MAKERERE UNIVERSITY

PRODUCTION OF CARDBOARD FROM WASTE BAGASSE BY CHEMICAL PULPING METHOD

BY

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A PROJECT REPORT SUBMITTED TO DEPARTMENT OF CHEMISTRY IN PARTIAL FULLFILLMENT OF THE REQUIREMENTS FOR THE AWARD OF THE DEGREE OF BACHELOR OF SCIENCE IN INDUSTRIAL CHEMISTRY OF MAKERERE UNIVERSITY

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Declaration

I TUMUSIIME DENIS do declare that this project report is mine and has never been submitted to any university or institution for higher learning for any academic award.

Signature ………………………………………. Date ………………………………………

TUMUSIIME DENIS

Approval

This is to certify that TUMUSIIME DENIS a student of Makerere University pursuing a Bachelor of Science in Industrial Chemistry degree has successfully completed his final year project research from 18th September 2022 to 22th October 2022 under my close supervision.

Signature ……………………………   Date………………………………

DR. DAN EGESA (PhD)

Dedication

I would like to dedicate this piece of work to my beloved mother Mrs. TIBAKANYA FLORENCE who has been there for me at any point of my life especially through prayer. She always motivates me to do my best in life but most importantly because she taught me how to pray for the best.

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Abstract

This experimentation was carried out in an effort to search an alternative use of bagasse waste to reduce its accumulation in different sugar processing industries and to mitigate the later effects of the waste in Uganda by utilizing it in production of cardboard. The properties of raw bagasse were determined and found to have moisture content of about 47.78% and lignin content of 13.8%. Bagasse was macerated using chemicals that pose less harm to the environment compared to those currently being employed in pulp and paper industries and the properties of its pulp such as lignin content, moisture content was evaluated. Sample sheets of paper were produced using hand sheet method on a laboratory scale and were duly tested for tearing resistance, tensile strength and burst strength. Therefore, its paper products can be used for writing and printing applications, but not suitable for wrapping and packaging.

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1 Introduction

1.1 Background

Cardboard, for a long period of time has been manufactured primarily from wood pulp and secondarily form recycled waste paper. Of recent there has been integration of rice husks and other non-wood agricultural residues have been used _(jeetah, 2015). From an environmental point of view, using virgin wood can be avoided because it poses negative environmental effects that greatly contribute to climatic change. The increased demand for wooden supplies can be met through enlarged utilization of forest waste, increased utilization of waste paper, increased utilization of non-wood fibrous plants such as bagasse, or other environmentally sound pulping process (Ashori, 2006).

Bagasse is a by-product of the sugar processing industry, with a total of over 100 million tons worldwide. Despite numerous exploitations as a fuel for cogeneration bagasse remains in excess amounts and in addition to its low nutritive properties, degradation resistance, abrasiveness, low apparent density and high ash content, attributed to another form of pollution phenomenon (Sun, 2001). Such efforts are handicapped. Consequently, useful applications for bagasse are required to solve this problem (Lee, 2013). The advantages of using bagasse include: insignificant damage on ecological balance since they are renewable raw materials (sugarcane) often plentiful in supply. The raw materials are locally available in many sugar- processing plants in Uganda a case at SCOUL and at a very low cost (MacLeod, 1988). Its sale provides further revenue to the industry and farmers who have little other opportunities for outside income like at Sezibwa sugar mill plant, Kamuli, Kayuge sugar factories. Employment is provided to rural labour. The major cost in such cases is incurred on collecting and transporting these raw materials. However, limitations may result due to the bulk of these raw materials, transportation can as well be a major cost factor in processing. Nearly all of these raw materials are collected manually and as such the labour costs constitute a big percentage of the total raw material costs. Thus, in countries with very low labour rates, pulp production with these raw materials can be extremely encouraging relative to wood pulping. Consequently, the possibility of manufacturing cardboard from bagasse was investigated.

Bagasse consists of cellulose 43.8%, hemicellulose 28.6%, lignin 23.5%, ash 1.3% and other components 2.8%. The two former components are hydrophilic and the latter is hydrophobic. The cellulose from sugarcane bagasse can be easily obtained by acid hydrolysis followed by an alkaline pulping process. During hydrolysis the reagents act on lignin, breaking the macromolecules into units of low molecular weight, which are soluble in the liquor solution. The strength of the cardboards was compared to that of new fibers from wood pulp (Wood, 1981) normally used in the production of cardboard for packaging, to see whether the cardboard obtained could replace to some extent the pulping material due to its flexibility (Kiaei, 2011) in normal cardboard production (Akgul, 2009). For that purpose, it was important to determine the optimum pulping time in terms of yield, kappa number and lignin content of various samples of bagasse pulp to compare the mechanical properties of cardboards manufactured from these samples. The optimal amount of virgin fiber to be added also had to be determined so as to maintain strength.

1.2 Problem statement

During my industrial training at Sugar Corporation of Uganda Limited, SCOUL, one of the leading sugar processing companies in Uganda, it was realized that the sugar process produces bagasse as a residue or fiber from cane. Bagasse is mainly used for cogeneration at the boiler house; however, this is produced in excess compared to their cogeneration capacity which leaves behind thousand tons of piles which occupy a large resourceful space in the Eastern side of the new production line. The storage facility is full hence the remaining is dumped in the open air. It has also become a waste which is expensive to handle and manage due to lack of where to dispose it off in the landfills as it takes quite some time to decompose which increases cost expenditure for the industry. Since the production capacity of the factory is increasing, there is an urgent need to remove the bagasse to avoid more space being consumed. Excessive exposure of the bagasse to harsh conditions such as rain reduces its properties to be used as a fuel in cogeneration or may require excess energy to regain its properties to be used as a fuel. Bagasse degrades air quality as it is always blown away by wind and due to its lightness hence polluting the air. When it mixes with water due to rains and then heat from the sun in the open space, it releases harmful emissions and combustion products like volatile organic acids and carbon monoxide. This poses harmful effects to public health. The accumulation of organic wastes is one of the most serious problems facing developing countries. These wastes attract a lot of insect vectors which thread the public health and cause many diseases. Developing countries via their environmental regulatory bodies are enforcing environmental and conservation safety rules of cleaner production technology. The bagasse is a very good raw material that can be used to make vast products such as cardboard and paper boxes. Due to properties of cardboards, that they are ecofriendly and can be used even as materials for both the industry and those outside the industry and they are economically viable.

1.3 Objectives

1.3.1 General objective

To produce cardboards from bagasse a sugarcane residue.

1.3.2 Specific objectives

To determine the average moisture content of the bagasse.

To determine optimum maceration time for best pulp quality.

To determine the yield of pulp

1.4 Justification

With increasing trends in waste prevention, zero waste and cleaner production technologies, all industries should aim at conserving the environment by reducing or having no waste produced at all. This is simply by putting to use the what would be waste into use for example bagasse as cardboard production raw material since its clean process leading to clean products that can be recycled and increasing returns on investment. Using bagasse as a substitute would offer import substitution, bagasse is fully utilized, and it will expand the economic viability of the existing paper mills and lead to their revival. Saving in foreign exchange will be attained by reducing the amount of imported pulp and exportation of papers and paper products to other countries. Environmental problems from this agricultural residue would be tackled. Having analyzed other alternative raw materials for cardboard production and alternative uses of bagasse there should be no doubt that the best alternative is using bagasse.

2 Literature review

2.1 The raw materials

Today (Kleinschmidt, 2021), the majority of our paper and cardboards are produced from either fresh fibers or recycled paper. The fibres from any plant or tree as they all contain cellulose, can be used to create paper, however, the strength and quality of these fibres varies among tree species. Hardwood trees tend to have shorter fibres which produce weaker paper but, this tends to also produce a smoother and opaque finish, generally more suitable for printing. On the other hand, softwood trees such as pines and firs, have longer, stronger fibres which produces the strength within corrugated packaging. (Dagger, 2022)

During the production industrially, Cellulose fibers, which are the basis for paper products, must be separated from lignin, hemicellulose, and resins (Ashori, 2006). For this purpose, the debarked wood in the form of wood chips is boiled in the sulphate process with sodium hydroxide and sodium sulphide at temperatures around 170 °C/175 °C, under high pressure for two to three hours. The paper then has to be bleached using chlorine dioxide or oxygen, hydrogen peroxide or ozone implying that it is chemical intensive. The production process for paper and cardboard made from virgin wood fibers is very energy- and water-intensive not forgetting the transport of the raw material– often the source of high energy consumption and environmental pollution. Most sources of these wood fibre materials are in the countryside and have to be transported to industrial parks that are located in urban centres for example Mbalala in Mukono Uganda. This results in very long transport distances of several kilometres that makes it costly and energy requiring.

The most common alternative to paper made from fresh fibers is the use of recycled paper - after all, a cellulose fiber can theoretically be reused up to six times. Use of recycled paper has an additional positive aspect is that up to 60% less energy and up to 70% less water is used to produce fresh paper ((ed.), 2012). Compared to wood for example in 2018, waste paper was used for 76% of all paper produced in Germany. In figures, this is an impressive 17.2 million tons of recycled paper (Bundesamt).

But even when using waste paper fibers to produce recycled paper, a certain number of fresh fibers is still required, because with each recycling process the wood fibers are shortened and these shortened fibers must be replaced by longer, fresh fibers. Deforestation continues, even if at a reduced rate.

Generally, this means that Pulp is not only produced from timber but can also be created in an environmentally friendly way by recycling woodchips and shavings leftover from lumber mill waste.

Newer paper developments experiment with hemp or bamboo. The idea is to replace fresh fibers from wood with grass fibers. Both materials contain pulp, the basic ingredient for paper. But grass has 75% less lignin and resin as wood, so it should be much easier to liberate the pulp. The production process of grass paper is easy in comparison to wood-based paper production. Starting material is hay, dried grass which has been grown on regional agricultural compensation areas. The hay is transported to the paper mill. There, it is cleaned, mechanically shredded, with the fibers being cut to a suitable length, and pressed to grass pellets. These pellets are then utilized directly in the paper production process without using any chemicals at all and resulting in the so-called “grass paper”. Though the final product may not be 100% grass-based.

Grass paper is the term used to describe a pulp-based product which, apart from virgin fiber from wood or recycled paper, contains a significant proportion of grass fibers.
Depending on the product, the grass proportion is in the range of at least 10 % up to 60 %. Grass paper is very versatile: it can be used for folding boxes, packaging – ideal for food – brochures, or labels. It is recyclable like normal waste paper, but also compostable - and it does not hide its origin; instead, it can easily be recognized by its slightly green colour. (Kleinschmidt, 2021)

Grass paper seems to be the better alternative. Its production process without the use of chemicals and with short transport routes is environmentally friendly. Compared to paper made from primary fibers, the advantage seems obvious, but how big is the real advantage over production from virgin fibers in terms of resources saved? The issue is only that grass has not posed any risk yet due to its abundance that need urgent attention like bagasse waste has. Grass is seasonal and may not be readily available yet there are already established sugarcane plantations in existence and the waste is much with great negative impacts to the environment hence need to take interest in bagasse as a raw material and no green grass for fresh wood substitution to form pulp.

2.2 Pulp Processes

The aim of the pulping process is to break down the structure of the fibre source into the fibres ready to be made into market pulp. To achieve this the fibres are put through either of the two processes that are used to develop the pulp. The two processes are mechanical pulping or chemical pulping (otherwise known as kraft). The fiber structure of the wood can also be separated mechanically. Transitions between the actual pulp and wood pulp production are the so-called semi-chemical, neutral sulfite semi-chemical pulp and chemo mechanical processes, in which a partial solution and softening of the lignin with chemical solutions takes place and mechanical defibration follows. Related to the mass of the debarked wood used, the yields in wood pulp production are 80-99%, in the CMP and CTMP processes 65% 97% and in the pulping process between 30 and 60% Pulp, mechanical pulp and waste paper are the fibrous materials in paper production (Bartels).

2.2.1 Chemical process

The chemical process, are well known which involves cooking the wood shavings in a sulphate solution to digest the wood. Both sulphate and sulphite can be used to separate the fibres from the lignin which, is a natural glue-like substance that bonds the fibres. Chemical pulping degrades the lignin into small water-soluble molecules which can be washed away without weakening the fibres (P. Musekiwa, 2020). The result of the chemical process is either a dark brown in colour or, it can be bleached during the procedure resulting in a white kraft. The cellulose production process is based on the penetration of digestion solutions into the wood and the leaching out of cell wall components (lignin, hemicelluloses, wood constituents) from the wood or any other fibre material. The technically important pulp production processes are subdivided into alkaline and sulfite processes. In both cases, the wood is debarked and transferred to the pulp digester in the form of wood chips. In the alkaline process the lignin is dissolved as sodium lignate. At the same time, other phenols are transferred into the solution as phenolates and the resins and fatty acids as salts. Therefore, after the sulfate process also resin-rich wood and less well debarked wood can be used. In addition to the solution of the wood components through salt formation, the ether bonds in the lignin are cleaved nucleophilically in the sulfate process by the sodium sulfide contained in the pulping solution, which significantly increases its solubility. In the sulfite process the wood chips are treated with an acidic bisulfite solution. The ether bonds in the lignin are also cleaved nucleophilically by the hydrogen sulfite ions. The actual solution of the lignin is achieved through the sulfitation reaction (formation of lignosulfonates). Some of the wood polysaccharides - especially the hemicelluloses - are hydrolyzed and transferred to the digestion solution in the form of simple sugars. In these processes, resins, fats and phenols essentially remain in the pulp, so that the sulfite process can only be used for wood that is low in wood content and well debarked (spruce, fir, beech, poplar).

Other chemicals used in pulping include hydrogen peroxide and glacial acetic acid as were used for delignification of rice husks by (jeetah, 2015)

2.2.2 Mechanical process

Mechanical pulping however involves grinding debarked logs against a revolving stone or disk grinders in order to break down the fibres to make a pulp.

The stone gets sprayed with water to remove the fibres, this however results in very little removal of lignin meaning paper quality is reduced, which therefore also indicates that the strength of the fibres may have been impaired from the process. Mechanical pulping however is a low-cost solution which generates a higher output.

Investigations by (Xu, 2007) on synergistic effects demonstrated hardwood chemical mechanical pulps give a higher bulk at a given tensile, or higher tensile at a given bulk, than their chemical pulps. Both chemical and chemical mechanical pulping processes can produce very strong pulps from hardwoods. Mixing hardwood (aspen) chemical pulp with up to 20% HWD chemical mechanical pulp, helps to not only improve pulp bulk and light scattering properties, but also maintain or improve the inter fiber bonding strength, in comparison to the chemical pulp alone.

There are synergistic effects between hardwood the chemical and the chemical mechanical pulps investigated: a blend of the two, (at a certain ratio), has a higher tensile and T.E.A., (or higher in-plane fracture resistance), than the sum of weighted contributions from its individual components.

According to_(jeetah, 2015), who carried out similar research using rice husks says that, Rice husk like bagasse does not have substantial commercial value and generally present an environmental problem concerning its disposal. The investigation was to determine the suitability of producing cardboard from rice husk, thus, reducing the amount of pulping material required from virgin wood as an advance to conserve the environment and other uses as listed. Maceration process was used to produce cardboards from their pulps. This involved use of catalytic oxidative lignification of the hulls and bagasse using hydrogen peroxide and glacial acetic acid for some days until digestion was attained at optimal conditions. For comparative evaluation, along with rice husk, bagasse and waste paper were used depending on properties as seen in the table below. The latter were blended in different ratios and their mechanical strength determined. Rice husk contained 15.2% lignin, with kappa number of 99.48 while bagasse had 13.70% lignin and kappa number of 88.39. The maceration period of rice husk and bagasse was between 6 and 15 days and 5–10 days with the corresponding pulp yield of 40.44–46.55% and 46.01–36.76%, respectively corresponding to the optimum maceration days. The tensile index, edgewise crush resistance, average bursting index of cardboard from rice husk was 11.31 N m/g, 1.11 kN/m and 0.84 kPa m2 /g, respectively. For the rice husk mixed bagasse cardboard, the optimal ratios were (20/80), (40/60), and (60/40) with a tensile index of 17.96, 16.66 and 12.94 N m/g, respectively. The edgewise compressive resistance was 2.91, 2.42 and 1.99 kN/m, respectively. The bursting index was 1.88, 1.55, and 1.26 kPa m2 /g, respectively. The optimal rice husk mixed waste paper ratio was (20/80) with a tensile index of 21.52 N m/g with an edgewise compressive resistance of 2.75 kN/m and a bursting index of 1.35 kPa m2 /g. From the experiment, it showed that the mixed samples and the one with highest percentage of bagasse resulted into better cardboard with best properties hence implying that when only bagasse is used, better properties that for the mixtures could be obtained and hence a need to experiment using bagasse only. Additionally, these cardboards were suitable for packaging as corrugating medium, wrapping and insulating board. However, in comparison between rice husks and bagasse alone, rice husks give low yield, they have much lignin implying the yield of cardboard production is slightly lower and more chemicals will be required, thus, making such substitution material less economically viable. It also showed that it required more energy due to longer maceration time for the kappa number evaluated as seen in the table below (jeetah, 2015).

Table 1: Initial characteristics of raw materials

Initial characteristics of the rawmaterials.

	Sample Moisture content(%)	Ash content (%)	Kappa number	Lignin(%)
Rice husk	37.30	20.56	99.48	15.20
Waste paper	7.40	17.54	–	–

The resulting cardboards were of less tensile strength all attributed to the much lignin content. Waste paper showed good properties of the cardboard that was produced however, the paper material is less in abundance and hence cannot be used alone or maybe has be used as a blending material to compare the strength (Akgul, 2009).

2.2.3 Finishing

Before the pulp can be made into the finished paper product however (Dagger, 2022), it must go through a process called “beating”. In effect, the pulp is squeezed and pounded by machine beaters in a large tub. Filler materials such as chalks and clays can be added which influences the opacity of the final product. Sizing’s such as starch, rosins and gums can also be added at this stage, a sizing will affect the way inks react with the paper, the choice of sizing is dependent upon the intended use of the paper. For the pulp to then be made into paper, the pulp is fed into a large automated machine, often a Fourdrinier. The machine has a moving fine mesh belt on which the pulp is squeezed through rollers to drain water while a suction device underneath drains the excess water.

The next stage is for the nearly made paper to be pressed between wool felt rollers, and then pass through a series of steam heated cylinders to remove any remaining water. Paper with the intended use of corrugated paperboard is now wound onto a wheel and the process is finished.

On a small-scale beating can be done using wooden mortar and pestle for sufficient tine to allow disintegration to take place. The contact surfaces are however covered to avoid direct contact with the pulps to prevent alteration of properties. The resulting product was ready to make cardboard that required heating under the sun until sufficient water has been lost. (Ibrahim H. , 2008.)

3 Chapter 3: Materials and methods

3.1 Materials

Depithed bagasse (Dixit) which was oven dried

Oven

Beakers (2000ml, and 250ml), measuring cylinders (1000ml, 250ml, 100ml and 25ml), pipette 25ml, burette 50ml conical flask 100ml, stop watch, weighing scale, thermometer, plastic buckets, water bath, sheet formers

3.2 Chemicals

- 4N Sulphuric Acid
- 0.1N Potassium Permanganate
- 0.1N Sodium thiosulphate
- 0.2% Starch indicator
- 1N Potassium Iodide
- 30% Hydrogen Peroxide
- Glacial acetic acid
- Distilled water

3.3 Methods

3.3.1 Average moisture content

The samples of raw bagasse were weighed to obtained average weight W_1 for raw samples. They were then oven dried at 100°C for 80 minutes, cooled and reweighed to obtain mass W_2 for the dried samples. Average moisture content was obtained as follows

$M = w_1 - w_2$ …………… *Equation 1*

3.3.2 Pulping by cold maceration

The maceration fluid was prepared by mixing 1 part of 30% hydrogen peroxide solution, 4 parts of distilled water, and 5 parts of glacial acetic acid. 100.011g of dried bagasse was soaked in 1000ml of the maceration mixture for days until digestion. The mixture was thoroughly stirred each day. According to (Ibrahim H. , 2008.), digestion is achieved when the pulp is formed, that is when the bagasse has softened. The average room temperature was 20^0C. The pulps were then washed and screened into accept and reject. Finally, the accepted pulp is oven dried so as to determine the yield.

3.3.3 Determination of optimum maceration conditions, in terms of pulp yield, kappa number and lignin content.

Samples of 15 g of bagasse and waste paper were soaked in 80 ml of the macerating liquor. They were allowed to macerate for 5, 8, 10 and 15 days. At the end, the pulps are washed with equal bathing ratio and screened.

3.3.4 Determination of kappa number and lignin content for raw bagasse

600 ml of distilled water was added to 0.5 g of the bagasse. 75 ml of 4 N sulphuric acid and 75 ml of 0.1 N potassium permanganate were mixed, and added to the solution of bagasse. The mixture was stirred and its temperature maintained at 25 ^{0}C for about 10 min using a water bath. After 10 min, 15 ml of the 1 N potassium iodide was added to the mixture and stirred. 25 ml of the mixture was titrated against 0.1 N sodium thiosulphate to pale color, two drops of starch indicator solution were added and the titration continued to colorless solution. The kappa number and lignin content were determined as follows;

$P = 75 - v$ …………….. *Equation 2*

$k = \frac{P \times f}{w}$ …………………. *Equation 3*

$^0/_0\, L = k \times 0.155$ ……… *Equation 4* where P = permanganate number; v = titre value (ml); L = lignin content; K = kappa number; f = correction factor (50%); and w = weight of raw sample mixed with distilled water (g)

3.3.5 Pulp kappa number and lignin content of bagasse pulp

This method was used by (Ibrahim H. , 2008.) which was adapted from TAPPI 236 om-06. 1500 ml of distilled water were added to 1.0 g of dry weight of pulp and stirred thoroughly. 40 ml of 4 N Sulphuric acid solution were added to the mixture and stirred. After about 5 min, 40 ml of 0.1 N potassium permanganate were added and stirred. After another 5 min, 5 ml of the 1 N potassium iodide were added and stirred. The reaction temperature noted. 25 ml of the solution was titrated against the 0.1 N sodium thiosulphate to pale color. Two drops of starch indicator solution were added and the titration continued to colorless solution. Kappa number and the lignin content were evaluated as follows:

$P = 40 - v$ ………………….. *Equation 5*

$\theta = T_r - T_0$ ………………… *Equation 6*

$T = \theta[1 \cdot 8]$ ………………… *Equation 7*

$k = P - T$ …………………..... *Equation 8*

The kappa number K was corrected to 50%

%L = K x 0.147 …………… *Equation 9*

Where θ = temperature difference (^{0}C); v = titre value (ml); T_r = reaction temperature (^{0}C); T_o = ambient temperature (^{0}C); and T = temperature (^{0}C), P is actual permanganate consumed.

3.3.6 Pulp yield

This refers to the mass of moisture free pulp recovered after cooking with maceration liquor as a percentage of mass of moisture free chips charged into the digester. Yield was determined as the oven dry weight of the accepted pulp divided by the oven dry weight of the pulp chips. The accepted pulp was that portion of the pulp ·which passed through the 0.010-inch slot screen but did not pass through the 50-mesh tub screen. The Oven dry weight was determined after storing the pulp in about solids condition for some time under refrigeration. In addition, the oven dry weight of the material which would not pass through the slot screen (large rejects) was also determined (Estes, 1962). This was obtained by measuring a mass of oven dried accepts, W_1, and mass of oven dry rejects to obtain overall oven dry weight of pulp chips, W_2. The weight W_1 was expressed as a percentage of W_2 to obtain percentage yield,

Pulp yield = $\frac{w1}{w2} x100\%$..................*Equation 10*

3.4 Forming of cardboard sheets

This involved two major steps, pulp refining and then finishing

3.4.1 Pulp refining by beating

The accepted pulp was pounded using a wooden mortar and a pestle for about 20 minutes. The inner part of the mortar was covered with a nylon bag and the pestle was wrapped with a cellophane bag to avoid direct contact. At the end of the beating, the refined pulp was mixed with plenty water to a consistency of about 0.3%.

3.4.2 Sheet Formation

After thorough mixing, a sheet former (mould) was dipped into the pulp suspension and raised out of the suspension. A layer of cellulose fibre was formed on the mould which was sun dried for about 4 hours. The paper formed was carefully removed from the sheet former and then left on the sun for further drying.

4 Results and discussion

4.1 Moisture content

The average moisture content according to ***table 2*** for bagasse obtained was 47.78% which was slightly higher than that obtained by (jeetah, 2015) which was 39.10 and that obtained by (Ibrahim, 2011) which was 14.14% but lower than what was obtained as by (Lois-Correa, 2010). The high-water content was due to the high hygroscopic properties of the material upon storage and the equilibria changes depending on temperature and relative humidity. Many strength properties depend on the moisture content of the material and that's why it should be analyzed. Increase in moisture content decreases edgewise compressive strength by over 40% and on the other hand, dust quantities of bagasse increase with decrease in moisture content and this would lead to health problems. (M. Sheehan, 2022) Therefore, controlling the moisture content levels helps to easily achieve the optimal mechanical properties of the cardboard and mitigate health hazards. However, for dry pulp the moisture content decreases on storage and hence proper conditions should be provided during storage of the materials.

Table 2: Results of analysis before and after maceration

Properties	W_1(g)	W_2(g)	M(g)	MC (%)	P(cm$^{3)}$	K(cm/g)	%L
Raw bagasse analysis	50.02	26.12	23.90	47.78	45.00	89.01	13.80
Pulp analysis	2.01	0.35	1.66	82.41	-	-	-

Note 1: Where W_1 is the green weight, W_1 is the dry weight, M is mass of moisture, MC is moisture content, P is permanganate number, K is kappa number and L is lignin content.

4.2 Maceration Analysis**:**

The results of the analysis before and after maceration are presented on table 2. The moisture content of the raw bagasse was found on the average to be 47.78% which is in the range of what was achieved by (SCOUL, 2022) because of storage conditions and the extent of extraction where it absorbed water being hygroscopic and was left with more water during extraction respectively hence deviating from theoretically known values that range from 12.5 and beyond. The Kappa number of the bagasse was found to be 89.01 and lignin content 13.8% which is less than the literature value which ranges. 100.011g of bagasse was soaked in 1000ml of the macerating liquor yielded a bath ratio of 10:1. 2.012g dry weight of chips was soaked in 10ml of the macerating liquor yielded the bath ratio 5:1, the bath ratios were chosen depending on the what would give the better digestion that's from 3.5:1 as determined by (Tripathi, 2016) The pulp moisture content was found to be 82.41%. Then the pulp yield was 49.78% which is in the range as found in literature.

4.2.1 Optimum Maceration Time on Pulp Yield, Kappa Number and Lignin Content:

To determine the optimum maceration time that yield the best quality pulp in terms of pulp yield, Kappa number and lignin content, four samples of equal weight of bagasse were macerated for 5, 8, 10 and 15 days with equal bath ratio. The results are presented in ***table 3.***

Table 3: Pulp characteristics

Length of maceration	V (cm^3)	P (cm^3)	T_r ^{0}c	ϴ ^{0}c	T ^{0}c	Pulp yield %	Kappa number	Lignin content %
5 days	22.25	17.75	25.50	2.50	4.50	49.78	13.25	1.95
8 days	22.15	17.85	25.70	2.70	4.86	30.68	12.99	1.89
10 days	22.05	17.95	25.90	2.60	5.22	28.46	12.73	1.87
15 days	22.00	18.00	26.00	3.00	5.40	25.92	12.60	1.85

Note 2: The ambient temperature was standard 23^{o}c, v was obtained by titration while values of P, ϴ, T, kappa number and lignin content were obtained using formulas 5, 6, 7, 8 and 9 respectively.

4.2.2 Pulp yield

From these results obtained using ***equation 10***, it can be observed that the best period for complete digestion of bagasse is between 5 and 8 days with optimum yield of 49.78%. In order to optimize yield of the pulp, maceration should be left to for days in that range because the yield from **Figure *2*** increases rapidly. it is increasing due to increase in glucose concentration (Çöpür, 2005) until the 8 days when yield starts to decrease sharply. Beyond the 10th day there is much decrease in pulp yield and insignificant change in lignin content after 10 days. This is attributed to carbohydrate degradation through hydrolysis reactions and lignin removal according to (Wan Rosli, 2009) and equation 12. The optimum pulp yield for bagasse occurs over a short time compared to that of rice husks (jeetah, 2015) implies that bagasse has a short digestion period that requires less time, energy and chemicals in comparison to other fibrous materials that require more time, energy and chemicals making the process expensive. The pulp yield increases initially to optimal due to increased rate of delignification and later decreases due to decrease in the rate of delignification thus less pulp is formed. The yield however is lower compared to mechanical pulping normally above 80% because of complete decomposition of cellulosic components by the chemicals. It is also attributed to the chemicals used which is weaker compared to the commonly used methods like alkalization using sodium hydroxide a stronger chemical.

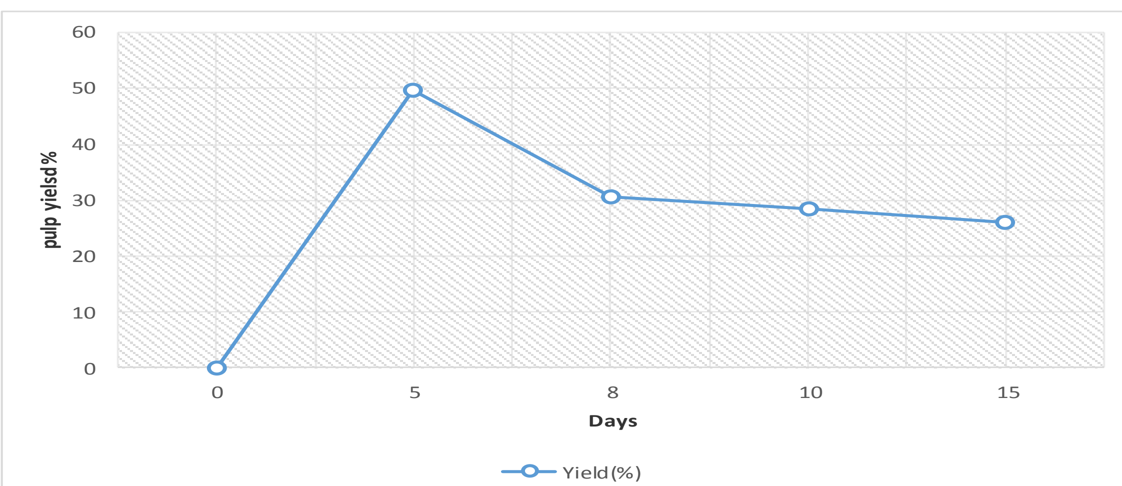


Figure *2*: Variation of pulp yield and with time

4.2.3 Kappa number

This is the measure of the degree of fibrous pulp digestion. The kappa number is a fundamental test method for determining lignin content remaining in a sample after pulping process according to TAPPI 236 om-06. It is based on the reaction of a strong oxidizing agent in this case Potassium permanganate with lignin according to the ***equation 12*** below.

Lignin + MnO_4^- + H^+ $\longrightarrow$ Oxidized lignin + H^+ + Excess MnO_4^-………*Equation 11*

The excess potassium permanganate is reacted with potassium iodide which is oxidized to iodine and this is titrated with sodium thiosulphate and starch indicator following ***equations 13*** and ***14***

$2MnO_4^-$ + 10I- + $16H^+$ $\longrightarrow$ $2Mn_2$+ + $8H_2O$ + $5I_2$……………*Equation 12*

$I_2 + 4S_2O_3^{2-} \longrightarrow 2I^- + S_4O_6^{2-}$ ………… *Equation 13*

The titre value corresponds to the unreacted permanganate and can be used to obtained the reacted permanganate as permanganate number from ***equation 5***. This is used to obtain the kappa number for the original weight of the fiber corrected to 50% for the consumption of the solution and then the lignin percentage is obtained. The value ranges between 0 to 100 for all fibrous materials decreases as the maceration period increases as seen from the ***figure 3*** below. The values obtained were in the range 12.6 – 13.25 which is partly close to those obtained by (Vu, 2003) for kraft pulping of bamboo. This is because lignin decreases as the maceration time increases, more lignin is oxidized by the potassium permanganate from ***equation 12***, however it does not go to zero at optimal maceration because beyond that the yield would be low.

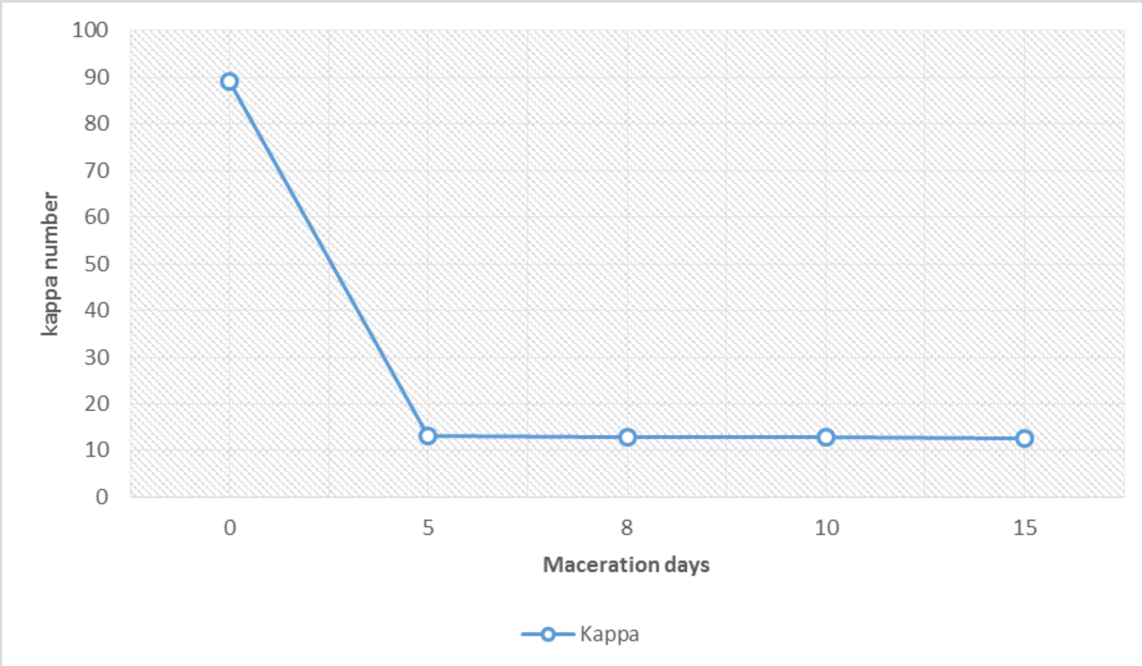


Figure 3: ***Variation of kappa number and maceration time***

From ***equation 8***, there is relationship between kappa number and temperature, there is a slight decrease in kappa number and hence lignin according to ***equation 9*** since the two are directly proportion with increase temperature which would imply there is better digestion at higher temperature but in order to obtain optimum yield (P. Musekiwa, 2020) a lower temperature was chosen rather than a higher temperature. However, this would require a longer cooking time than usual. Kappa number of 13.25 is relatively low and desirable as this will reduce the chemical costs for bleaching and ensure the process is more environmentally sustainable with minimal waste emissions.

4.2.4. Lignin

Figure 4 shows that lignin content decreased rapidly from 0 the 5th day and gradually to almost constant beyond 10 days since it was being decomposed by the maceration chemicals (B. Kuznetsov, 2021). The hydrogen peroxide, glacial acetic acid mixture attacks the acetyl group in the lignin structure, breaking it into soluble fragments into solution hence decreasing it concentration. The longer the time the more chemicals penetrate the fibers breaking the lignin. This implies that the bagasse required less time to be decomposed and less chemicals and hence a good material for cardboard production

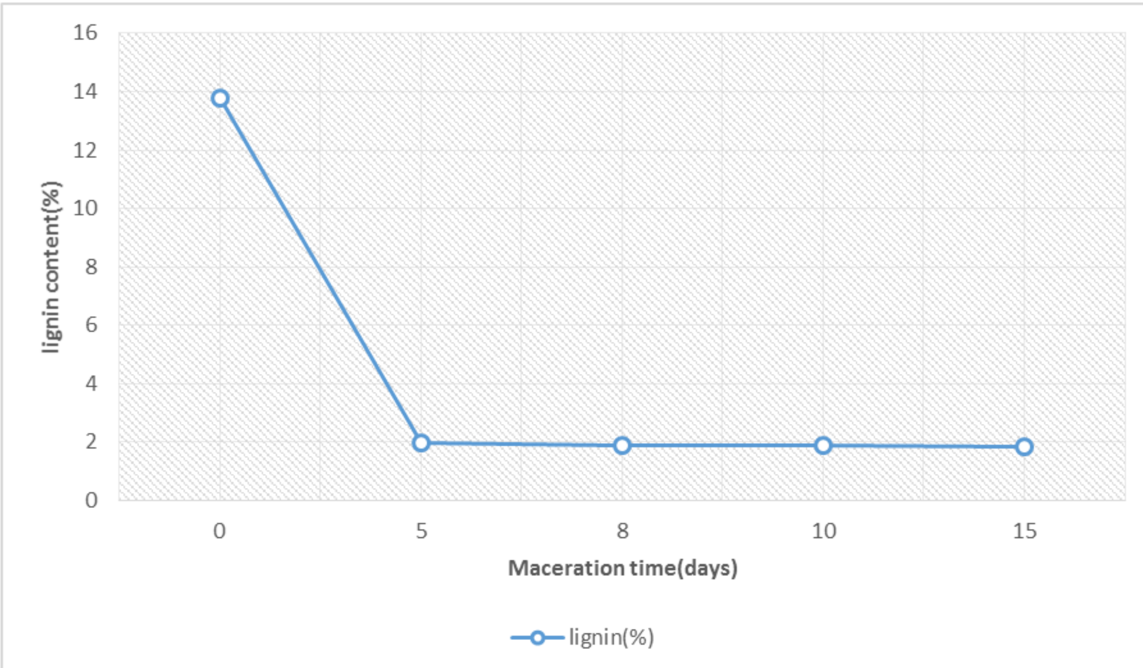


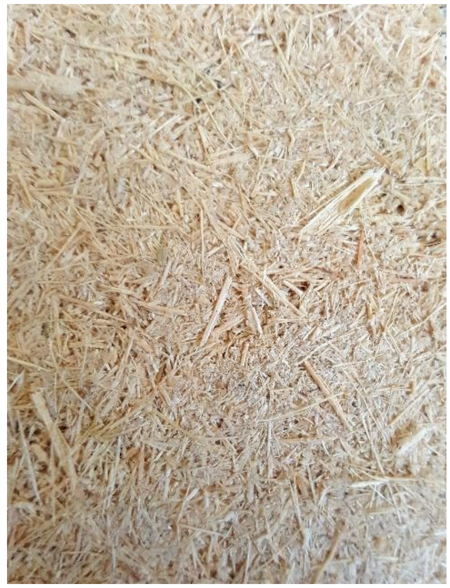
Figure 4: ***Variation of lignin content and maceration time***

4.3 Physical properties of the cardboard

The resulting product or cardboard was brownish in color as seen from ***figure 5***, somehow elastic because when bent by application of a small force and left, it would attain its original shape. It was very soft but would become hard and brittle depending on drying. The fibers were big because of poor disintegration that was used which accepting and rejecting pulps due to lack of instruments. The cardboard product is air permeable material and light.

4.4 Samples

a) wet cardboard



b) dry cardboard

Figure 5 Cardboard samples

5 Conclusion and recommendations

5.1 Conclusion

Bagasse was evaluated for the production of pulp and cardboard. It has low lignin content suitable for paper making. It had generally low moisture content that could easily be delt with. It has a short maceration period as shown above, requires less chemicals for digestion and can easily be bleached with relatively environment friendly chemicals. Samples paper were produced and when observed for some physical properties and it exhibited good quality. Therefore, its papers can be used for writing, printing, corrugating medium and insulating board applications.

5.2 Recommendations

- Next researchers should establish standard properties of pulp for easy reference and also experiment on the variation of pulp with yield at varying temperature.
- Mechanical properties need to be standardized besides those of Tappi which conflict with some other theoretical values and those used by some pulp and paper industries.
- The university should continuously support students in all ways to engage more in research.
- It would also be better if students are guided to start their projects earlier enough before final year to enable them master the art of research.

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7 Appendices

7.1 Appendix 1

Material Safety Data Sheet

1. Product Identification

   Synonyms: Sulphuric Acid, Hydrogen Sulphate, Oil of Vitriol, Battery Acid

   Chemical Name: Sulfuric Acid

   Chemical Family: Inorganic Acid

   Chemical Formula: H2SO4

   CAS Reg. No.: 7664-93-9

   Appearance: Odorless, clear to amber, heavy, oily liquid. A pungent odor may exist if certain impurities are present in the acid.

   Danger! Extremely corrosive. Causes severe burns and / or eye damage. Mist: Causes respiratory irritation. Harmful if inhaled. Harmful or fatal if swallowed. Reacts violently with water. Concentrated Sulfuric Acid will react with many organic materials and may cause fire due to the heat of the reaction

   Attention: Have emergency eyewash station / safety shower available in work area. SKIN CONTACT: Immediately flush skin with running water for a minimum of 20 minutes. Start flushing while removing contaminated clothing. If irritation persists, repeat flushing. Obtain medical attention immediately. Do not transport victim unless the recommended flushing period is completed or flushing can be continued during transport. Discard heavily contaminated clothing and shoes in a manner that limits further exposure.

2. **Product name**: Hydrogen Peroxide 3%

   Classification of the substance or mixture: Oxidizing, Corrosive, Irritant

   Hazard statements: May cause fire or explosion; strong oxidizer, Harmful if swallowed, causes severe skin burns and eye damage Harmful if inhaled

   Precautionary statements: If medical advice is needed, have product container or label at hand Keep out of reach of children Read label before use, Keep away from heat/sparks/open flames/hot surfaces. Take any precaution to avoid mixing with combustibles, Wash hands thoroughly after handling Do not eat, drink or smoke when using this product, avoid release to the environment, Wear protective gloves/protective clothing/eye protection/face protection.

3. **Product Synonym**: Acetic acid; Ethanoic acid; Ethylic acid; Glacial acetic acid; Methane carboxylic acid; Vinegar acid

   CAS No.: 64-19-7,

   Molecular Weight: 60.05

   Chemical Formula: CH3COOH

   Product Code: C2H4O2

   Appearance: Colorless liquid Physical State: Liquid Odor: vinegar odor

   Hazards of Product: Corrosive, flammable liquid and vapor. Causes severe digestive and respiratory tract burns. Causes severe eye and skin burns. May be harmful if absorbed through the skin. Acetic acid forms icelike solid below 17°C (62°F).

   Handling Procedures: Keep away from heat. Keep away from sources of ignition. Ground all equipment containing material. Do not ingest. Do not breathe gas/fumes/ vapor/spray. Never add water to this product. In case of insufficient ventilation, wear suitable respiratory equipment. If ingested, seek medical advice immediately and show the container or the label. Avoid contact with skin and eyes. Keep away from incompatibles such as oxidizing agents, reducing agents, metals, acids, alkalis.

4. **Other chemicals**

   Potassium permanganate, very oxidizing agent, very toxic and can be handled like any of the above.

   Potassium iodide can cause allergic reactions, should avoid direct contact

   Sodium thiosulphate: Avoid the spillage or runoff entering drains, sewers or watercourses. Collect and place in suitable waste disposal containers and seal securely.

7.2 Appendix 2

Factors f to correct the permanganate number

P	0	1	2	3	4	5	6	7	8	9
30	0.958	0.960	0.962	0.964	0.966	0.968	0.970	0.973	0.975	0.977
40	0.979	0.981	0.983	0.985	0.987	0.989	0.991	0.994	0.996	0.998
50	1.000	1.002	1.004	1.006	1.009	1.011	1.013	1.015	1.017	1.019
60	1.022	1.024	1.026	1.028	1.030	1.033	1.035	1.037	1.039	1.042
70	1.044									

5 / Kappa number of pulp

Table 1. Suitable amounts of oven-dry pulp in the kappa number range 5 to 100

Kappa number	*Amount of sample, g*
5	10.0
6	8.3
8	6.3
10	5.0
15	3.3
20	2.5
25	2.0
30	1.7
35	1.4
40	1.3
45	1.1
50	1.0
55	0.9
60	0.8
70	0.7
80	0.6
90	0.6
100	0.5