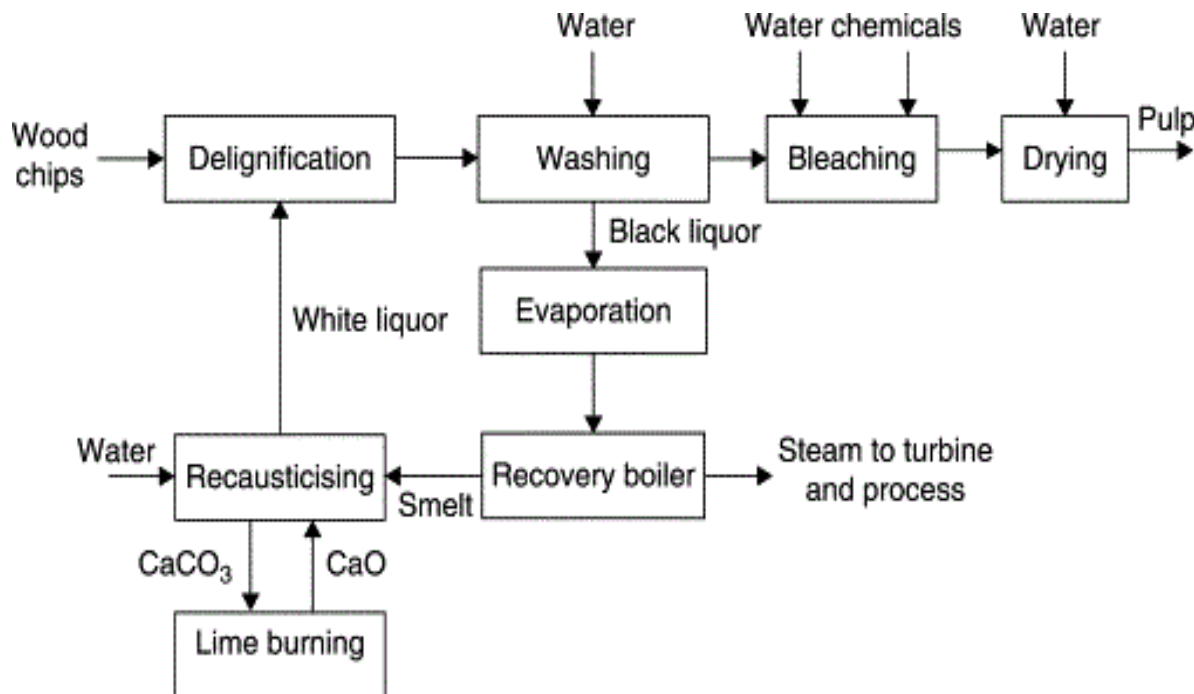


Figure 1: Schematic of the Kraft Pulping Process (Researchgate.net, 2018)

Nonetheless, pulp production from plantain (*musa acuminata*) is still novel and unexplored with little or no kinetic data available about the process. The present work therefore provides a kinetic model based on the kraft process from experimental determination of the rate of delignification reaction of plantain stem. Reaction rate measurement applied the Arrhenius kinetic model to find the Rate Constant from the Activation Energy and pre – exponential factor. Significance of this work lies in the increasing volumes of agricultural waste globally and, use of recycling as an effective method of waste management. Also, while literature abound on production of pulp even from banana, it is not so for *musa acuminata*. However, the work is limited to experimental study of the kraft pulping process primarily to establish relevant kinetic parameters as stated earlier. It shall thereafter develop reaction rate model to describe the established kinetics of the process.

1.1 Reaction Kinetics of the Pulping Process:

The alkaline delignification kinetics of the kraft process has been well established (Gierer, 1985) and fits a first order Arrhenius kinetics with respect to lignin and hydroxide concentrations of NaOH (sodium hydroxide) in the liquor. This gives the rate equation.

$$\frac{dL}{dt} = k [OH^-] \cdot L \quad (1)$$

Where:

$\frac{dL}{dt}$ = the reaction rate constant, independent of liquor concentration

2.0 Materials and Method

To effectively study the kinetics of kraft pulping process of plantain trunk, an elaborate experimental procedure was followed as outlined below.

2.1 Experimental Materials and Apparatus:

Fiber digestion apparatus, weighing balance, volumetric flask, beaker (500ml), Sintered crucible, furnace, measuring cylinder glass tray, stirring rod, knife, blender, open air/oven, bowl / bucket (for washing), cloth/mesh. Stop clock.

2.2 Preparation of Cooking Liquor

Cooking liquor for the kraft process; sodium hydroxide is prepared to a 15% solution (Gullichsen, 1999).

2.3 Processing of Plantain Trunk:

Prior to digestion, the plantain trunk is first processed by washing off dirt (sand, etc), debarked using knife or cutlass, size, oven dried or air dried and weighed. This raw material is then sent to the digester. A 15% NaOH solution was then used for digestion of samples for 0, 1, 2, 3, 4 and 5 hours respectively at constant temperature of 90 degree centigrade. The resultant samples were then used for lignin and cellulose determination.

2.4 Method for Determination of Acid Detergent Lignin

Procedure: Residue from ADF (write acronym in full also) was used for the Acid Detergent Fibre. The crucible containing the residue obtained from ADF analysis was placed in a glass tray having one end at 2.0cm higher so that acid could drain away from the crucible. The content of the crucible was covered with 72% H₂SO₄ (cooled at 5⁰C) and stirred with glass rod to a smooth paste to break all the lumps. Crucible containing the content was filled half way with acid and stirred at hourly interval as the acid drained away with the glass rod allowed to remain inside the crucible. The crucible was kept at 20⁰C to 23⁰C, after which the acid was filtered off as much as possible with suction pump. The content was washed with hot water (85 – 95⁰C) until it was free of acid, the stirring rod washed and removed. The crucible was dried for 12 hours at 100⁰C and weighed. The residue was ashed in a muffle furnace at 500 – 600⁰C for three hours, then cooled to about 250⁰C and transferred to a desiccator, and further cooled to room temperature and weighed.

$$\% \text{ Lignin} = \frac{\text{wt. of crucible} - \text{wt. of crucible and ash}}{\text{wt. of sample}} \times \frac{100}{1} \quad (2)$$

$$\% \text{ Cellulose} = \% \text{ ADF} - \% \text{ Lignin} \quad (3)$$

3.0 Results and Discussion:

Delignification of pulp from *musa acuminata* was carried out at atmospheric pressure and temperatures 90°C. The percentage yield of lignin and cellulose with time as shown in Table 1. While the percentage lignin content of the sample decreased with time, that of cellulose increased as known from theoretical principles. The process achieved a maximum cellulose yield of 83.87% after 5 hours of reaction time. In the contrary, lignin content of the digest decreased from 6.36% to 3.45%.

Table 1: Percentage Delignification with Time of *Musa Specie*

S/N	Time of Sample Digestion (hrs)	% Lignin	% Cellulose	ln Lignin	ln Cellulose
1	0	6.36	61.41	1.85	4.12
2	1	5.30	73.04	1.67	4.29
3	2	4.05	80.86	1.40	4.39
4	3	3.36	80.90	1.21	4.39
5	4	3.24	82.50	1.18	4.41
6	5	3.45	83.87	1.24	4.43

Similarly, the lignin and cellulose contents of *Musa Pradisiaca* have been given by different authors (Subagyo and Chafidz, 2018) and shown in Table 2. The *Pradisiaca* specie has far higher lignin content of (13.88%) and lower cellulose (49.33%) content than the *Musa acuminata* shown in Table 3. The foregoing implies that *musa specie* has better pulp production potential than the *pradisiaca specie*, therefore a clear justification for more studies on it, as the present one.

Table 2: Lignin and Cellulose Contents of *Musa Pradisiaca*

Sample	% Lignin	% Cellulose
1	5.10	63.20
2	15.07	31.27
3	18.6	63.9
4	15.07	31.26
5	15.55	57
Average	13.88	49.33

Adapted from: Subagyo and Chafidz (2018)

The rate of change of lignin content of the pulp digest with time is also shown by Figure 2, where the slope of the curve gives the reaction rate constant; $k = 0.163/\text{hr}$. Value of the rate constant

reveals that the delignification reaction of *musa acuminata* is a relatively slow reaction that requires five hours to achieve about half of lignin concentration reduction.

Table 3: Lignin and Cellulose Contents of the Two Species

Sample	% Lignin	% Cellulose
<i>Musa Specie</i>	6.36	61.41
<i>Musa Pradisiaca</i>	13.88	49.33

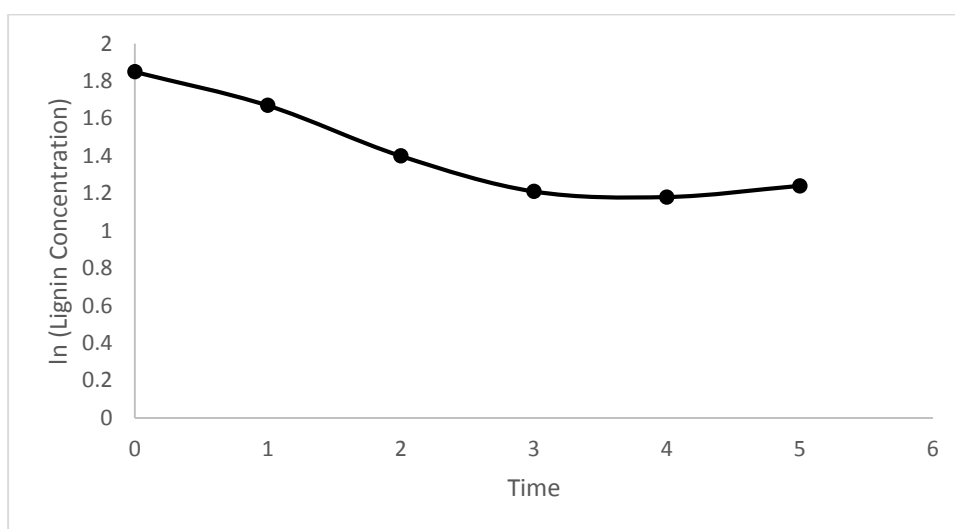


Figure 2: Change in Concentration of Lignin with Reaction Time

Figure 3 gives profile of the activation energy E_A of the delignification reaction. From Arrhenius equation, a plot of $\ln A$ (being natural logarithm of the pre – exponential factor) against the Activation Energy gives a slope that is the reciprocal of the product of the reaction temperature and the universal gas constant ($1/RT = 0.00033$), while the intercept gives the natural logarithm of the rate constant ($\ln k = 1.814$). From Figure 3 therefore, the exact kinetic parameter combination between the pre – exponential factor and the activation energy to define the rate of delignification based on Arrhenius theory is well established.

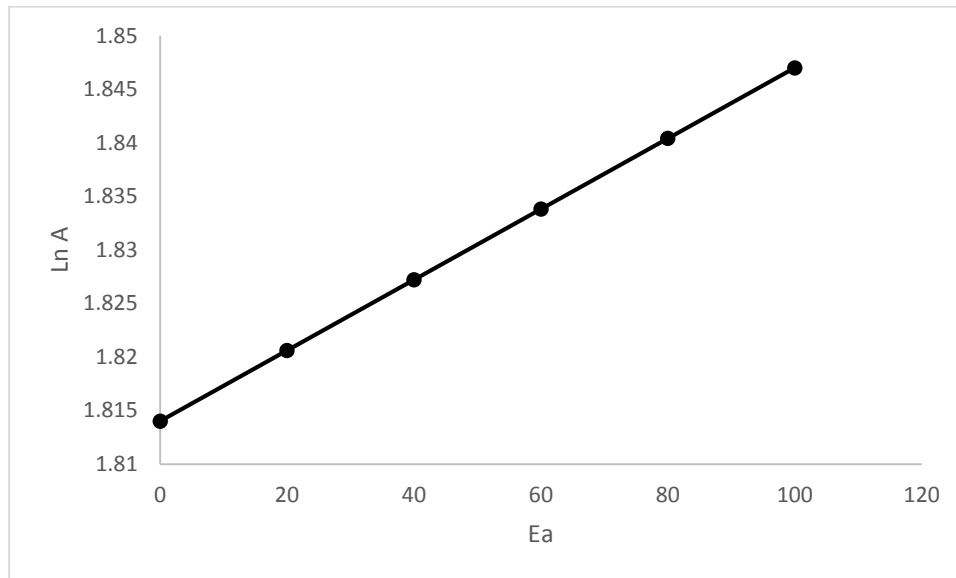


Figure 3: Activation Energy Profile of Plantain Pulping Process

4.0 Conclusion

Plantain as an agricultural crop is often confused, mistaken and sometimes deliberately mixed up with banana which is a crop in same genus with it. As have clearly been shown in this work, plantain (*musa acuminata*) is similar in chemical composition and morphology to banana (*musa paradisiaca*) but different in the amounts of the various components, lignin, cellulose, ash, water, etc. While literature is replete with studies on bananas, the same is not the case for plantain. Ironically, the present work has shown that plantain has higher amounts of cellulose which is the major substance in pulping than bananas. The work which was able to precisely define a kinetic model for delignification of plantain therefore presents a great opportunity for exploitation of yet another field of waste recycling and management.

5.0 Recommendation

Plantain is a staple food to many regions and tribes especially in tropical Africa. The cultivation and consumption of plantain in these areas of the world cannot be overemphasized. The foregoing presents problem of waste management arising from the pseudostem and peels of plantain. While several other uses of these plantain waste exist, the present use for pulping is a sure process that requires industrial quantities of the waste. It is therefore going to be a major application for plantain waste management as well as a veritable alternative to wood pulping for the paper and allied industries. With the precise definition of a kinetic scheme for the plantain pulping process, a new vista of industrial pulp production has been opened, particularly for areas that produce a lot of this resource.

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