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Virgin Kraft Pulp and Paper Characteristics of Vitex Pubescens Vahl. (Halban) Wood

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Abstract*: Insufficient wood-based materials due to environmental sustainability have further enhanced the search for alternatives in the paper industry. Thus, wood sample from Vitex Pubescens Vahl (Halban) was evaluated based on the pulp characteristics; and paper physical, mechanical and optical properties as alternative raw material for papermaking. The wood chips were chemically Kraft cooked. Laboratory hand sheet with 120 gsm of grammage was produced without beating and bleached treatment. Overall procedures and tests were conducted according to the Technical Association of the Pulp and Paper Industry (TAPPI) and the Malaysian International Organization for Standardization (MS-ISO). The result shows that Halban virgin Kraft pulp recorded a value of screened yield percentage (38.6%), Kappa number (22.1), drainage time (6.44s), and Canadian Standard Freeness (555ml). Halban paper sheet has apparent density of 0.302g/cm^3. In an optical analysis, brightness (19.81%) and opacity (99.5%) had been measured. Mechanical characteristic possess considerable tensile index (29.33Nm/g), tear index (6.028 mN.m^2/g), burst index (1.04 kPa.m^2/g), but low folding no (3). In conclusion, Halban wood could be considered as alternative wood-based material for papermaking based on its promising characteristics' and also compatible with other wood-based material proposed by the previous study. However, more in-depth evaluation should be considered to improve the qualities of the pulp and paper made from Halban wood.

***Index Terms*: Kraft; Pulping; Paper; Wood;**

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I. INTRODUCTION

Pulp and paper mills are complicated and incorporate many distinct processes, including the preparing of wood, pulping, chemical regeneration, bleaching and papermaking, in order to transform wood into the end product [1]. Paper is an important product used in the packaging industry globally due to its impressive characteristics such as natural, renewable, cheap and biodegradable [2]. About 45% of the fiber used in globally papermaking manufacturing was virgin fiber in 2010, and the remaining 55% was recovered paper [3]. The use of paper has increased due to high demand from industry and the market. However, the global supply of wood based raw material for papermaking was insufficient due to the deforestation and environmental issues. The growing demand for wood-based material for paper making indirectly increases the activity of deforestation and also affects the environment [4]. Besides, Malaysia has a small total capacity of pulp and paper local production and is a pulp and paper net importer especially industrial virgin long fiber [2,5]. Therefore, new alternative wood-based papermaking material should be proposed. Thus, this research utilized Vitex Pubescens Vahl. (Halban) wood as newly explored material for papermaking. Besides, based on author knowledge there was less published research on the utilization of Halban fiber for papermaking application.

In Malaysia, Halban wood is utilized in production of popular musical instrument which is Kompang due to its special characteristics that suitable to produce very good sound. It was found that there were a lot of Halban wood waste produced in Kompang industries (Fig. 1). Thus, the utilization of Halban wood excess from Malaysian Kompang manufacturer in papermaking application wood be beneficial to reduce the waste consumption.

Fig. 1. Halban wood excess waste

The main objective of this study is to investigate the physical, mechanical and optical characteristics of virgin (unbeaten and unbleached) pulp and paper produced by Kraft pulping method. Overall process and characteristics' test involved in this research were conducted according to MS ISO and TAPPI standard. The results observed in this research were compared with established previous wood-based Kraft pulp and paper studies. Thus, the outcomes of this research are very useful for the paper industry in highlighting Halban wood as one of the alternative wood-based materials for paper production.

II. LITERATURE REVIEW

A. Vitex Pubescens Vahl. (Halban)

This study was focused in producing virgin Kraft pulp from Halban wood. In the Malaysian peninsula, Vitex pubescens Vahl. (Verbenaceae) is known as Halban [6]. Vitex or Vitex Pinnata was others scientific name for Halban trees. Halban or Laban is one of the pioneer wood plant species are long-lived, have properties that hardwood, easily to found and dominated the secondary forest, especially shortly after the primary forest is opened [7]. Laban wood usually found in Bangladesh, Cambodia, India, Indonesia, Laos, Malaysia, Myanmar, Philippines, Sri Lanka, Thailand, Vietnam and Guatemala. Halban is a typical evergreen tree that has smaller to medium size. Usually, the height of this tree reached 20 m to 30 m tall and up to 70 cm in diameter at breast height [8]. The brown wood of Halban is very hard and durable with density of 800-950 kg/m³ at 15% moisture content [9].

This tree has many advantages especially in medicine area [10–12]. A bark decoction is used to relieve stomach distress and a poultice of the leaves is used in fevers and injuries [13]. Communities utilized Halban wood as raw material for fishing boats, building a house, household appliances, even the skin is extracted as antifungal [8]. Because of its small dimensions, the timber is favored locally for construction, boats and equipment [9]. Laban wood also used for making charcoal [7, 14]. Several studies also utilized Halban wood in producing liquid smoke [15] and wood vinegar [12]. Table 1 shows that Halban wood has a promising quality as an alternatives hardwood based papermaking raw material based on its chemical composition especially holocellulose content and lignin are within the range of various papermaking hardwood and softwood. Therefore, Halban wood suitability as papermaking material should be investigated.

Table 1. Halban, softwood and hardwood chemical composition

Wood type	Holo-cellulose (%)	Cellulose (%)	Lignin (%)
Vitex Pinnata[16]	72.15 ±0.72	44.87 ±0.30	29.84 ±0.11
Vitex pubescens Vahl[17]	-	43.76	-
Various softwood[18]	60-80	-	21-37
Various hardwood[18]	71-89	-	14-34

B. Kraft Pulping

The separation of fiber from wood is known as pulping. Chemical pulping use chemical to separates the lignin by dissolving non-cellulose and non-fibrous component of the wood [19]. The Kraft process is the dominant chemical pulping method. Because of the strength of the pulp, the versatility of the process, the ability to handle a wide range of raw materials and the ready availability of a chemical recovery system, Kraft pulping has become the common process for the production of full chemical pulp. Kraft pulping process uses sodium hydroxide (NaOH) and sodium sulfide (Na_2S) from the conversion of wood to wood pulp [20]. The combination of NaOH and Na_2S known as white liquor where it can separates the bonding of lignin, hemicellulose, and cellulose. It produced many advantages by using sodium hydroxide and sulfide during a Kraft cook, it can produce high quality of fiber strength compared to the other process. It also does less damage to the cellulose fibers [21]. However, loss in pulp yield caused by carbohydrate instability of degradation during the alkaline reaction is usually happened in Kraft pulping [8]. Table 2 shows the Kraft pulping condition for various wood and non-wood conducted by previous researchers. Based on these conditions, Na_2S (25%), cooking time (120 minutes) and cooking temperature (170°C) were selected as pulping parameters in the present study.

Table 2. Previous study Kraft pulping condition

Cooking Condition	AA (%)	Na_2S (%)	L:M ratio	CT (min)	T (℃)
Wood waste[20]	20	25%	4:1	60	171
Acacia [22]	12	25%	3.5:1	120	170
Recycling Acacia[23]	12	25%	-	120	170
Macaranga [24]	12-16	25%	5:1	120	170
Kenaf [25]	15	25%	6:1	120	170
Eucalyptus[26]	18	25%	-	30	170

AA: Active Alkali dosage Sodium Hydroxide (NaOH)
NA_2S : Sodium Sulphide dosage
L:M : Liquor to oven dry weight material ratio
CT: Cooking time at cooking temperature
T: Cooking temperature (℃)

III. RESEARCH METHODOLOGY

A. Material Preparation

The *Halban* wood excess waste in Fig. 2(b) was obtained from Perusahaan Kompang & Jidor Parit Sumarto, Batu Pahat, Johor, Malaysia. The raw material was cut into uniform size by using a chipping machine as Fig. 2(a).The standard and ideal size of chip usually was approximately 10 mm width x 30 mm length x 2-5 mm thickness. The wood chip then using a chip classifier and moisture content were determined.

(a) (b)

Fig. 2. (a) Chipping machine (b) Halban wood chip

B. Kraft Pulping

In this process, Kraft pulping of Halban wood was conducted with 25% sulphidity (Na_2S) at 18% of NaOH 25% with 6:1 liquor to material ration in a rotary digester. The Kraft pulping were carried out at 170℃ of cooking temperature and 90 minutes is required for liquor to reach the cooking temperature.

The rotary digester was run for 120 minutes. This condition is selected based on previous study of kenaf by (Adnan et al., 2004). The oven drying method is conducted based on Malaysian Standard MS ISO 287: 1985, IDT to measure the moisture content of *Halban* fiber. The screening process undergo by using PTI Sommerville Fractionators according to TAPPI T 275 standard with slot size of 0.15 mm. By using Neng Shin spinning drying machine water contained in the pulp is reduced. The pulp was dry spin for 10 minutes. Then, the dry pulp is placed inside the mixing bowl of Hobart Mixer machine in order to disperse the pulp. The pulp is weighed to gain the screened yield percentage. The screen yield was obtained based on the moisture content of the pulp. Finally, the pulp as shown in Fig. 3 was stored inside the chiller at 6 °C before proceed to laboratory hand sheets preparation. KAPPA no was determine according to TAPPI T 236 om-99 standard.

Fig. 3. Halban wood virgin Kraft pulp

C. Laboratory Hand Sheet Preparation

The hand sheet was produced using a semi-automatic sheet machine (British Hand-sheet Machine) according to TAPPI T 205 sp-02 and MS ISO 5269-1: 2007 (Fig. 4). Hand sheet with as basis weight of 120 gsm was produced. The pulp drainage time was measured according to TAPPI T221-cm 99. The pulp Canadian Standard Freeness (CSF) was determined according the TAPPI T 227 om-99 by an L&W freeness test apparatus. The sheets were dried and conditioned at 23 ± 1 °C and 50 ± 2.0% RH according to TAPPI T 402 sp-03 and MS ISO 187: 2001 for at least 24 h before testing was carried out (Fig. 5).

(a) (b) (c)

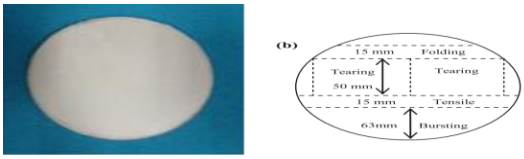
Fig. 4. Hand sheet formation (a) 1 liter of pulp (b) Hand sheet machine (c) Press machine

(a) (b)

Fig. 5. (a) Drying ring (b) hand sheet conditioning

D. Characteristics Test

Several tests were conducted to determine the characteristics of paper made from Halban virgin Kraft pulp. The produced hand sheet were tested according to tensile test, tearing test, bursting test, folding test, thickness test, grammage test, brightness, opacity test, Scanning Electron Microscopy (SEM) and Atomic Force Microscope (AFM). Tensile, tearing and burst strength characteristics were expressed in indices (ratio of strength value to grammage). The entire testing was conducted according to the standard listed in Table 3. Hand sheet weighing, thickness measurement, brightness and opacity test were conducted before the sample was divide and cut into size according to the test conducted requirements. Fig. 6(a) shows sample of Halban virgin Kraft paper and Fig. 6(b) shows the sample division for characteristics' test.



(a) (b)

Fig. 6. (a) Halban Kraft paper (b) test sample division [4]

Table 3 Pulp and Paper characteristics test standard

No.	Testing	Standard TAPPI/MS-ISO
1.	Grammage	MS-ISO 536:2001
2.	Moisture content	MS ISO 287:2010
3.	Thickness	MS-ISO 534: 2007
4.	Brightness	MS-ISO 2470-1:2010

5.	Opacity	MS-ISO 2471:2010
6.	Bursting	MS-ISO 2758:2007
7.	Tensile	MS-ISO 1924-2:2010
8.	Tearing	MS-ISO 1974:1999
9.	Folding	MS-ISO 5626:1999
10.	Freeness	TAPPI T 227 om-99
11.	Drainage Time	TAPPI T 272
12.	Kappa Number	TAPPI T 236 om-99

E. Scanning Electron Microscopy (SEM)

Scanning Electron Microscope (SEM) is the machine that focused the beam of electrons that are reflected to form an image. The resolution of SEM achieved better than 1 nm. SEM was conducted to determine the characterisation paper sample such as topography (surfaces feature of an object) or morphology, shape and size of paper fiber. Areas ranging from approximately 1 cm to 5 microns in width imaged in a scanning mode using conventional SEM techniques.

The samples were coated with gold in an Ion sputter coater in the low vacuum with a layer of 150-200 nm thick. Paper was mounted on specimen holders with the help of electro conductive tape. Accelerating potential used was 20kV. The magnification ranging from 20x to approximately 30000x, the resolution of 50 to 100nm.

IV. RESULTS AND DISCUSSION

A. Halban Kraft Pulp Characteristics

Table 4 shows the screened yield of Halban is 38.6%. CSF Freeness of Halban Kraft pulp recorded a value of 555 ml while Kappa number for Halban is 22.1. Kappa no. reflects with the lignin content in the wood which resulting in the amount required for bleaching agents. The average of drainage time for Halban virgin Kraft pulp is 6.44 s.

Table 4. Pulp characteristics

Characteristics	Value
Screened Yield (%)	38.6
CSF Freeness (ml)	555
Kappa no.	22.1
Drainage Time (s)	6.44 ± 2

B. Hand Sheet Physical Characteristics

Table 5 shows the physical characteristics of paper made from unbleached and unbeaten Halban Kraft pulp via thickness, grammage and apparent density. The grammage produced is 120.36 gsm indicates that the correction process during the stock preparation is required to achieve the specific target value of grammage. The mean thickness for a sheet of paper is 396.8µm while the apparent density mean value obtained from Halban paper is 0.302 g/cm^3. Apparent density is one of the most significant properties of paper that influences almost all mechanical, physical, and electrical properties [27].

Table 5. Hand sheet physical characteristics

Physical Characteristics	Mean Value	STDV
Grammage (g/m^2)	120.36	-
Thickness (µm)	396.8	2.25
Apparent Density (g/cm^3)	0.302	0.002

C. Hand Sheet Mechanical Characteristics

Table 6 listed the mechanical characteristics of Halban paper. The Halban hand sheet obtained a value of tensile index (29.33 N.m/g), tear index (6.028 mN.m^2/g) and bursting index (1.04 kPa.m^2/g). These values is very important for future in-depth research to be compared as control virgin pulp. However, folding no. for Halban virgin Kraft paper is showing a very low result as shown in Table 6. In order to achieve better folding no. and other mechanical properties, beating and blending process should be considered in future research. A paper sheet made from virgin pulp without beating or refining has low strength, bulkiness and rough surface [28].

Table 6. Hand sheet mechanical characteristics

Mechanical Characteristics	Mean Value	Standard Deviation (STDV)
Tensile Index(N.m/g)	29.33	0.63
Tearing Index(mN.m^2/g)	6.028	0.05
Bursting Index(kPa.m^2/g)	1.04	0.02
Folding No.	3	0.76

D. Hand Sheet Optical Characteristics

The low brightness level (<20% ISO) was recorded by Halban virgin Kraft paper (19.81%). However in opacity, high value of 99.50% is obtained. The average for contrast ratio for Halban virgin Kraft pulp is 98.09%. For the transparency test the result obtained was 6.68%. In future, pre-hydrolysis is recommended to achieve better brightness. Bleaching procedure also could be carried out in enhancing the optical characteristics especially brightness.

D. Comparison with previous researches

Halban Kraft pulp produced lower screened yield percentage (38.6%) compare to Eucalyptus, Aspen and Maritime Pine, the yield obtained was 45.1%, 45.2% and 53.8% respectively. In Table 7, Halban pulp shows smaller Kappa no. compared to European Aspen Jasika, Maritime Pine, Eucalyptus Kraft pulp and Pine species. However, screened yield percentage of virgin Halban Kraft pulp is quite similar and near to Acacia mangium and Cypress species. It is recommended to optimize the Kraft pulping parameters (active alkali, sulphidity, liquor to material ratio, cooking temperature and cooking time) in achieving more higher screened yield percentage for Halban.

Table 8 shows the different apparent density of Halban virgin kraft pulp which is 0.302g/cm^3 is lower compared to commercial scale virgin Acacia mangium and Eucalyptus globulus. In Table 9, the tensile index value of Halban wood (24.84 Nm/g) was higher than softwood Aspen (27.42 Nm/g) and virgin hardwood Acacia mangium (2.53 Nm/g) and Eucalyptus globulus (24.84 Nm/g). In tearing index, Halban performs better than Eucalyptus, Aspen, Acacia mangium and Eucalyptus globulus. As for the tensile strength, bursting strength was depending on inter-fiber bonding. Halban virgin Kraft paper apparent density (1.04 kPa.m^2/g) shows better value compared to virgin Eucalyptus globulus but lower than other wood species.

Virgin Halban kraft pulp has shown it compatible quality compared to other papermaking wood based material. These original properties of virgin Halban kraft pulp and paper shows promising quality and has opportunity of improvement in order to achieve commercial standard of quality .

Table 7. Screened yield and Kappa no. comparison

Wood Species	Wood Type	Screened Yield (%)	Kappa no.
Halban	Hardwood	38.6	22.1
Eucalyptus [29]	Hardwood	45.93-51.81	19.20-24.00
European Aspen Jasika [30]	Softwood	45.2	12.8
Maritime Pine[30]	Hardwood	53.8	60.3
Acacia Mangium[31]	Hardwood	37.60-44.6	10.5-44.6
Cypress Arizona[32]	Softwood	37.7	32
Cypress lustanica[32]	Softwood	36.7	31.6
Cypress sempervines[32]	Softwood	38.7	28.7
Pine Pinaster[32]	Softwood	40.8	23.4
Pine sylbestris[32]	Softwood	42.8	21.4

Table 8. Hand sheet mechanical characteristics

Wood type	Apparent Density (g/cm^3)
Halban	0.302
Acacia mangium[27]	0.49
Eucalyptus globulus[27]	0.54

Table 9. Mechanical characteristics comparison

Wood Species	Tensile Index (Nm/g)	Tear Index (mN.m^2/g)	Burst Index (kPa.m^2/g)
Halban	29.33	6.028	1.04
Acacia mangium[22]	~80	~ 9	~4
Macaranga gigatea[24]	79.0	12.0	4.5.0
Acacia mangium[27]	2.53	3.28	6.76
Eucalyptus globulus[27]	24.84	4.33	0.13
Eucalyptus[29]	45.09-53.9	4.00-5.49	3.04-3.72
*European Aspen Jasika[30]	27.42	5.20	1.71
Maritime Pine[30]	32.67	19.59	2.86
Acacia mangium[31]	30.76-47.06	3.62-4.99	1.14-1.90

* = softwood

Table 10 shows the ISO brightness for Halban Kraft pulp (14.31%) is better than Pine and quite similar with Macaranga but lower than Aspen. This was supported by the results of Kappa no. for Halban pulp is better than Pine and lower than Aspen as shown in Table 7. Therefore, brightness result also depends on wood species due to different lignin content. The brightness of all pulps decreased due to residual lignin containing highly colored chromophoric groups on fiber surfaces [30]. Table 10 shows the opacity of Halban compared with other woods. The opacity of Halban virgin Kraft paper was higher than Maritime Pine and Aspen.

Table 10. Hand sheet optical characteristics

	Brightness	Opacity
Halban	19.81	99.50
Macaranga[24]	< 20	99.1-99.2
Maritime Pine[30]	14.31	97.66
Aspen[30]	24.61	95.47

F. SEM analysis

Fig. 7 and Fig. 8 show the SEM image of Halban virgin Kraft paper surface morphology with 500 x and 1000x magnification, respectively. It can be seen that Halban Kraft pulp fiber arrangement and binding was not so uniform. The fiber arrangements were not straight and have some crimps and kinks. Inter-fiber bonding and fiber individual strength are the key features in paper characteristics. The paper sheet strength properties depends on its original qualities and strength of the fibres and to the extent of bonding between the fibres that make up the sheet [28]. In future, beating and bleaching process should be taken as consideration to improve the inter-fiber bonding of virgin Halban Kraft pulp.

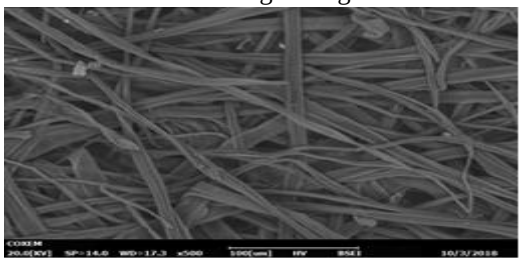


Fig. 7. Halban Kraft hand sheet surface morphology (x500 magnification)

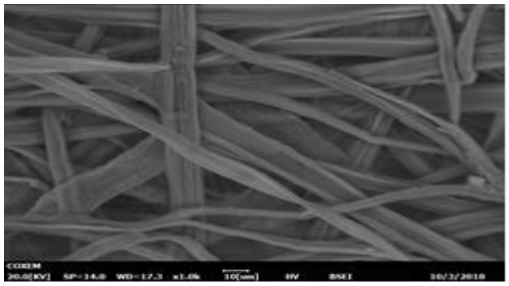


Fig. 8. Halban Kraft hand sheet surface morphology (x1000 magnification)

V. CONCLUSION

Laboratory scale Halban virgin Kraft pulp and paper was successfully produced. The Halban wood pulp was produced with Kraft pulping condition of 18% active alkali with L: M ratio of 6:1 with 25% sulphidity and cooked for 120 minutes at 170 ^{o}C. In this study, the physical, mechanical and optical characteristic of pulp and paper made from Halban wood were investigated and obtained. The results shows Halban Kraft pulp recorded screened yield percentage (38.6%), CSF Freeness (555ml), Kappa no. (22.1) and drainage time (6.44s). In physical and mechanical characteristics, paper that produced from unbeaten and unbleached Halban Kraft pulp shows value of apparent density (0.302 g/cm^3), tensile index (29.33 N.m/g), tear index (6.028 mN.m^2/g) and burst index (1.04 Kpa.m^2/g). However, the performance of folding no.

(3) is low and required in-depth study to improve it. Halban wood Kraft pulp and paper also shows compatible characteristics compared to various type papermaking wood-based material.

As a recommendation, applying beating treatment could enhances the physical and mechanical characteristics of virgin pulp and paper. Beating promotes pulp with fiber shortening, good fiber bonding and more quality hand sheet formation. Kraft pulping variables (active alkali, sulphidity, liquor to material ratio, cooking time and cooking temperature) need to be optimized in producing the Halban Kraft pulp and paper with the most optimum characteristics. ISO brightness level for Halban Kraft (19.81%) is low and should be improved to achieve commercial paper optical characteristics requirement. Besides pulping condition optimization, applying the bleaching sequence also could be utilized in order to increase the optical characteristics.

In future, the performance of blending Halban Kraft pulp with sizing agents, recycle paper material, softwood industrial long fiber should be investigated to evaluate the evaluate the performance in linerboard and corrugated medium application. In conclusion, Malaysia species of Halban wood has shown its potential and promising quality to be developed as a raw material in papermaking. However, more in-depth study need to be conducted to explore the optimum quality of Halban wood Kraft pulp as recommended.

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