UNIVERSITI PUTRA MALAYSIA

DEVELOPMENT OF EFFICIENT PROCESSING METHOD FOR THE PRODUCTION OF CELLULOSE NANOFIBRILS FROM OIL PALM BIOMASS

LIANA BINTI NOOR MEGASHAH

FBSB 2021 20

DEVELOPMENT OF EFFICIENT PROCESSING METHOD FOR THE PRODUCTION OF CELLULOSE NANOFIBRILS FROM OIL PALM BIOMASS

By

LIANA BINTI NOOR MEGASHAH

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfilment of the Requirements for the Degree of Doctor of Philosophy

February 2021

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Doctor of Philosophy

DEVELOPMENT OF EFFICIENT PROCESSING METHOD FOR THE PRODUCTION OF CELLULOSE NANOFIBRILS FROM OIL PALM BIOMASS

By

LIANA BINTI NOOR MEGASHAH

February 2021

Chair : Hidayah Ariffin, PhD
Faculty : Biotechnology and Biomolecular Sciences

Cellulose nanofibrils (CNFs) is an emerging, versatile nanomaterial with vast applications such as plastics, papers, composites, thickener agents, healthcare, coatings etc. Nevertheless, there are several issues in the sustainable production of CNFs pertaining to the non-ecofriendly pretreatment method for cellulose isolation related to the use of chlorinated solution, as well as high energy intensity and throughput limitation which limit the productivity during nanofibrillation process by wet disc mill (WDM). The natural cellulose high degree of polymerization (DP) caused the formation of a highly viscous cellulose suspension during processing and was hypothesized to contribute to the high energy requirement and low productivity of the nanofibrillation process. In this research, cellulose isolation from oil palm biomass was conducted by using a totally chlorine free (TCF) bleaching for lignin removal. A multi-step pretreatment method consisting of a sequence of pretreatment, *i.e.,* superheated steam (SHS), enzymatic hydrolysis and 5% NaOH was evaluated for its effectiveness in hemicellulose removal and its effect on the environmental loads. The multi-step pretreatment method was compared with the conventional soda pulping method at 14% NaOH under elevated pressure. After cellulose isolation step, the cellulose was treated by SHS at 150°C for 1 and 2h (SHS1 and SHS2) aimed at depolymerization for DP reduction. This method was compared with the enzymatic hydrolysis. It was shown that the multi-step pretreatment method produced lesser purity cellulose from oil palm biomass (83-88%) as compared to soda pulping method (89-95%). Its environmental load based on qualitative analysis was however similar to that of soda pulping. The TCF bleaching successfully removed the lignin almost completely, showing the effectiveness of

TCF bleaching as an alternative to chlorinated bleaching. In the subsequent experiment for cellulose DP reduction, it was demonstrated that SHS treatment caused cellulose DP reduction up to 43% after 2h of SHS treatment (SHS2). As

a comparison, enzymatic hydrolysis contributed to almost similar percentage reduction after 6h and 12h of hydrolysis using 20 FPU/g and 10 FPU/g cellulase, respectively. The SHS treated cellulose was used in nanofibrillation process, and it was interesting to note that SHS2 cellulose (DP - 820) contributed to lower viscosity CNFs suspension (60 cP), shorter processing duration (4.0 h/kg), and smoother processing without clogging even at 4 wt% solid content processing; compared to the untreated (UT) cellulose (DP - 1,440). All these contributed to higher CNFs productivity by 86% from 0.044 kg/h to 0.320 kg/h, and lower energy consumption by 90% from 42.3 kWh/kg to 4.2 kWh/kg, compared to the untreated (UT) cellulose. The results obtained confirmed the hypothesis that CNFs productivity and energy consumption were related to the original characteristic of cellulose, *i.e.,* high DP. The SHS treatment also contributed to versatile properties of CNFs produced, as exhibited by the characteristics of the CNFs as well as the CNF films. CNF-SHS films were thinner, stiffer and had smoother surface compared to CNF-UT film. Higher light transmittance by 22.5% and greater water-repellent property by 15.1% were also recorded for CNF-SHS2 film as compared to the CNF-UT film. SHS treatment also promotes the production of versatile mechanical properties of CNF films, to meet vast applications of nanofilms. Feasibility analysis conducted showed that the pretreatment and production methods proposed are technical feasible, which can attribute to the lower environmental loads compared to the conventional process, the simplicity of the process, as well as the availability of the steam energy should the plant be located near the palm oil mill. It is also economically feasible with the NPV of USD 714,031 for 10 years and IRR of 45%. CNFs from OPEFB is also potentially marketable based on its comparable characteristics to those of commercial CNFs, as well as its market acceptability based on the survey. Overall, the proposed processing methods provided herewith will contribute significantly towards a more sustainable CNFs production from oil palm biomass in the near future.

Abstrak tesis yang dikemukakan kepada Senat of Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Doktor Falsafah

PEMBANGUNAN KAEDAH PEMPROSESAN TENAGA YANG EFISIEN DALAM PENGHASILAN NANOFIBRIL SELULOSA DARIPADA SISA BIOMAS KELAPA SAWIT

Oleh

LIANA BINTI NOOR MEGASHAH

Februari 2021

Pengerusi : Hidayah Ariffin, PhD
Fakulti : Bioteknologi dan Sains Biomolekul

Nanofibril selulosa (CNFs) merupakan nanomaterial baru serta serba boleh dengan aplikasi yang luas seperti plastik, kertas, komposit, agen pemekat, produk kesihatan, pelapis permukaan dan sebagainya. Walaupun begitu, terdapat beberapa masalah dalam penghasilan CNFs yang berkesinambungan dengan kaedah pra-rawatan tidak mesra iaitu pengekstrakan selulosa menggunakan peluntur klorat, serta intensiti tenaga yang tinggi dan daya pemprosesan yang membatasi produktiviti semasa proses nanofibrilasi oleh penggilingan cakera basah (WDM). Darjah pempolimeran (DP) tahap tinggi oleh selulosa semula jadi menyebabkan penghasilan larutan selulosa yang berkelikatan tinggi semasa pemprosesan, dan dihipotesis akan mempengaruhi kepada penggunaan tenaga tinggi dan penurunan produktiviti bagi proses nanofibrilasi. Dalam penyelidikan ini, pengekstrakan selulosa dari biomas kelapa sawit dijalankan dengan menggunakan peluntur bebas klorin (TCF) untuk penyingkiran lignin. Kaedah pra-rawatan pelbagai langkah yang terdiri daripada susunan pra-rawatan, iaitu rawatan stim panas lampau (SHS), hidrolisis enzim dan rawatan beralkali berkepakatan 5% telah dinilai memberi keberkesanan dalam penyingkiran hemiselulosa dan memberi impak terhadap beban persekitaran. Kaedah pra-rawatan pelbagai langkah dibandingkan dengan rawatan konvensional pulpa-soda berkepekatan alkali 14% melalui tekanan tinggi. Setelah langkah pengasingan selulosa, selulosa tersebut dirawat menggunakan SHS pada suhu 150°C selama 1 dan 2 jam (SHS1 dan SHS2), bertujuan depolimerisasi untuk mengurangkan DP. Kaedah ini dibandingkan dengan hidrolisis enzim. Kaedah pelbagai langkah memberi hasil nilai selulosa yang lebih rendah daripada biomas kelapa sawit (83-88%) jika dibandingkan dengan kaedah pulpa-soda (89-95%). Walau bagaimanapun, beban persekitaran berdasarkan analisis kualitatif adalah setanding dengan pulpa-

soda. Peluntur TCF berjaya menyingkirkan lignin hampir keseluhurannya, membuktikan keberkesanan peluntur TCF sebagai rawatan alternatif bagi menggantikan peluntur klorit. Dalam eksperimen berikutnya untuk pengurangan DP selulosa, rawatan SHS menunjukkan penurunan DP selulosa sehingga 43% dalam rawatan SHS selama 2 jam (SHS2). Sebagai perbandingan, hidrolisis enzim menyumbang kepada pengurangan peratusan yang hampir sama setelah hidrolisis selama 6 dan 12 jam menggunakan enzim “cellulase’ pada 20 FPU/g dan 10 FPU/g. Rawatan SHS selulosa telah digunakan dalam proses nanofibrilasi, dan yang menarik perhatian bahawa selulosa SHS2 (DP - 820) menyumbang kepada kelikatan CNFs yang lebih rendah (60 cP), jangka masa pemprosesan yang lebih pendek (4.0 h/kg), dan pemprosesan yang lebih lancar tanpa menyebabkan penyumbatan, walaupun pada pemprosesan dengan kelikatan 4% kandungan pepejal; berbanding dengan selulosa (UT) yang tidak dirawat (DP - 1,440). Kaedah ini menyumbang kepada peningkatan produktiviti CNFs sebanyak 86% dari 0.044 kg/h kepada 0.320 kg/h, dan penggunaan tenaga yang lebih rendah sebanyak 90% daripada 42.3 kWh/kg kepada 4.2 kWh/kg berbanding dengan selulosa yang tidak dirawat (UT). Hasil yang diperoleh mengesahkan secara hipotesis bahawa produktiviti dan penggunaan tenaga CNFs adalah berkait dengan ciri asal selulosa, iaitu DP yang tinggi. Rawatan SHS juga menyumbang kepada sifat serbaguna CNFs yang dihasilkan, seperti yang dipamerkan oleh ciri-ciri CNFs dan juga CNF filem. Filem daripada CNF-SHS adalah lebih nipis, kuat dan mempunyai permukaan yang lebih licin berbanding filem daripada CNF-UT. Transmisi cahaya adalah lebih tinggi iaitu 22.5% dan sifat kalis air yang tinggi sebanyak 15.1% juga dicatatkan untuk filem CNF-SHS2 berbanding dengan filem CNF-UT. Rawatan SHS juga mendorong penghasilan sifat mekanikal serbaguna filem CNF, bagi memenuhi aplikasi nano-filem yang luas. Analisis kebolehlaksanaan yang dilakukan menunjukkan bahawa kaedah pra-rawatan dan proses penghasilan yang dicadangkan secara teknikal adalah fisibel yang tersedia yang mana dapat menyumbang kepada pengurangan beban persekitaran berbanding proses konvensional, kesederhanaan proses, serta ketersediaan tenaga stim sekiranya lokasi kilang berhampiran dengan kilang sawit. Ia juga dapat dilaksanakan secara ekonomi dengan nilai NPV iaitu USD 714,031 bagi tempoh 10 tahun dan IRR sebanyak 45%. CNFs dari OPEFB juga berpotensi untuk dipasarkan berdasarkan ciri kesetandingnya dengan ciri-ciri CNFs komersial, serta penerimaan pasaran berdasarkan tinjauan. Secara keseluruhan, kaedah pemprosesan yang dicadangkan dapat menyumbang secara signifikan terhadap pengeluaran CNFs yang lebih mampan dari biomas kelapa sawit pada masa hadapan.

ACKNOWLEDGEMENTS

Bismillah Ar-Rahman Ar-Rahim

Allah, the Almighty, belongs whatever is on the earth and whatever is in the heavens and to Him the ease from every difficulty. Indeed, He created a great journey in my PhD study and made me complete this thesis successfully, and the Prophet Muhammad (SAW) is the source of inspiration as he (peace and blessings of Allah be upon him) said:

"Whoever takes a path for seeking knowledge, Allah will ease for him the path to Paradise".

First and foremost, I want to express my deepest gratitude to my main supervisor, Professor Ts. Dr. Hidayah Ariffin. I am extremely grateful to be one of her students, and with her guidance, advice, and untiring support, I managed to convert my Master to PhD level. It is indeed a great honor that I am being able to publish journal articles under her supervision.

Also, a special thanks to Associate Professor Dr. Mohd Rafein Zakaria for guiding me to improve my written skills to publish the research paper in a good journal and as advisor's support for my research. I am extremely thankful to my lab head in Biorefinery Complex, Professor Dato' Dr. Mohd Ali Hassan for providing outstanding research environment. Also, I express my thank to my co-supervisor Associate Professor Dr. Yoshito Andou for his encouragement and insightful comments. I would also like to thank my colleagues in the Biomaterials Group and Environmental Biotechnology Research member in UPM for lending a helping hand, sharing ideas, and helped me to get the "Big Picture" of biorefinery concept in my research.

I extend my gratitude to School of Graduate Studies for financial assistance. I also acknowledge Japan International Cooperation Agency (JICA) and Japan Services Organization (JASSO) for giving me a sponsorship to conduct a research project at Kyushu Institute of Technology, Japan.

At last, I wish to pay my special regards to my father, Mr. Noor Megashah Abdullah, my siblings, as well as my late mother and brother for their love and giving me strength to finish my PhD journey. Finally, my thanks to those who have contributed to this thesis and supported me, directly or indirectly.

Thank you!

This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Doctor of Philosophy. The members of the Supervisory Committee were as follows:

Hidayah binti Ariffin, PhD
Professor Ts.
Faculty of Biotechnology and Biomolecular Sciences
Universiti Putra Malaysia
(Chairman)

Mohd Rafein bin Zakaria @ Mamat, PhD
Associate Professor
Faculty of Biotechnology and Biomolecular Sciences
Universiti Putra Malaysia
(Member)

Yoshito Ando, PhD
Associate Professor
Graduate School of Life Sciences and System Engineering
Kyushu Institute of Technology, Japan
(Member)

ZALILAH MOHD SHARIFF, PhD
Professor and Dean
School of Graduate Studies
Universiti Putra Malaysia

Date: 14 October 2021

Declaration by graduate student

I hereby confirm that:

- this thesis is my original work;
- quotations, illustrations and citations have been duly referenced;
- this thesis has not been submitted previously or concurrently for any other degree at any other institutions;
- intellectual property from the thesis and copyright of thesis are fully-owned by Universiti Putra Malaysia, as according to the Universiti Putra Malaysia (Research) Rules 2012;
- written permission must be obtained from supervisor and the office of Deputy Vice-Chancellor (Research and Innovation) before thesis is published (in the form of written, printed or in electronic form) including books, journals, modules, proceedings, popular writings, seminar papers, manuscripts, posters, reports, lecture notes, learning modules or any other materials as stated in the Universiti Putra Malaysia (Research) Rules 2012;
- there is no plagiarism or data falsification/fabrication in the thesis, and scholarly integrity is upheld as according to the Universiti Putra Malaysia (Graduate Studies) Rules 2003 (Revision 2012-2013) and the Universiti Putra Malaysia (Research) Rules 2012. The thesis has undergone plagiarism detection software.

Signature:______________ Date:__________

Name and Matric No.: Liana binti Noor Megashah, GS47569

Declaration by Members of Supervisory Committee

This is to confirm that:

- the research conducted and the writing of this thesis was under our supervision;
- supervision responsibilities as stated in the Universiti Putra Malaysia (Graduate Studies) Rules 2003 (Revision 2012-2013) are adhered to.

Signature:	
Name of Chairman of Supervisory Committee:	Hidayah binti Ariffin

Signature:	
Name of Member of Supervisory Committee:	Mohd Rafein bin Zakaria @ Mamat

Signature:	
Name of Member of Supervisory Committee:	Yoshito Ando

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

α	Alpha
β	Beta
θ	Theta
°C	Degree Celsius
η	intrinsic viscosity
η inh	inherent viscosity
AGU	Anhydroglucose unit
AFM	Atomic force microscopy
AQ	Anthraquinone
AXU	Active xylanase unit
ATR	Attenuated total reflectance
BNC	Bacterial nanocellulose
CED	Cupriethylenediamine
CNF	Cellulose nanofibril
CNC	Cellulose nanocrystal
cP	Centipoise
CrI	Crystallinity index
DP	Degree of polymerization
ECF	Elemental chlorine free
GPa	Giga-pascal
FE-SEM	Field emission-scanning electron microscope
FPU	Filter Paper Unit
FTIR	Fourier-transform infrared spectroscopy

GNI	Gross National Income
KBr	Potassium bromide
kHz	Kilohertz
kN	Kilo-newton
nm	nanometer
MFC	Microfibrillated cellulose
MPa	Mega-pascal
MPOB	Malaysian Palm Oil Board
NaOH	Sodium hydroxide
NREL	National Renewable Energy Laboratory
OPEFB	Oil palm empty fruit bunch
OPF	Oil palm frond
OPMF	Oil palm mesocarp fiber
OPT	Oil palm trunk
PA	Peracetic acid
PHA	Polyhydroxyalkanoates
PKS	Palm kernel shell
POME	Palm oil mill effluent
PP	Polypropylene
PSD	Power spectral density
SEM	Scanning electron microscopy
Ra	Arithmetic mean
SDGs	Standard development goals
SiC	Silicon carbide
SHS	Superheated steam
TAPPI	Technical Association Pulp & Paper Industry

TCF	Totally chlorine free
TEMPO	2,2,6,6-Tetramethylpiperidine-1-oxyl radical
TG	Thermal gravimetric
WDM	Wet disc mill
XRD	X-Ray diffractometer

CHAPTER 1

INTRODUCTION

1.1 Overview

About 80 million tons of oil palm biomass is being generated in Malaysia annually (Aljuboori, 2013; Hassan et al., 2019). Oil palm biomass consists of oil palm mesocarp fiber (OPMF), oil palm empty fruit bunches (OPEFB), oil palm fronds (OPF), oil palm trunks (OPT), leaves and roots. Oil palm biomass are mainly used for fuel generation, composting and mulching (Abas et al., 2011; Hamzah et al., 2019). Other applications include animal feed, organic fertilizer, biosugar, biogas, biochar, and biocomposites (Hassan et al., 2019; Nordin et al., 2017; Samsudin et al., 2019; Zainal et al., 2017). Recently, the use of oil palm biomass for cellulose nanofibrils (CNFs) production has been reported (Norrrahim et al., 2018; Yasim-Anuar et al., 2019).

CNFs production from plant cellulose has attracted interest and great deal of research has been widely done (Bardet & Bras, 2014; Foster et al., 2018). CNF's are generally lightweight, has high aspect ratio, gel-like in water, hydrophilic and semi-crystalline (Klemm et al., 2011). Due to these characteristics, CNFs is used to reinforce biocomposites, enhance paper properties, functions as a thickener in paints and coatings, as a low calorie food additive, and could act as a functional material in many other versatile applications (Ariffin et al., 2018; Bardet & Bras, 2014; Kasuga et al., 2018; Missoum et al., 2013; Mohamad Haafiz et al., 2013). At present, commercial scale CNFs production mainly takes place in developed countries such as USA, Canada, Japan, UK, Sweden and Finland, and the CNFs is produced from wood-based resources (Future Markets Inc., 2019). Based on the report, commercial CNFs from non-wood resources is very little, mainly from bamboo. Being a country with abundance of oil palm biomass, Malaysia has great potential to be CNFs producer considering its potential as an emerging material with versatile applications. Therefore, the feasibility of CNFs production from oil palm biomass should be determined.

One of the challenges in CNFs production is related to the isolation of cellulose from lignocellulosic materials since the current pretreatment methods are time-consuming and involve hazardous chemicals. Desizing, scouring and bleaching are the three common pretreatment process to prepare high degree of whiteness of cellulose pulp with minimum degradation (Prabaharan & Rao, 2003). In the conventional process, pulping such as steam explosion and kraft pulping are used to rupture the fiber cell wall and results in removal of hemicellulose (Nechyporchuk et al., 2016; Suzuki et al., 2017). Besides pulping, other cellulose isolation methods are by using ethanol organosolv, acid, alkali, or ionic liquid. These pretreatment methods are inefficient for complete cellulose isolation (Tian et al., 2017), mainly due to the presence of residual lignin and recalcitrant hemicellulose. Bleaching agents like sodium chlorite, sodium hypochlorite, chlorine dioxide, and chlorate which are strong oxidizing agent are commonly used to remove the lignin. However, these bleaching agents are toxic and could affect human health if handled carelessly; and at the same time, the disposal of these chemicals into the water stream could have a negative impact on aquatic life and other organisms. Thus, it is important to consider the type of pretreatment process in cellulose isolation towards sustainable production of CNFs.

On top of cellulose isolation, the major obstacles in CNFs production are the high energy consumption for the disintegration of the cellulose fibers into CNFs, and the low productivity of the CNFs production process. CNFs is produced through multiple cycle mechanical process of cellulose suspension in order to provide shearing forces to allow fibrillation of the cellulose into nanocellulose. This generally results in high energy consumption. The CNFs suspension eventually becomes thicker throughout the process due to the nanofibrillation which causes the cellulose suspension to increase in viscosity.

Dissertations by Norrrahim (2018) and Yasim-Anuar (2018) reported that mechanical processing of oil palm biomass into CNFs using a wet disc mill (WDM) has several advantages compared to other processes such as high pressure homogenization and ultrasonication. CNFs produced by WDM had smaller diameter size (<50 nm), and the productivity is much higher compared to the other two methods due to the ability to process cellulose suspension with higher cellulose content (wt%) in WDM. Moreover, WDM does not involve any chemicals such as strong acid to disintegrate the fibers (Hideno et al., 2009; Xiao-zheng Sun et al., 2017; Zakaria et al., 2015). WDM is a promising method for large scale processing of CNFs.

1.2 Problem statements

There are three main issues related to the sustainable production of CNFs as outlined earlier:

i) a need for efficient and sustainable cellulose isolation methods
ii) a major cost to producing CNF relate to high energy consumption
iii) the long cellulose fibers resulting in the low productivity of CNF

A further goal is to prepare CNFs without chemical derivatization of the cellulose. For instance, there are large numbers of publications in which TEMPO mediated oxidation is commonly used. However, the process been considered too expensive. In order to produce CNFs, lignocellulosic material including oil palm biomass need to be pretreated for cellulose isolation, with the aim to remove lignin and hemicellulose which can interfere the nanofibrillation process. Regardless, current pretreatment is not environmentally friendly and is highly dependent on chemicals usage, which may lead to environmental issues. The common pretreatment used to fractionate the lignocellulosic component requiring active chlorine or halogenated chemicals which is unfavorable to the environment. It has been demonstrated that complete removal of hemicellulose is not needed as the presence of some amount of hemicellulose could promote the nanofibrillation of cellulose (Norrrahim et al., 2018). It is hence in this research the pretreatment is designed in such a way to use a more environmentally friendly pretreatment method and yet efficient for the removal of hemicellulose and lignin.

The high energy consumption during nanofibrillation is postulated due to the increase in cellulose suspension viscosity when the number of cycles is increased, as a result of nanofibrils formation. The fibrillation causes cellulose surface area to increase and exposes abundance of hydroxyl groups, which promotes the interaction with water through hydrogen bonds. This effect is related to the cellulose degree of polymerization (DP). Cellulose with higher chain length results in higher viscosity and eventually requires more energy for the microfibrils disintegration into nanofibrils. In this study, controlled reduction of cellulose DP is designed to lower the energy consumption. The effect of the DP reduction on the nanocellulose characteristics is portrayed by characterizing the nanofilm produced from the nanocellulose with reduced DP.

Productivity of the CNFs relates to the cellulose throughput during WDM processing. In the conventional processing using WDM, cellulose throughput is between 1 – 2 wt% of the total cellulose volume suspension processed (Nair et al., 2014; Qin et al., 2016; Wang & Zhu, 2016). Higher cellulose suspension concentration used leads to clogging, and high energy consumption due to the increased in viscosity. This cellulose feature (long fiber length) is the main drawback of produce CNFs at high concentration using WDM. It is postulated that the productivity can be increased when the viscosity issue is solved while achieves at high solid content (in kg) of CNFs product.

The research was designed to tackle the above-mentioned issues as it is important to offer a platform for sustainable CNFs processing, especially for the production of CNFs from the local biomass. Techno-economic feasibility of the CNFs was also conducted.

1.3 Objectives

The general objective of this research was to develop a sustainable processing method for CNFs production from oil palm biomass. The specific objectives of this study were:

1. To determine the feasibility of reducing the use of hazardous chemicals for cellulose isolation from oil palm biomass by using non-halogenated chemical pretreatment method.
2. To investigate the effect of superheated steam and cellulase enzyme treatments on controlled reduction of cellulose degree of polymerization.
3. To determine the influence of cellulose degree of polymerization on the productivity of cellulose nanofibrils production and energy consumption in wet disc milling process.
4. To characterize nanocellulose films developed from various degree of polymerization cellulose nanofibrils for their physical, mechanical, and thermal characteristics.
5. To evaluate the techno-economic feasibility of cellulose nanofibrils production from oil palm biomass based on multiplier to an economic factor.

1.4 Experimental overview

Chapter 1 of this thesis consists of the general overview, the problem statements, and the objectives of this research. Figure 1.1 shows the overall experimental overview of this research.

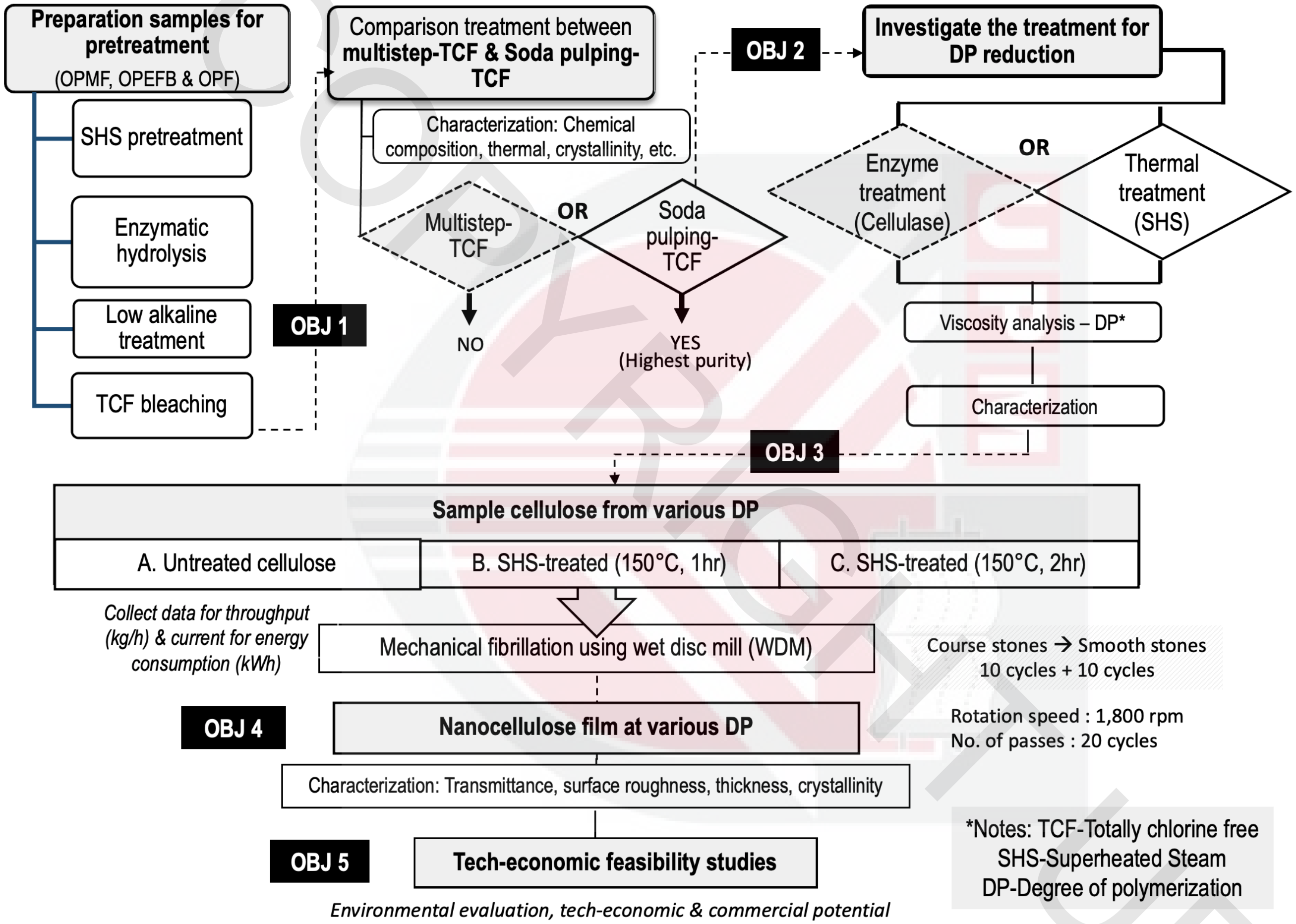

Figure 1.1: Experimental overview

REFERENCES

Aadland, R. C., Dziuba, C. J., Heggset, E. B., Syverud, K., Torsaeter, O., Holt, T., … Bryant, S. L. (2018). Identification of Nanocellulose Retention Characteristics in Porous Media. *Nanomaterials (Basel, Switzerland)*, *8*(7).

Abas, R., Fairuz, M., A Borhan, K., Nordin, A., & arif Simeh, M. (2011). A Study on the Malaysian Oil Palm Biomass Sector - Supply and Perception of Palm Oil Millers. In *Oil Palm Industry Economic Journal* (Vol. 11).

Abdel-Halim, E. S. (2014). Chemical modification of cellulose extracted from sugarcane bagasse : Preparation of hydroxyethyl cellulose. *Arabian Journal of Chemistry*, *7*(3), 362–371.

Abdul Khalil, H. P. S., Bhat, A. H., Jawaid, M., Amouzgar, P., Ridzuan, R., & Said, M. R. (2009). Agro-wastes: Mechanical and physical properties of resin impregnated oil palm trunk core lumber. *Polymer Composites*, *31*(4), NA-NA.

Abdul Khalil, H. P. S., Nurul Fazita, M. R., Bhat, A. H., Jawaid, M., & Nik Fuad, N. A. (2010). Development and material properties of new hybrid plywood from oil palm biomass. *Materials and Design*, *31*(1), 417–424.

Abdullah, M. A., Nazir, M. S., Raza, M. R., Wahjoedi, B. A., & Yussof, A. W. (2016). Autoclave and ultra-sonication treatments of oil palm empty fruit bunch fi bers for cellulose extraction and its polypropylene composite properties. *Journal of Cleaner Production*, *126*, 686–697.

Abdullah, N., & Sulaiman, F. (2013a). Oil palm biomass as a sustainable energy source: A Malaysian case study. *Biomass and Bioenergy*, *3*(1), 97–103.

Abdullah, N., & Sulaiman, F. (2013b). The Oil Palm Wastes in Malaysia. In M. D. Matovic (Ed.), *Biomass Now - Sustainable Growth and Use*. Rijeka: InTech.

Abdullah, S. S. S., Shirai, Y., Ali, A. A. M., Mustapha, M., & Hassan, M. A. (2016). Case study: Preliminary assessment of integrated palm biomass biorefinery for bioethanol production utilizing non-food sugars from oil palm frond petiole. *Energy Conversion and Management*, *108*, 233–242.

Abe, K., Iwamoto, S., & Yano, H. (2007). Obtaining Cellulose Nanofibers with a Uniform Width of 15 nm from Wood. *Biomacromolecules*, *8*(10), 3276–3278.

Abitbol, T., Rivkin, A., Cao, Y., Nevo, Y., Abraham, E., Ben-Shalom, T., … Shoseyov, O. (2016). Nanocellulose, a tiny fiber with huge applications. *Current Opinion in Biotechnology*, *39*(I), 76–88.

Acquah, G. E., Via, B. K., Fasina, O. O., Adhikari, S., Billor, N., & Eckhardt, L. G. (2017). Chemometric modeling of thermogravimetric data for the compositional analysis of forest biomass. *PLoS ONE*, *12*(3), e0172999.

Adney, B., & Baker, J. (2008). Measurement of Cellulase Activities Laboratory Analytical Procedure (LAP) Issue Date : 08 / 12 / 1996 Measurement of Cellulase Activities Laboratory Analytical Procedure (LAP). *Renewable Energy*, (January), 8.

Ahmad Farid, M. A., Hassan, M. A., Taufiq-Yap, Y. H., Shirai, Y., Hasan, M. Y., & Zakaria, M. R. (2017). Waterless purification using oil palm biomass-derived bioadsorbent improved the quality of biodiesel from waste cooking oil. *Journal of Cleaner Production*, *165*, 262–272.

Ahmad, N., & Zakaria, M. R. (2019). Oligosaccharide From Hemicellulose. In *Lignocellulose for Future Bioeconomy* (pp. 135–152).

AIM. (2013). *National Biomass Strategy 2020: New wealth creation for Malaysia's biomass industry*. Retrieved from https://www.cmtevents.com/MediaLibrary/BStgy2013RptAIM.pdf

AIM. (2018). *International Workshop: Future Perspective of Bioenergy Development in Asia Session 1: Setting the Scene-An overview of Asian Bioenergy Policy and Market*. Retrieved from https://www.ieabioenergy.com/wp-content/uploads/2018/09/1.3-Timothy-Ong.pdf

Alemdar, A., & Sain, M. (2008). Isolation and characterization of nanofibers from agricultural residues: wheat straw and soy hulls. *Bioresource Technology*, *99*(6), 1664–1671.

Alfy, A., Kiran, B. V., Jeevitha, G. C., & Hebbar, H. U. (2016). Recent Developments in Superheated Steam Processing of Foods—A Review. *Critical Reviews in Food Science and Nutrition*, *56*(13), 2191–2208.

Aljuboori, A. H. R. (2013). Oil Palm Biomass Residue in Malaysia : Availability and Sustainability. *International Journal of Biomass & Renewables*, *2*, 13–18.

American Process Inc. and Birla Carbon Announce Joint Development Agreement for Combining Nanocellulose and Carbon Black in Tires - Birla Carbon. (2017, March 2). Retrieved April 13, 2020, from https://birlacarbon.com/american-process-inc-birla-carbon-announce-joint-development-agreement-combining-nanocellulose-carbon-black-tires/

Anastas, P. (1998). *Green chemistry : theory and practice*. Oxford [England] ;;New York: Oxford University Press.

Ariffin, H., Norrrahim, M. N. F., Yasim-Anuar, T. A. T., Nishida, H., Hassan, M.

A., Ibrahim, N. A., & Yunus, W. M. Z. W. (2018). Oil Palm Biomass Cellulose-Fabricated Polylactic Acid Composites for Packaging Applications. In M. Jawaid & S. K. Swain (Eds.), *Bionanocomposites for Packaging Applications*. Cham: Springer, Cham.

Arola, S., Malho, J. M., Laaksonen, P., Lille, M., & Linder, M. B. (2013). The role of hemicellulose in nanofibrillated cellulose networks. *Soft Matter*, *9*(4), 1319–1326.

Ashrafi, O., Yerushalmi, L., & Haghighat, F. (2015). Wastewater treatment in the pulp-and-paper industry: A review of treatment processes and the associated greenhouse gas emission. *Journal of Environmental Management*, *158*, 146–157.

Bahrin, E., Baharuddin, A., Ibrahim, M., Nafis Abdul Razak, M., Sulaiman, A., Hassan, M., … Nishida, H. (2012). Physicochemical property changes and enzymatic hydrolysis enhancement of oil palm empty fruit bunches treated with superheated steam. *Bioresources*, *7*, 1784–1801.

Bank Negara Malaysia. (2020). Labor market: Wages/Earnings | Bank Negara Malaysia | Central Bank of Malaysia. Retrieved February 14, 2020, from https://www.bnm.gov.my/index.php

Bardet, R., & Bras, J. (2014). Cellulose Nanofibers and Their Use in Paper Industry. In *Handbook of Green Materials* (pp. 207–232).

BC (Bacterial Cellulose; Microbial Cellulose; Bacterial Nanocellulose; BioCellulose) - Cellulose Lab | Nanocellulose, Cellulose NanoCrystal (CNC or NCC), Cellulose Nanofibrils (CNF) and Bacterial Cellulose (BC) Supplier. (n.d.). Retrieved April 10, 2020, from https://www.celluloselab.com/our-products/bacterial-cellulose/

Bee, S., Hamid, A., & Moinul, M. (2015). Cellulase biocatalysis : key influencing factors and mode of action Cellulase biocatalysis : key influencing factors and mode of action. *Cellulose*, *22*(4), 2157–2182.

Benko, H. (2017). ISO Technical Committee 229 Nanotechnologies. In *Metrology and Standardization of Nanotechnology* (pp. 259–268). https://doi.org/10.1002/9783527800308.ch14

Bensah, E. C., & Mensah, M. (2013). Chemical Pretreatment Methods for the Production of Cellulosic Ethanol: Technologies and Innovations. *International Journal of Chemical Engineering*, *2013*, 719607.

Berglund, L., Noël, M., Aitomäki, Y., Öman, T., & Oksman, K. (2016). Production potential of cellulose nanofibers from industrial residues : Efficiency and nanofiber characteristics. *Industrial Crops & Products*, *92*, 84–92.

BIS. (2020). Leading Chemical Supplier From Malaysia. Retrieved February 16, 2020, from https://www.bischem.com/products/

Blanco, A., Monte, M. C., Campano, C., Balea, A., Merayo, N., & Negro, C. (2018). Nanocellulose for industrial use: Cellulose nanofibers (CNF), cellulose nanocrystals (CNC), and bacterial cellulose (BC). In *Handbook of Nanomaterials for Industrial Applications* (pp. 74–126). Elsevier.

Borrega, M., & Orelma, H. (2019). Cellulose Nanofibril (CNF) Films and Xylan from Hot Water Extracted Birch Kraft Pulps. *Applied Sciences*, *9*(16), 3436.

Boufi, S., & Gandini, A. (2015). Triticale crop residue: a cheap material for high performance nanofibrillated cellulose. *RSC Adv.*, *5*(5), 3141–3151.

Boukir, A., Fellak, S., & Doumenq, P. (2019). Structural characterization of Argania spinosa Moroccan wooden artifacts during natural degradation progress using infrared spectroscopy (ATR-FTIR) and X-Ray diffraction (XRD). *Heliyon*, *5*(9), e02477.

Brodeur, G., Yau, E., Badal, K., Collier, J., Ramachandran, K. B., & Ramakrishnan, S. (2011). Chemical and Physicochemical Pretreatment of Lignocellulosic Biomass: A Review. *Enzyme Research*, *2011*, 787532.

Chakrabarty, A., & Teramoto, Y. (2018). Recent Advances in Nanocellulose Composites with Polymers: A Guide for Choosing Partners and How to Incorporate Them. *Polymers*, *10*(5), 517.

Chakraborty, A., Sain, M., & Kortschot, M. (2005). Cellulose microfibrils: A novel method of preparation using high shear refining and cryocrushing. *Holzforschung*, *59*(1), 102–107.

Chang, F., Lee, S. H., Toba, K., Nagatani, A., & Endo, T. (2012). Bamboo nanofiber preparation by HCW and grinding treatment and its application for nanocomposite. *Wood Science and Technology*, *46*(1–3), 393–403.

Cheim, L., Platts, D., Prevost, T., & Xu, S. (2012, March). Furan analysis for liquid power transformers. *IEEE Electrical Insulation Magazine*, Vol. 28, pp. 8–21.

Chen, H., Baitenov, A., Li, Y., Vasileva, E., Popov, S., Sychugov, I., … Berglund, L. (2019). Thickness Dependence of Optical Transmittance of Transparent Wood: Chemical Modification Effects. *ACS Applied Materials and Interfaces*, *11*(38), 35451–35457.

Chen, W., Yu, H., Liu, Y., Chen, P., Zhang, M., & Hai, Y. (2011). Individualization of cellulose nanofibers from wood using high-intensity ultrasonication combined with chemical pretreatments. *Carbohydrate Polymers*, *83*(4), 1804–1811.

Chen, Y., Huang, J., Yeap, Z. Q., Zhang, X., Wu, S., Ng, C. H., & Yam, M. F. (2018). Rapid authentication and identification of different types of A. roxburghii by Tri-step FT-IR spectroscopy. *Spectrochimica Acta - Part A: Molecular and Biomolecular Spectroscopy*, *199*, 271–282.

Chiew, Y. L., Iwata, T., & Shimada, S. (2011). System analysis for effective use of palm oil waste as energy resources. *Biomass and Bioenergy*, *35*(7), 2925–2935.

Chirayil, C. J., Mathew, L., & Thomas, S. (2014). Review of recent research in nano cellulose preparation from different lignocellulosic fibers. *Reviews on Advanced Materials Science*, *37*(1–2), 20–28.

Coates, J. (2006). Interpretation of Infrared Spectra, A Practical Approach. In *Encyclopedia of Analytical Chemistry*. American Cancer Society.

Conde-Mejía, C., Jiménez-Gutiérrez, A., & El-Halwagi, M. (2012). A comparison of pretreatment methods for bioethanol production from lignocellulosic materials. *Process Safety and Environmental Protection*, *90*(3), 189–202.

Currie, H. A., & Perry, C. C. (2007). Silica in Plants: Biological, Biochemical and Chemical Studies. *Annals of Botany*, *100*(7), 1383–1389.

Dai, J., Chae, M., Beyene, D., Danumah, C., Tosto, F., & Bressler, D. C. (2018). Co-production of cellulose nanocrystals and fermentable sugars assisted by endoglucanase treatment of wood pulp. *Materials*, *11*(9).

Delgado-Aguilar, M., Tarrés, Q., Pèlach, M. À., Mutjé, P., & Fullana-I-Palmer, P. (2015). Are Cellulose Nanofibers a Solution for a More Circular Economy of Paper Products? *Environmental Science and Technology*, *49*(20), 12206–12213.

Dhumpa, R., Kelly, K., & Tallahassee. (2018). *Manufacture of hydrated nanocellulose sheets for use as a dermatological treatment*.

Dimic-Misic, K., Maloney, T., & Gane, P. (2018). Effect of fibril length, aspect ratio and surface charge on ultralow shear-induced structuring in micro and nanofibrillated cellulose aqueous suspensions. *Cellulose*, *25*(1), 117–136.

Dufresne, A. (2013). Nanocellulose: A new ageless bionanomaterial. *Materials Today*, Vol. 16, pp. 220–227. Elsevier Ltd.

Dungani, R., H.P.S, A. K., Sumardi, I., Suhaya, Y., Sulistyawati, E., Islam, M. N., … Aprilia, S. (2014). Non-wood Renewable Materials: Properties Improvement and Its Application. In *Biomass and Bioenergy: Applications* (pp. 1–29).

Effland, M., & Leatham, G. (1987). Assessment of 30 White Rot Basidiomycetes for Selective Lignin Degradation. *Holzforschung*, *41*(6), 343–349. https://doi.org/]

Efforts toward the Cellulose Nanofiber by Nikken Housing System's lid Lab was introduced on YouTube Channel of the Japanese Ministry of the Environment, "MIRAI EYES (Case Studies)" | NIKKEN HOUSING SYSTEM. (2020). Retrieved April 13, 2020, from https://www.nikkenhs.co.jp/en/NEWS/cnf2020-2

EFT | EFTec^{TM} Nanofibrillated Fiber. (n.d.). Retrieved April 13, 2020, from http://www.eftfibers.com/prod_eftec.php

El-Dalatony, M. M., Salama, E. S., Kurade, M. B., Hassan, S. H. A., Oh, S. E., Kim, S., & Jeon, B. H. (2017). Utilization of microalgal biofractions for bioethanol, higher alcohols, and biodiesel production: A review. *Energies*, *10*(12).

EPA, U. (n.d.). Safer Chemical Ingredients List. Retrieved October 17, 2020, from https://www.epa.gov/saferchoice/safer-ingredients#searchList

Eriksen, Ø., Syverud, K., & Gregersen, Ø. (2008). The use of microfibrillated cellulose produced from kraft pulp as strength enhancer in TMP paper. *Nordic Pulp and Paper Research Journal*, *23*(3), 299–304.

Escamilla-Alvarado, C., Pérez-Pimienta, J. A., Ponce-Noyola, T., & Poggi-Varaldo, H. M. (2017). An overview of the enzyme potential in bioenergy-producing biorefineries. *Journal of Chemical Technology and Biotechnology*, *92*(5), 906–924.

Eugenio, J., Moreno, S., Dianez, F., Santos, M., Carrasco, G., & Urrestarazu, M. (2009). Effects of peracetic acid disinfectant on the postharvest of some fresh vegetables. *Journal of Food Engineering*, *95*(1), 11–15.

Eyley, S., & Thielemans, W. (2014). Surface modification of cellulose nanocrystals. *Nanoscale*, *6*(14), 7764–7779.

Fahma, F., Iwamoto, S., Hori, N., Iwata, T., & Takemura, A. (2010). Isolation, preparation, and characterization of nanofibers from oil palm empty-fruit-bunch (OPEFB). *Cellulose*, *17*(5), 977–985.

Fairhurst, T., & Härdter, R. (2003). *The Oil Palm. Management for Large and Sustainable Yields*. Canada.

Faris, A. H., Mohamad Ibrahim, M. N., Abdul Rahim, A., Hussin, M. H., & Brosse, N. (2015). Preparation and Characterization of Lignin Polyols from the Residues of Oil Palm Empty Fruit Bunch. *BioResources*, *10*(4), 7339–7352.

Fatah, I. Y. A., Abdul Khalil, H. P. S., Hossain, M. S., Aziz, A. A., Davoudpour, Y., Dungani, R., & Bhat, A. (2014). Exploration of a chemo-mechanical technique for the isolation of nanofibrillated cellulosic fiber from oil palm empty fruit bunch as a reinforcing agent in composites materials. *Polymers*, *6*(10), 2611–2624.

Fernandes Diniz, J. M. B., Gil, M. H., & Castro, J. A. A. M. (2004). Hornification - Its origin and interpretation in wood pulps. *Wood Science and Technology*, *37*(6), 489–494.

FiorMarkets. (2019). Global Nanocellulose Market by Type, Application, Region, Industry Analysis, Size, Share, Growth, Trends, and Forecast 2015 to 2025. Retrieved April 9, 2020, from https://www.fiormarkets.com/report/global-nanocellulose-market-by-type-nanocrystalline-cellulose-nanofibrillated-367085.html

Foster, E. J., Moon, R. J., Agarwal, U. P., Bortner, M. J., Bras, J., Camarero-Espinosa, S., … Youngblood, J. (2018). Current characterization methods for cellulose nanomaterials. *Chem. Soc. Rev.*, *47*(8), 2609–2679.

French, A. D. (2014). Idealized powder diffraction patterns for cellulose polymorphs. *Cellulose*, *21*(2), 885–896.

Future Markets Inc. (2019). *Nanocellulose Investment and Pricing Guide 2019*. Retrieved from https://www.futuremarketsinc.com/the-nanocellulose-investment-and-pricing-guide/

Gan, S., Zakaria, S., Chia, C. H., Padzil, F. N. M., & Ng, P. (2015). Effect of hydrothermal pretreatment on solubility and formation of kenaf cellulose membrane and hydrogel. *Carbohydrate Polymers*, *115*, 62–68.

Ganesh Kumar, C., Pradeep Kumar, M., Gupta, S., Shyam Sunder, M., Veera Mohana Rao, K., Jagadeesh, B., … Kamal, A. (2015). Isolation and Characterization of Cellulose from Sweet Sorghum Bagasse. *Sugar Tech*, *17*(4), 395–403.

Gangwar, A. K., Prakash, N. T., & Prakash, R. (2014). Applicability of Microbial Xylanases in Paper Pulp. *BioResources*, *9*(2), 3733–3754.

GAR. (2019, January 11). Zero waste of the palm oil fruit - Golden Agri-Resources. Retrieved March 29, 2020, from Environment website: https://goldenagri.com.sg/id/zero-waste-of-the-palm-oil-fruit/

Gavrilescu, D., Puitel, A. C., Dutuc, G., & Craciun, G. (2012). Environmental impact of pulp and paper mills. *Environmental Engineering and Management Journal*, *11*(1), 81–86.

Gaweł, B. A., Ulvensøen, A., Łukaszuk, K., Arstad, B., Muggerud, A. M. F., & Erbe, A. (2020). Structural evolution of water and hydroxyl groups during thermal, mechanical and chemical treatment of high purity natural quartz. *RSC Advances*, *10*(48), 29018–29030.

Gleadall, A., Pan, J., & Atkinson, H. (2012). A simplified theory of crystallisation induced by polymer chain scissions for biodegradable polyesters. *Polymer Degradation and Stability*, *97*(9), 1616–1620.

Gooch, J. W. (2011). Kraemer Equation. In J. W. Gooch (Ed.), *Encyclopedic Dictionary of Polymers* (p. 414). New York, NY: Springer New York.

Graham, M. S., Lomax, G., & Skipp, G. (2012). Peracetic acid (PAA) versus chlorination/de-chlorination - A disinfection comparison. *WEFTEC 2012 - 85th Annual Technical Exhibition and Conference*, *8*(11), 4672–4684. Water Environment Federation.

Gralén, N., & Svedberg, T. (1943). Molecular weight of native cellulose. *Nature*, Vol. 152, p. 625. Nature Publishing Group.

Haji Badri, K. (2016). Thermal behaviors of oil palm empty fruit bunch fiber upon exposure to acid-base aqueous solutions. *Malaysian Journal of Analytical Science*, *20*, 1095–1103.

Hallac, B. B., & Ragauskas, A. J. (2011). Analyzing cellulose degree of polymerization and its relevancy to cellulosic ethanol. *Biofuels, Bioproducts and Biorefining*, *5*(2), 215–225.

Hamzah, N., Tokimatsu, K., & Yoshikawa, K. (2019). Solid fuel from oil palm biomass residues and municipal solid waste by hydrothermal treatment for electrical power generation in Malaysia: A review. *Sustainability (Switzerland)*, *11*(4), 1–23.

Harmsen, P., Huijgen, W., López, L., & Bakker, R. (2010). Literature Review of Physical and Chemical Pretreatment Processes for Lignocellulosic Biomass. *Food and Biobased Research*, (September), 1–49.

Hasanjanzadeh, H., Hedjazi, S., Ashori, A., Mahdavi, S., & Yousefi, H. (2014). Effects of hemicellulose pre-extraction and cellulose nanofiber on the properties of rice straw pulp. *International Journal of Biological Macromolecules*, *68*, 198–204.

Hassan, M. A., Ahmad Farid, M. A., Shirai, Y., Ariffin, H., Othman, M. R., Samsudin, M. H., & Hasan, M. Y. (2019). Oil Palm Biomass Biorefinery for Sustainable Production of Renewable Materials. *Biotechnology Journal*, *14*(6), 1–8.

Hassan, N., Idris, A., & Akhtar, J. (2019). Overview on Bio-refinery Concept in Malaysia: Potential High Value Added Products from Palm Oil Biomass (Gambaran Keseluruhan mengenai Konsep Penapisan Bio di Malaysia: Potensi Produk Penambahan Nilai Tinggi dari Biomas Minyak Sawit). *Jurnal Kejuruteraan SI*, *2*(1), 113–124.

Heinze, T. (2016). Cellulose: Structure and Properties. In J. O. Rojas (Ed.), *Cellulose Chemistry and Properties: Fibers, Nanocelluloses and Advanced Materials* (pp. 1–52). Cham: Springer International Publishing.

Henson, I. E., Betitis, T., Tomda, Y., & Chase, L. D. C. (2012). The estimation of frond base biomass (FBB) of oil palm. *Journal of Oil Palm Research*, *24*(December), 1473–1479.

Herrera, M. A. (2015). *Preparation and Characterization of Nanocellulose Films and Coatings from Industrial Bio-Residues*.

Herrera, M. A., Mathew, A. P., & Oksman, K. (2014). Gas permeability and selectivity of cellulose nanocrystals films (layers) deposited by spin coating. *Carbohydrate Polymers*, *112*, 494–501.

Hideno, A., Inoue, H., Tsukahara, K., Fujimoto, S., Minowa, T., Inoue, S., … Sawayama, S. (2009). Wet disk milling pretreatment without sulfuric acid for enzymatic hydrolysis of rice straw. *Bioresource Technology*, *100*(10), 2706–2711.

Hietala, M., & Oksman, K. (2014). Technologies for Separation of Cellulose Nanofibers. In *Handbook of Green Materials* (pp. 53–71). Retrieved from http://www.worldscientific.com/doi/abs/10.1142/9789814566469_0005

Hietala, M., Varrio, K., Berglund, L., Soini, J., & Oksman, K. (2018). Potential of municipal solid waste paper as raw material for production of cellulose nanofibres. *Waste Management*, *80*, 319–326.

Hosseini, S. E., Bagheri, G., Khaleghi, M., & Abdul Wahid, M. (2015). Combustion of biogas released from palm oil mill effluent and the effects of hydrogen enrichment on the characteristics of the biogas flame. *Journal of Combustion*, *2015*.

Hsieh, M. C., Koga, H., Suganuma, K., & Nogi, M. (2017). Hazy Transparent Cellulose Nanopaper. *Scientific Reports*, *7*, 1–7.

Huang, J., Ma, X., Yang, G., & Alain, D. (2019). Introduction to Nanocellulose. In *Nanocellulose* (pp. 1–20). John Wiley & Sons, Ltd.

Huang, L., Zhao, H., Yi, T., Qi, M., Xu, H., Mo, Q., … Liu, Y. (2020). Preparation and Properties of Cassava Residue Cellulose Nanofibril/Cassava Starch Composite Films. *Nanomaterials*, *10*(4), 755.

Huang, S., & Wang, D. (2017). A Simple Nanocellulose Coating for Self-Cleaning upon Water Action: Molecular Design of Stable Surface Hydrophilicity. *Angewandte Chemie International Edition*, *56*(31), 9053–9057.

Hubbe, M. A., Ferrer, A., Tyagi, P., Yin, Y., Salas, C., Pal, L., & Rojas, O. J. (2017). Nanocellulose in Thin Films, Coatinga, and Plies for Packaging Applications: A Review. *BioResources*, *12*, 2143–2233.

Hubbell, C. A., & Ragauskas, A. J. (2010). Effect of acid-chlorite delignification on cellulose degree of polymerization. *Bioresource Technology*, *101*(19), 7410–7415.

Hwangbo, S., Heo, J., Lin, X., Choi, M., & Hong, J. (2016). Transparent superwetting nanofilms with enhanced durability at model physiological condition. *Scientific Reports*, *6*(19178).

Iberahim, N. I., Jahim, J. M., Harun, S., Nor, M. T. M., & Hassan, O. (2013). Sodium Hydroxide Pretreatment and Enzymatic Hydrolysis of Oil Palm Mesocarp Fiber. *International Journal of Chemical Engineering and Aplications*, *4*(3), 101–105. https://doi.org/\

Ilyas, R. A., Sapuan, S., Atiqah, A., Ibrahim, R., Abral, H., Ishak, M., … Ya, H. (2019). Sugar palm (Arenga pinnata [Wurmb.] Merr) starch films containing sugar palm nanofibrillated cellulose as reinforcement: Water barrier properties. *Polymer Composites*, 1–9.

Ishak, H., Yoshida, H., Muda, N. A., Ismail, M. H. S., & Izhar, S. (2019). Rapid processing of abandoned oil palm trunks into sugars and organic acids by sub-criticalwater. *Processes*, *7*(9). https://doi.org/]

Isroi, Cifriadi, A., Panji, T., Wibowo, N. A., & Syamsu, K. (2017). Bioplastic production from cellulose of oil palm empty fruit bunch. *IOP Conference Series: Earth and Environmental Science*, *65*(1).

Iwamoto, M., Shimatai, A., Honda, M., & Matsukata, M. (2018). Depolymerization of Cellulose with Superheated Steam: Remarkable Obstruction Effects of Sodium and High Reactivity of Crystalline Cellulose. *ACS Sustainable Chemistry and Engineering*, *6*(5), 6570–6576.

Iwamoto, S., Abe, K., & Yano, H. (2008). The Effect of Hemicelluloses on Wood Pulp Nanofibrillation and Nanofiber Network Characteristics. *Biomacromolecules*, *9*, 1022–1026.

Iwamoto, S., & Endo, T. (2015). 3 Nm Thick Lignocellulose Nano Fibers Obtained From Esterified Wood With Maleic Anhydride. *ACS Macro Letters*, *4*(1), 80–83.

Iwamoto, S., Yamamoto, S., Lee, S. H., Ito, H., & Endo, T. (2014). Mechanical and thermal properties of polypropylene composites reinforced with lignocellulose nanofibers dried in melted ethylene-butene copolymer. *Materials*, *7*(10), 6919–6929.

Jedvert, K., & Heinze, T. (2017). Cellulose modification and shaping - A review. *Journal of Polymer Engineering*, *37*(9), 845–860.

Josset, S., Orsolini, P., Siqueira, G., Tejado, A., Tingaut, P., & Zimmermann, T. (2014). Energy consumption of the nanofibrillation of bleached pulp, wheat straw and recycled newspaper through a grinding process 3D Printing of Cellulose Reinforced Composites View project Porous Nanofibrillated Cellulose Functional Materials View project. *Article in Nordic Pulp and Paper Research Journal*, *29*(1), 167–175.

Julie Chandra, C. S., George, N., & Narayanankutty, S. K. (2016). Isolation and characterization of cellulose nanofibrils from arecanut husk fibre. *Carbohydrate Polymers*, *142*, 158–166.

K. Ince, B., Cetecioglu, Z., & Ince, O. (2011). Pollution Prevention in the Pulp and Paper Industries. In *Environmental Management in Practice*. InTech.

Kandhola, G., Djioleu, A., Rajan, K., Labbé, N., Sakon, J., Carrier, D. J., & Kim, J. W. (2020). Maximizing production of cellulose nanocrystals and nanofibers from pre-extracted loblolly pine kraft pulp: a response surface approach. *Bioresources and Bioprocessing*, *7*(1), 19.

Kapu, N., & L. Trajano, H. (2014). Review of hemicellulose hydrolysis in softwoods and bamboo. *Biofuels, Bioproducts and Biorefining*, *8*.

Karasu, F., Müller, L., Ridaoui, H., Ibn ElHaj, M., Flodberg, G., Aulin, C., … Leterrier, Y. (2018). Organic-Inorganic Hybrid Planarization and Water Vapor Barrier Coatings on Cellulose Nanofibrils Substrates. *Frontiers in Chemistry*, *6*, 571.

Kasuga, T., Isobe, N., Yagyu, H., Koga, H., & Nogi, M. (2018). Clearly Transparent Nanopaper from Highly Concentrated Cellulose Nanofiber Dispersion Using Dilution and Sonication. *Nanomaterials*, *8*(2), 104.

Khazraji, A. C., & Robert, S. (2013). Self-Assembly and Intermolecular Forces When Cellulose and Water Interact Using Molecular Modeling. *Journal of Nanomaterials*, *2013*, 12.

Kim, J. S., Lee, Y. Y., & Kim, T. H. (2016). A review on alkaline pretreatment technology for bioconversion of lignocellulosic biomass. *Bioresource Technology*, Vol. 199, pp. 42–48. Elsevier Ltd.

Kim, S., & Jang, J. (2013). Effect of degree of polymerization on the mechanical properties of regenerated cellulose fibers using synthesized 1-allyl-3-methylimidazolium chloride. *Fibers and Polymers*, *14*(6), 909–914.

Kim, U. J., Eom, S. H., & Wada, M. (2010). Thermal decomposition of native cellulose: Influence on crystallite size. *Polymer Degradation and Stability*, *95*(5), 778–781.

Kitis, M. (2004). Disinfection of wastewater with peracetic acid: A review. *Environment International*, *30*(1), 47–55.

Klemm, D., Heublein, B., Fink, H. P., & Bohn, A. (2005, May 30). Cellulose: Fascinating biopolymer and sustainable raw material. *Angewandte Chemie - International Edition*, Vol. 44, pp. 3358–3393. John Wiley & Sons, Ltd.

Klemm, D., Kramer, F., Moritz, S., Lindström, T., Ankerfors, M., Gray, D., & Dorris, A. (2011). Nanocelluloses : A New Family of Nature-Based Materials. *Angewandte Chemie International Edition*, *50 24*, 5438–5466.

Konczewicz, W., & Kozłowski, R. M. (2012). Enzymatic treatment of natural fibres. In *Handbook of Natural Fibres* (pp. 168–184). Elsevier.

Kusashio, T. (2017, May 5). Cellulose nanofiber is heading for your house and car - Nikkei Asian Review. Retrieved April 13, 2020, from https://asia.nikkei.com/Business/Technology/Cellulose-nanofiber-is-heading-for-your-house-and-car

Lani, N., Ngadi, N., Johari, A., & Jusoh, M. (2014). Isolation, Characterization, and Application of Nanocellulose from Oil Palm Empty Fruit Bunch Fiber as Nanocomposites. *Journal of Nanomaterials*, *2014*, 1–9.

Lapierre, L., Bouchard, J., & Berry, R. (2009). The relationship found between fibre length and viscosity of three different commercial kraft pulps. *Holzforschung*, *63*(4), 402–407.

Lars Wågberg, Gero Decher, Magnus Norgren, Tom Lindstro¨m, Mikael Ankerfors, and K. A. (2008). The Build-Up of Polyelectrolyte Multilayers of Microfibrillated.pdf. *PEMs of MFC and Cationic Polyelectrolytes Oxide*, *24*(10), 784–795.

Launch of World's First Commercial Products Made of Functional Cellulose Nanofibers | Press Releases | Nippon Paper Group. (2015, September 16). Retrieved April 13, 2020, from https://www.nipponpapergroup.com/english/news/year/2015/news150916003182.html

Lee, H., & Mani, S. (2017). Mechanical pretreatment of cellulose pulp to produce cellulose nanofibrils using a dry grinding method. *Industrial Crops and Products*, *104*(January), 179–187.

Li, X., Wei, Y., Xu, J., Xu, N., & He, Y. (2018). Quantitative visualization of lignocellulose components in transverse sections of moso bamboo based on FTIR macro- and micro-spectroscopy coupled with chemometrics. *Biotechnology for Biofuels*, *11*(1), 263.

Lin, N., & Dufresne, A. (2014). Nanocellulose in biomedicine: Current status and future prospect. *European Polymer Journal*, *59*, 302–325.

Ling, Z., Wang, T., Makarem, M., Santiago Cintrón, M., Cheng, H. N., Kang, X., … French, A. D. (2019). Effects of ball milling on the structure of cotton cellulose. *Cellulose*, *26*(1), 305–328.

Liu, W. J., Jiang, H., & Yu, H. Q. (2015, July 6). Thermochemical conversion of lignin to functional materials: a review and future directions. *Green Chemistry*, Vol. 17, pp. 4888–4907. Royal Society of Chemistry.

Liu, Y., & Kim, H. (2017). Fourier Transform Infrared Spectroscopy (FT-IR) and Simple Algorithm Analysis for Rapid and Non-Destructive Assessment of Developmental Cotton Fibers. *Sensors*, *17*(1469), 1–13.

Loerbroks, C., Rinaldi, R., & Thiel, W. (2013). The electronic nature of the 1,4-β-glycosidic bond and its chemical environment: DFT insights into cellulose chemistry. *Chemistry - A European Journal*, *19*(48), 16282–16294.

Loh, S. K. (2017). The potential of the Malaysian oil palm biomass as a renewable energy source. *Energy Conversion and Management*, *141*, 285–298.

Lum, W. C., Lee, S. H., Ahmad, Z., Abdul Halip, J., & Chin, K. L. (2019). Lignocellulosic nanomaterials for construction and building applications. In *Industrial Applications of Nanomaterials* (pp. 423–439). Elsevier.

Ma, P., Fu, S., Zhai, H., Law, K., & Daneault, C. (2012). Influence of TEMPO-mediated oxidation on the lignin of thermomechanical pulp. *Bioresource Technology*, *118*, 607–610. https://doi.org/10.1016/j.biortech.2012.05.037

Mahendra, I. P., Wirjosentono, B., Tamrin, Ismail, H., & Mendez, J. A. (2019). Thermal and morphology properties of cellulose nanofiber from TEMPO-oxidized lower part of empty fruit bunches (LEFB). *Open Chemistry*, *17*(1), 526–536.

Marx-Figini, M. (1978). Significance of the intrinsic viscosity ratio of unsubstituted and nitrated cellulose in different solvents. *Die Angewandte Makromolekulare Chemie*, *72*(1), 161–171.

Mat Rasat, M. S., Wahab, R., Sulaiman, O., Moktar, J., Mohamed, A., Tabet, T., & Khalid, I. (2011). Properties of composite boards from oil palm frond agricultural waste. *Bioresources*, *6*, 4389–4403.

Matsuo, M., Umemura, K., & Kawai, S. (2011). Kinetic analysis of color changes in cellulose during heat treatment. *Journal of Wood Science*, *58*, 113–119.

Matsuoka, S., Kawamoto, H., & Saka, S. (2011). Thermal glycosylation and degradation reactions occurring at the reducing ends of cellulose during low-temperature pyrolysis. *Carbohydrate Research*, *346*(2), 272–279.

McClements, D. J., & Rao, J. (2011). Food-Grade nanoemulsions: Formulation, fabrication, properties, performance, Biological fate, and Potential Toxicity. *Critical Reviews in Food Science and Nutrition*, *51*(4), 285–330.

Md Yunos, N. S. H., Baharuddin, A. S., Md Yunos, K. F., Naim, N., & Nishida, H. (2012). Physicochemical property changes of oil palm mesocarp fibers treated with high-pressure steam. *BioResources*, *7*(4), 5983–5994.

Meine, N. (2012). *Novel Routes for the Catalytic Depolymerization of Cellulose*. Ruhr-Universität Bochum.

Miller, J. (2017). *PRESENTED BY Cellulose Nanomaterials: State of the Industry The Road to Commercialization Acknowledgments*. Retrieved from www.risiinfo.com/product/nanocellulose-technology-applications-markets/

Missoum, K., Belgacem, M. N., & Bras, J. (2013). Nanofibrillated Cellulose Surface Modification: A Review. *Materials*, *6*, 1745–1766.

Mohamad Haafiz, M. K., Eichhorn, S. J., Hassan, A., & Jawaid, M. (2013). Isolation and characterization of microcrystalline cellulose from oil palm biomass residue. *Carbohydrate Polymers*, *93*(2), 628–634.

Mohammad Padzil, F. N., Gan, S., Zakaria, S., Mohamad, S. F., Mohamed, N. H., Seo, Y. B., & Ellis, A. V. (2018). Increased solubility of plant core pulp cellulose for regenerated hydrogels through electron beam irradiation. *Cellulose*, *25*(9), 4993–5006.

Mohd Yusof, S. J. H., Roslan, A. M., Ibrahim, K. N., Syed ABDULLAH, S. S., Zakaria, M. R., Hassan, M. A., & Shirai, Y. (2019). Life Cycle Assessment for Bioethanol Production from Oil Palm Frond Juice in an Oil Palm Based Biorefinery. *Sustainability*, *11*(24).

Morton, W. E., & Hearle, J. W. S. (Eds.). (2008). Woodhead Publishing in Textiles. In *Physical Properties of Textile Fibres (Fourth Edition)* (Fourth Edi, pp. xv–xix). Woodhead Publishing.

MPOB. (2020). *Overview of the Malaysian Oil Palm Industry 2019*.

Mukarakate, C., Mittal, A., Ciesielski, P. N., Budhi, S., Thompson, L., Iisa, K., … Donohoe, B. S. (2016). Influence of Crystal Allomorph and Crystallinity on the Products and Behavior of Cellulose during Fast Pyrolysis. *ACS Sustainable Chemistry & Engineering*, *4*(9), 4662–4674.

Nair, S. S., Zhu, J. Y., Deng, Y., & Ragauskas, A. J. (2014). Characterization of cellulose nanofibrillation by micro grinding. *Journal of Nanoparticle Research*, *16*(4), 2349.

Nakagaito, A. N., & Yano, H. (2004). The effect of morphological changes from pulp fiber towards nano-scale fibrillated cellulose on the mechanical properties of high-strength plant fiber based composites. *Applied Physics A*, *78*(4), 547–552.

Nanocellulose materials for biomedical applications - Engineering Sciences - Uppsala University, Sweden. (n.d.). Retrieved April 13, 2020, from https://teknik.uu.se/research-areas/nanocellulose-materials-for-biomedical-applications/

Nascimento, P., Marim, R., Carvalho, G., & Mali, S. (2015). Nanocellulose Produced from Rice Hulls and its Effect on the Properties of Biodegradable Starch Film. *Material Research*, *19*(1), 1–8.

National Biomass Strategy 2020 : New wealth creation for Malaysia ' s biomass industry. (2013). (June).

Nechyporchuk, O., Belgacem, M. N., & Bras, J. (2016). Production of cellulose nanofibrils : A review of recent advances. *Industrial Crops & Products*, *93*, 2–25.

Nechyporchuk, O., Pignon, F., & Belgacem, M. N. (2014). Morphological properties of nanofibrillated cellulose produced using wet grinding as an ultimate fibrillation process. *Journal of Materials Science*, *50*(2), 531–541.

Neoh, B. K., Thang, Y. M., Zain, M. Z. M., & Junaidi, A. (2011). Palm pressed fibre oil: A new opportunity for premium hardstock? *International Food Research Journal*, *18*(2), 769–773.

Nevell, T. P. (1985). Cellulose and its derivatives: Chemistry, biochemistry and applications edited by J. F. Kennedy, G. O. Phillips, D. J. Wedlock and P. A. Williams, Ellis Horwood, Ltd, Chichester, 1985. pp. 551, price £45.00. ISBN 0-85312-704-2. *British Polymer Journal*, *17*(4), 378–378.

Ng, W. P. Q., Lam, H. L., Ng, F. Y., Kamal, M., & Lim, J. H. E. (2012). Waste-to-wealth: Green potential from palm biomass in Malaysia. *Journal of Cleaner Production*, *34*, 57–65.

Nie, S., Zhang, K., Lin, X., Zhang, C., Yan, D., Liang, H., & Wang, S. (2018). Enzymatic pretreatment for the improvement of dispersion and film properties of cellulose nanofibrils. *Carbohydrate Polymers*, *181*, 1136–1142.

Nikonenko, N. A., Buslov, D. K., Sushko, N. I., & Zhbankov, R. G. (2000). Investigation of stretching vibrations of glycosidic linkages in disaccharides and polysaccharides with use of IR spectra deconvolution. *Biopolymers*, *57*(4), 257–262.

Nishiyama, Y., Langan, P., & Chanzy, H. (2002). Crystal structure and hydrogen-bonding system in cellulose Iβ from synchrotron X-ray and neutron fiber diffraction. *Journal of the American Chemical Society*, *124*(31), 9074–9082.

Nogi, B. M., Iwamoto, S., & Nakagaito, A. N. (2009). Optically Transparent Nanofiber Paper. *Advanced Materials*, *21*, 1595–1598.

Nogi, M., Karakawa, M., Komoda, N., Yagyu, H., & Nge, T. T. (2015). Transparent Conductive Nanofiber Paper for Foldable Solar Cells. *Scientific Reports*, *5*, 17254.

Nogi, M., Kim, C., Sugahara, T., Inui, T., Takahashi, T., & Suganuma, K. (2013). High thermal stability of optical transparency in cellulose nanofiber paper. *Applied Physics Letters*, *102*(18).

Nordin, N. A., Sulaiman, O., Hashim, R., Haafiz, M., & Kassim, M. (2016). *Characterization of Different Parts of Oil Palm Fronds (Elaeis Guineensis) and Its Properties Characterization of Different Parts of Oil Palm Fronds (Elaeis Guineensis) and Its Properties .* (April).

Nordin, N. I. A. A., Ariffin, H., Andou, Y., Hassan, M. A., Shirai, Y., Nishida, H., … Ibrahim, N. A. (2013). Modification of oil palm mesocarp fiber characteristics using superheated steam treatment. *Molecules*, *18*(8), 9132–9146.

Nordin, N. I. A. A., Ariffin, H., Hassan, M. A., Shirai, Y., Ando, Y., Ibrahim, N. A., & Yunus, W. M. Z. W. (2017). Superheated steam treatment of oil palm mesocarp fiber improved the properties of fiber-polypropylene biocomposite. *BioResources*, *12*(1), 68–81.

Norrrahim, M N F, Ariffin, H., Yasim-Anuar, T. A. T., Hassan, M. A., Nishida, H., & Tsukegi, T. (2018). One-pot nanofibrillation of cellulose and nanocomposite production in a twin-screw extruder. *{IOP} Conference Series: Materials Science and Engineering*, *368*, 12034.

Norrrahim, Mohd Nor Faiz. (2018). *Superheated steam pretreatment of oil palm biomass for improving nanofibrillation of cellulose and performance of polypropylene/cellulose nanofiber composites*. Universiti Putra Malaysia.

Norrrahim, Mohd Nor Faiz, Ariffin, H., Yasim-Anuar, T. A. T., Ghaemi, F., Hassan, M. A., Ibrahim, N. A., … Yunus, W. M. Z. W. (2018). Superheated steam pretreatment of cellulose affects its electrospinnability for microfibrillated cellulose production. *Cellulose*, *25*(7), 3853–3859.

Nuraje, N., Asmatulu, R., Cohen, R. E., & Rubner, M. F. (2011). Durable Antifog Films from Layer-by-Layer Molecularly Blended Hydrophilic Polysaccharides. *Langmuir*, *27*(2), 782–791.

Nyakuma, B. B., Ahmad, A., Johari, A., Abdullah, T. A. T., Oladokun, O., & Alkali, H. (2016). Gasification of oil palm empty fruit bunches (OPEFB) briquettes for bio-syngas production. *Jurnal Teknologi*, *78*(8–3), 83–88.

Oberlerchner, J. T., Rosenau, T., & Potthast, A. (2015). Overview of Methods for the Direct Molar Mass Determination of Cellulose. *Molecules*, 10313–10341.

Ogeda, T. L., Silva, I. B., Fidale, L. C., El Seoud, O. A., & Petri, D. F. S. (2012). Effect of cellulose physical characteristics, especially the water sorption value, on the efficiency of its hydrolysis catalyzed by free or immobilized cellulase. *Journal of Biotechnology*, *157*(1), 246–252.

Okoroigwe, E. C., Li, Z., Onyegegbu, S. O., & Christopher, M. (2012). Maximizing The Energy Potential Of Palm Kernel Shell By Pyrolytic Conversion To Biofuel. *4th International Renewable Energy Congress*, 3–4.

Ona, T., Sonoda, T., Shibata, M., & Fukazawa, K. (1995). Small-scale method to determine the content of wood components from multiple eucalypt samples. *Tappi Journal*, *78*(3), 121–126.

Onyianta, A. J., Dorris, M., & Williams, R. L. (2018). Aqueous morpholine pre-treatment in cellulose nanofibril (CNF) production: comparison with carboxymethylation and TEMPO oxidisation pre-treatment methods. *Cellulose*, *25*(2), 1047–1064.

Pääkko, M., Ankerfors, M., Kosonen, H., Nykänen, A., Ahola, S., Österberg, M., … Lindström, T. (2007). Enzymatic hydrolysis combined with mechanical shearing and high-pressure homogenization for nanoscale cellulose fibrils and strong gels. *Biomacromolecules*, *8*(6), 1934–1941.

Padzil, F. N. M., Zakaria, S., Chia, C. H., Jaafar, S. N. S., Kaco, H., Gan, S., & Ng, P. (2015). Effect of acid hydrolysis on regenerated kenaf core membrane produced using aqueous alkaline-urea systems. *Carbohydrate Polymers*, *124*, 164–171.

Panthapulakkal, S., & Sain, M. (2012). Preparation and characterization of cellulose nanofibril films from wood fibre and their thermoplastic polycarbonate composites. *International Journal of Polymer Science*, *2012*.

Park, C. W., Han, S. Y., Choi, S. K., & Lee, S. H. (2017). Preparation and properties of holocellulose nanofibrils with different hemicellulose content. *BioResources*, *12*(3), 6298–6308.

Park, J., Shin, H., Yoo, S., Zoppe, J. O., & Park, S. (2015). Delignification of lignocellulosic biomass and its effect on subsequent enzymatic hydrolysis. *BioResources*, *10*(2), 2732–2743.

Park, S., Baker, J. O., Himmel, M. E., Parilla, P. A., & Johnson, D. K. (2010). Cellulose crystallinity index: Measurement techniques and their impact on interpreting cellulase performance. *Biotechnology for Biofuels*, *3*(1), 10.

Paul, D. K., Shim, H. K. (Key), Giorgi, J. B., & Karan, K. (2016). Thickness dependence of thermally induced changes in surface and bulk properties of Nafion® nanofilms. *Journal of Polymer Science Part B: Polymer Physics*, *54*(13), 1267–1277.

Peng, Y., Gardner, D. J., & Han, Y. (2012). Drying cellulose nanofibrils: In search of a suitable method. *Cellulose*, *19*(1), 91–102.

Pengertian Saturated Steam | | Artikel Teknologi Indonesia. (n.d.). Retrieved April 9, 2020, from http://artikel-teknologi.com/pengertian-saturated-steam/#

Peresin, M. S., Vartiainen, J., Kunnari, V., Kaljunen, T., Tammelin, T., & Qvintus, P. (2012). Large-Scale Nanofibrillated Cellulose Film: an Overview on Its Production, Properties, and Potential Applications. *Proceeding of the 4Th International Conference on Pulping, Papermaking and Biotechnology (Icppb `12), Vols. I and Ii*, (November), 891–895.

Peters, M. S., Timmerhaus, K. D., & West, R. E. (2003). *Plant Design and Economics for Chemical Engineers*. McGraw-Hill Education.

Poletto, M., Pistor, V., & J., A. (2013). Structural Characteristics and Thermal Properties of Native Cellulose. In *Cellulose - Fundamental Aspects*. InTech.

Postek, M. T., Moon, R. J., Rudie, A. W., & Bilodeau, M. A. (2013). *Production and Applications of Cellulose Nanomaterials*. 21–24.

Prabaharan, M., & Rao, J. V. (2003). Combined desizing, scouring and bleaching of cotton using ozone. In *Indian Journal of Fibre & Textile Research* (Vol. 28).

PubChem. (n.d.). Retrieved October 17, 2020, from https://pubchem.ncbi.nlm.nih.gov/

Purwandari, F. A., Sanjaya, A. P., Millati, R., Cahyanto, M. N., Horváth, I. S., Niklasson, C., & Taherzadeh, M. J. (2013). Pretreatment of oil palm empty fruit bunch (OPEFB) by N-methylmorpholine-N-oxide (NMMO) for biogas production: Structural changes and digestion improvement. *Bioresource Technology*, *128*, 461–466.

Qin, Y., Qiu, X., & Zhu, J. Y. (2016). Understanding longitudinal wood fiber ultra-structure for producing cellulose nanofibrils using disk milling with diluted acid prehydrolysis. *Scientific Reports*, *6*(October).

Rafidah, D., Ainun, Z. M. A., Hazwani, H. A., Rushdan, I., Luqman, C. A., Sharmiza, A., & Jalaluddin. (2017). TROPICAL AGRICULTURAL SCIENCE Characterisation of Pulp and Paper Manufactured from Oil Palm Empty Fruit Bunches and Kenaf Fibres. *Pertanika J. Trop. Agric. Sci*, *40*(3), 449–458.

Rajaratanam, D. D., Ariffin, H., Hassan, M. A., & Nishida, H. (2016). Changes in diad sequence distribution by preferential chain scission during the thermal hydrolysis of poly(3-hydroxybutyrate-co-3-hydroxyhexanoate). *Polymer Journal*, *48*(7), 839–842.

Rambabu, N., Panthapulakkal, S., Sain, M., & Dalai, A. K. (2016). Production of nanocellulose fibers from pinecone biomass: Evaluation and optimization of chemical and mechanical treatment conditions on mechanical properties of nanocellulose films. *Industrial Crops and Products*, *83*, 746–754.

Ramírez, C. A. R., Rol, F., Bras, J., Dufresne, A., Garcia, N. L., & Accorso, N. D. (2019). Isolation and Characterization of Cellulose Nanofibers from Argentine Tacuara Cane (Guadua Angustifolia Kunth). *Journal of Renewable Materials*, *7*(4), 373–381.

Ramli, R., Junadi, N., Beg, H., & Yunus, R. (2015). Microcrystalline Cellulose (MCC) from oil palm empty fruit bunch (EFB) fiber via simultaneous ultrasonic and alkali treatment. *International Journal of Chemical, Nuclear, Materials and Metallurgical Engineering*, *9*, 8–11.

Renuart, E., & Viney, C. (2000). Chapter 8 Biological fibrous materials: Self-assembled structures and optimised properties. In *Pergamon Materials Series* (Vol. 4, pp. 223–267). Elsevier Ltd.

Ribeiro, R. S. A., Pohlmann, B. C., Calado, V., Bojorge, N., & Pereira, N. (2019). Production of nanocellulose by enzymatic hydrolysis: Trends and challenges. *Engineering in Life Sciences*, *19*(4), 279–291.

Rizal, N. F. A. A., Ibrahim, M. F., Zakaria, M. R., Bahrin, E. K., Abd-Aziz, S., & Hassan, M. A. (2018). Combination of superheated steam with laccase pretreatment together with size reduction to enhance enzymatic hydrolysis of oil palm biomass. *Molecules*, *23*(4), 811.

Rojas, J., Bedoya, M., & Ciro, Y. (2015a). Current Trends in the Production of Cellulose Nanoparticles and Nanocomposites for Biomedical Applications. In *Cellulose - Fundamental Aspects and Current Trends*. InTech.

Rojas, J., Bedoya, M., & Ciro, Y. (2015b). Current Trends in the Production of Cellulose Nanoparticles and Nanocomposites for Biomedical Applications. In *Cellulose - Fundamental Aspects and Current Trends*. https://doi.org/10.5772/61334

Rol, F., Karakashov, B., Nechyporchuk, O., Terrien, M., Meyer, V., Dufresne, A., … Bras, J. (2017). Pilot-Scale Twin Screw Extrusion and Chemical Pretreatment as an Energy-Efficient Method for the Production of Nanofibrillated Cellulose at High Solid Content. *ACS Sustainable Chemistry and Engineering*, *5*(8), 6524–6531.

Roncero, M. B., Torres, A. L., Colom, J. F., & Vidal, T. (2000). Effects of xylanase treatment on fibre morphology in totally chlorine free bleaching (TCF) of Eucalyptus pulp. *Process Biochemistry*, *36*(1–2), 45–50.

Rowell, R. M. (2005). *Handbook of wood chemistry and wood composites*. CRC Press.

Rushdan, I., Latifah, J., Hoi, W. K., & Nor, M. Y. M. (2007). Commercial-scale production of soda pulp and medium paper from oil palm empty fruit bunches. *Journal of Tropical Forest Science*, *19*(3), 121–126.

Safwan, M., Ong, M., Lin, H., & Tieng, W. (2016). Characterization of nanocellulose recovery from Elaeis guineensis frond for sustainable development. *Clean Technologies and Environmental Policy*.

Saka, S., & Bae, H.-J. (2016). Chapter 11 - Secondary Xylem for Bioconversion. In Y. S. Kim, R. Funada, & A. P. Singh (Eds.), *Secondary Xylem Biology* (pp. 213–231). Boston: Academic Press.

Samsudin, M. H., Hassan, M. A., Idris, J., Ramli, N., Yusoff, M. Z. M., Ibrahim, I., … Shirai, Y. (2019). A one-step self-sustained low temperature carbonization of coconut shell biomass produced a high specific surface area biochar-derived nano-adsorbent. *Waste Management & Research*, *37*(5), 551–555.

Saritha, M., Arora, A., & Lata. (2012, June 14). Biological Pretreatment of Lignocellulosic Substrates for Enhanced Delignification and Enzymatic Digestibility. *Indian Journal of Microbiology*, Vol. 52, pp. 122–130.

Saurabh, C. K., Mustapha, A., Masri, M. M., Owolabi, A. F., Syakir, M. I., Dungani, R., … Abdul Khalil, H. P. S. (2016). Isolation and characterization of cellulose nanofibers from gigantochloa scortechinii as a reinforcement material. *Journal of Nanomaterials*, *2016*(July).

Segal, L., Creely, J. J., Martin, A. E., & Conrad, C. M. (1959). An Empirical Method for Estimating the Degree of Crystallinity of Native Cellulose Using the X-Ray Diffractometer. *Textile Research Journal*, *29*(10), 786–794.

Sehaqui, H., Zimmermann, T., & Tingaut, P. (2014). Hydrophobic cellulose nanopaper through a mild esterification procedure. *Cellulose*, *21*, 367–382.

Seiboth, B., Ivanova, C., & Seidl-Seiboth, V. (2011). Trichoderma reesei: A Fungal Enzyme Producer for Cellulosic Biofuels. *Biofuel Production-Recent Developments and Prospects*, (May 2014).

Serra, A., Gonz, I., Oliver-ortega, H., Tarrés, Q., Delgado-aguilar, M., & Mutjé, P. (2017). Reducing the Amount of Catalyst in TEMPO-Oxidized Cellulose Nanofibers : Effect on Properties and Cost. *Polymers*, *9*(557).

Shahabi-Ghahfarrokhi, I., Khodaiyan, F., Mousavi, M., & Yousefi, H. (2015). Preparation and characterization of nanocellulose from beer industrial residues using acid hydrolysis/ultrasound. *Fibers and Polymers*, *16*(3), 529–536.

Shahbandeh, M. (2020). • Global vegetable oil consumption, 2019/20 | Statista. Retrieved September 6, 2020, from https://www.statista.com/statistics/263937/vegetable-oils-global-consumption/

Shak, K. P. Y., Pang, Y. L., & Mah, S. K. (2018). Nanocellulose: Recent advances and its prospects in environmental remediation. *Beilstein Journal of Nanotechnology*, *9*(1), 2479–2498.

Shanmugam, K., Doosthosseini, H., Varanasi, S., Garnier, G., & Batchelor, W. (2018). Flexible spray coating process for smooth nanocellulose film production. *Cellulose*, *25*(3), 1725–1741.

Shanmugam, K., Varanasi, S., Garnier, G., & Batchelor, W. (2017). Rapid preparation of smooth nanocellulose films using spray coating. *Cellulose*, *24*(7), 2669–2676.

Sharip, N. S. (2016). *CHharacterization and Antifungal Pproperties of Oil Palm Mesocarp Fibre Superheated Steam Condensate*. Universiti Putra Malaysia.

Sharip, N. S., Ariffin, H., Hassan, M. A., Nishida, H., & Shirai, Y. (2016). Characterization and application of bioactive compounds in oil palm mesocarp fiber superheated steam condensate as an antifungal agent. *RSC Adv.*, *6*(88), 84672–84683.

Sharma, A., Thakur, M., Bhattacharya, M., Mandal, T., & Goswami, S. (2019, March 1). Commercial application of cellulose nano-composites – A review. *Biotechnology Reports*, Vol. 21, p. e00316. Elsevier B.V.

Shen, D., Xiao, R., Gu, S., & Zhang, H. (2013). The Overview of Thermal Decomposition of Cellulose in Lignocellulosic Biomass. In Theo van de Ven & J. Kadla (Eds.), *Cellulose - Biomass Conversion*. IntechOpen.

Silva, R. De, & Byrne, N. (2017). Utilization of cotton waste for regenerated cellulose fibres : Influence of degree of polymerization on mechanical properties. *Carbohydrate Polymers*, *174*, 89–94.

Siqueira, G., Bras, J., & Dufresne, A. (2010). Cellulosic bionanocomposites: A review of preparation, properties and applications. *Polymers*, *2*(4), 728–765.

Siró, I., & Plackett, D. (2010). Microfibrillated cellulose and new nanocomposite materials: a review. *Cellulose*, *17*(3), 459–494.

Souza, N. F., Pinheiro, J. A., Silva, P., Paulo, J., & Morais, S. (2015). Development of Chlorine-Free Pulping Method to Extract Cellulose Nanocrystals from Pressed Oil Palm Mesocarp Fibers Development of Chlorine-Free Pulping Method to Extract Cellulose Nanocrystals from Pressed Oil. *Journal of Biobased Materials and Bioenergy*, (October).

SPAN. (2017). Domestic supplies & Non-domestic supplies. Retrieved February 16, 2020, from https://www.span.gov.my

Spence, K. L., Venditti, R. A., Rojas, O. J., Habibi, Y., & Pawlak, J. J. (2011). A comparative study of energy consumption and physical properties of microfibrillated cellulose produced by different processing methods. *Cellulose*, *18*, 1097–1111.

Stigsson, L. (2005). *Patent No. US6946057B2*. Retrieved from https://patents.google.com/patent/US6946057

Su, S. (2017, June 29). How to Decide Whether a High Pressure Homogenizer or a High Shear Mixer is Your Best Option? Retrieved April 11, 2020, from https://www.emulsifyingmixer.com/application/high-pressure-homogenizer-vs-high-shear-mixer/

Sun, Xiao-zheng, Moon, D., Yagishita, T., & Minowa, T. (2017). *Evaluation of energy consumption and greenhouse gas emissions in preparation of cellulose nanofibers from woody biomass*. (July).

Sun, Xiuxuan, Wu, Q., Ren, S., & Lei, T. (2015). Comparison of highly transparent all-cellulose nanopaper prepared using sulfuric acid and TEMPO-mediated oxidation methods. *Cellulose*, *22*, 1123–1133.

Suzuki, A., Sasaki, C., Asada, C., & Nakamura, Y. (2017). Characterization of cellulose nanofiber from steam-exploded Japanese cedar. *BioResources*, *12*(4), 7628–7641.

Syamani, F. A., & Suryani, A. (2015). *Changes in Oil Palm Frond Fiber Morphology , Cellulose Crystallinity and Chemical Functional Groups during Cellulose Extraction Phases*. *7*(3), 105–114.

Syverud, K., & Stenius, P. (2008). Strength and barrier properties of MFC films. *Cellulose*, *16*(1), 75–85.

Szczesna-Antczak, M., Kazimierczak, J., & Antczak, T. (2012). Nanotechnology - methods of manufacturing cellulose nanofibres. *Fibres and Textiles in Eastern Europe*, *91*(2), 8–12.

Tao, J., Fang, Z., Zhang, Q., Bao, W., Zhu, M., Yao, Y., … Hu, L. (2017). Super-Clear Nanopaper from Agro-Industrial Waste for Green Electronics. *Advanced Electronic Materials*, *1600539*, 1–7.

TAPPI. (2011). *Roadmap for the Development of International Standards for Nanocellulose*. Retrieved from https://www.tappinano.org/media/1070/2011-roadmapfornanocellulosestandards.pdf

Tayeb, A. H., Amini, E., Ghasemi, S., & Tajvidi, M. (2018). Cellulose nanomaterials-binding properties and applications: A review. *Molecules*, *23*(10), 1–24.

Teixeira, R. S. S., Silva, A. S. da, Bon, E. P. S., Kim, H.-W., Jang, J.-H., Ishikawa, K., … Endo, T. (2015). Combining biomass wet disk milling and endoglucanase/Î²-glucosidase hydrolysis for the production of cellulose nanocrystals. *Carbohydrate Polymers*. Elsevier Ltd.

Thi, T., Ho, T., & Abe, K. (2015). Nanofibrillation of pulp fibers by twin-screw extrusion. *Cellulose*, *22*, 421–433.

Tian, D., Chandra, R. P., Lee, J. S., Lu, C., & Saddler, J. N. (2017). Biotechnology for Biofuels A comparison of various lignin - extraction methods to enhance the accessibility and ease of enzymatic hydrolysis of the cellulosic component of steam - pretreated poplar. *Biotechnology for*

Biofuels, 1–10.

TNB. (2018). Industrial Consumer - Tenaga Nasional Berhad. Retrieved February 16, 2020, from https://www.tnb.com.my/commercial-industrial/for-industrial/

Tokyo Motor Show 2019: NCV (Nano Cellulose Vehicle) project - MarkLines Automotive Industry Portal. (2019). Retrieved April 13, 2020, from https://www.marklines.com/en/report/rep1947_201911

Ural, Ç., Duran, I., Evmek, B., Kavut, I., Cengiz, S., & Yuzbasioglu, E. (2016). Light transmittance and surface roughness of a feldspathic ceramic CAD-CAM material as a function of different surface treatments. *BMC Oral Health*, *17*(1), 1–7.

van Hazendonk, J. M., van der Putten, J. C., & Keurentjes, J. T. F. (1995). 15 – A method for the determination of the surface tension of cellulosic fibres in their natural state and its relation with chemical composition. In *Cellulose and Cellulose Derivatives* (pp. 107–114).

Via, B. K., Fasina, O., & Pan, H. (2011). Assesment of pine biomass density through mid-infrared spectroscopy and multivariante modelind. *Bioresources*, *6*, 807–822.

W, Dence, C., & Reeve, D. W. (1996). Pulp Bleaching: Principles and Practice. In *Tappi Press*. Atlanta, Ga, USA.

Wang, B., & Sain, M. (2006). Dispersion of soybean stock-based nanofiber in plastic matrix. *ACS Symposium Series*, *938*, 187–208.

Wang, Q, & Zhu, J. Y. (2016). Effects of mechanical fibrillation time by disk grinding on the properties of cellulose nanofibrils. *Tappi Journal*, *15*(6), 419–423.

Wang, Qing, Song, H., Pan, S., Dong, N., Wang, X., & Sun, S. (2020). Initial pyrolysis mechanism and product formation of cellulose: An Experimental and Density functional theory(DFT) study. *Scientific Reports*, *10*(1), 1–18. https://doi.org/10.1038/s41598-020-60095-2

Wang, W., Mozuch, M. D., Sabo, R. C., & Kersten, P. (2015). Production of cellulose nanofibrils from bleached eucalyptus fibers by hyperthermostable endoglucanase treatment and subsequent microfluidization. *Cellulose*, 351–361.

Wang, W., Sabo, R. C., Mozuch, M. D., Kersten, P., & Jin, J. Y. Z. Y. (2015). Physical and Mechanical Properties of Cellulose Nanofibril Films from Bleached Eucalyptus Pulp by Endoglucanase Treatment and Microfluidization. *Journal of Polymers and the Environment*, (Scientific Journal).

Wang, Z., Cai, N., Dai, Q., Li, C., Hou, D., Luo, X., … Yu, F. (2014). Effect of Thermal Annealing on Mechanical Properties of Polyelectrolyte Complex Nanofiber Membranes. *Fibers and Polymers*, *15*, 1406–1413.

Warid, M. N. M., Ariffin, H., Hassan, M. ., & Shirai, Y. (2016). Optimization of Superheated Steam Treatment to Improve Surface Modification of Oil Palm Biomass Fiber. *BioResources*, *11*(3), 5780–5796.

Wildner, W., & Drummer, D. (2014). Wavelength Dependent Haze of Transparent Glass-Particle Filled Poly(Methyl Methacrylate) Composites. *ISRN Optics*, *2014*, 802369.

Wise, L. E. (1946). *Chlorite Holocellulose, Its Fractionation and Bearing on Summative Wood Analysis and on Studies on the Hemicelluloses*. Retrieved from https://books.google.com.my/books?id=QZWIGwAACAAJ

Wulandari, W. T., Rochliadi, A., & Arcana, I. M. (2016). Nanocellulose prepared by acid hydrolysis of isolated cellulose from sugarcane bagasse. *IOP Conference Series: Materials Science and Engineering*, *107*(1), 12045.

Xie, H., Du, H., Yang, X., & Si, C. (2018). Recent Strategies in Preparation of Cellulose Nanocrystals and Cellulose Nanofibrils Derived from Raw Cellulose Materials. *International Journal of Polymer Science*, *2018*, 25.

Xu, A., Mu, L., Fan, Z., Wu, X., Zhao, L., Bo, B., & Xu, T. (2013). Mechanism of heavy oil recovery by cyclic superheated steam stimulation. *Journal of Petroleum Science and Engineering*, *111*, 197–207.

Xu, F. (2010). Chapter 2 - Structure, Ultrastructure, and Chemical Composition. In R.-C. Sun (Ed.), *Cereal Straw as a Resource for Sustainable Biomaterials and Biofuels* (pp. 9–47). Amsterdam: Elsevier.

Yagyu, H., Saito, T., Isogai, A., Koga, H., & Nogi, M. (2015). Chemical Modification of Cellulose Nanofibers for the Production of Highly Thermal Resistant and Optically Transparent Nanopaper for Paper Devices. *ACS Applied Materials and Interfaces*, *7*(39), 22012–22017.

Yamada, H., Tanaka, R., Sulaiman, O., Hashim, R., Hamid, Z. A. A., Yahya, M. K. A., … Mori, Y. (2010). Old oil palm trunk: A promising source of sugars for bioethanol production. *Biomass and Bioenergy*, *34*(11), 1608–1613.

Yang, W., Jiao, L., Liu, W., & Dai, H. (2019). Manufacture of Highly Transparent and Hazy Cellulose Nanofibril Films via Coating TEMPO-Oxidized Wood Fibers. *Nanomaterials*, *9*(1), 107.

Yang, W., Jiao, L., Min, D., Liu, Z., & Dai, H. (2017). Effects of preparation approaches on optical properties of self-assembled cellulose nanopapers. *RSC Advances*, *7*(17), 10463–10468.

Yasim-Anuar, T.A.T., Ariffin, H., & Hassan, M. . (2018). Characterization of cellulose nanofiber from oil palm mesocarp fiber produced by ultrasonication. *IOP Conf. Ser. Mater. Sci. Eng.*, *368*, 1–11.

Yasim-Anuar, Tengku Arisyah Tengku. (2018). *Cellulose Nanofiber from Oil Palm Mesocarp Fiber and Their Utilization as Reinforcement Material in Low Density Polyethylene Composites*.

Yasim-Anuar, Tengku Arisyah Tengku, Ariffin, H., Norrrahim, M. N. F., & Hassan, M. A. (2017). Factors Affecting Spinnability of Oil Palm Mesocarp Fiber Cellulose Solution for the Production of Microfiber. *Bioresources*, *12*(1), 715–734.

Yasim-Anuar, Tengku Arisyah Tengku, Ariffin, H., Norrrahim, M. N. F., Hassan, M. A., Tsukegi, T., & Nishida, H. (2019). Sustainable one-pot process for the production of cellulose nanofiber and polyethylene / cellulose nanofiber composites. *Journal of Cleaner Production*, *207*, 590–599.

Yikrazuul. (2009). File:Xylan.svg - Wikimedia Commons. Retrieved April 2, 2020, from https://commons.wikimedia.org/wiki/File:Xylan.svg

Zainal, N. H., Aziz, A. A., Idris, J., Mamat, R., Hassan, M. A., Bahrin, E. K., & Abd-Aziz, S. (2017). Microwave-assisted pre-carbonisation of palm kernel shell produced charcoal with high heating value and low gaseous emission. *Journal of Cleaner Production*, *142*, 2945–2949.

Zakaria, M. R., Norrrahim, M. N. F., Hirata, S., & Hassan, M. A. (2015). Hydrothermal and wet disk milling pretreatment for high conversion of biosugars from oil palm mesocarp fiber. *Bioresource Technology*, *181*, 263–269.

Zakzeski, J., Bruijnincx, P. C. A., Jongerius, A. L., & Weckhuysen, B. M. (2010). The catalytic valorization of lignin for the production of renewable chemicals. *Chemical Reviews*, *110*(6), 3552–3599.

Zeng, Y., Zhao, S., Yang, S., & Ding, S. (2014). ScienceDirect Lignin plays a negative role in the biochemical process for producing lignocellulosic biofuels. *Current Opinion in Biotechnology*, *27*, 38–45.

Zhang, G., Yao, Y., Zhao, T., Wang, M., & Chen, R. (2020). From Black Liquor to Green Energy Resource: Positive Electrode Materials for Li-O2 Battery with High Capacity and Long Cycle Life. *ACS Applied Materials and Interfaces*, *12*(14), 16521–16530.

Zhao, X., Cheng, K., & Liu, D. (2009). Organosolv pretreatment of lignocellulosic biomass for enzymatic hydrolysis. *Applied Microbiology and Biotechnology*, *82*(5), 815–827.

Zhao, Y., Xu, C., Xing, C., Shi, X., Matuana, L. M., Zhou, H., & Ma, X. (2015). Fabrication and characteristics of cellulose nanofibril films from coconut palm petiole prepared by different mechanical processing. *Industrial Crops and Products*, *65*, 96–101.

Zhou, L., Yang, X., Xu, J., Shi, M., Wang, F., Chen, C., & Xu, J. (2015). Depolymerization of cellulose to glucose by oxidation-hydrolysis. *Green Chemistry*, *17*(3), 1519–1524.

Zhou, Y., & Azumi, R. (2016). Carbon nanotube based transparent conductive films: progress, challenges, and perspectives. *Science and Technology of Advanced Materials*, *17*(1), 1–24.

Zhu, J. Y., Sabo, R., & Luo, X. (2011). Integrated production of nano-fibrillated cellulose and cellulosic biofuel (ethanol) by enzymatic fractionation of wood fibers. *Green Chemistry*, *13*(5), 1339–1344.

Zhu, J. Y., & Zhuang, X. S. (2012). Conceptual net energy output for biofuel production from lignocellulosic biomass through biorefining q. *Progress in Energy and Combustion Science*, *38*(4), 583–598.

Zimmermann, T., Bordeanu, N., & Strub, E. (2010). Properties of nanofibrillated cellulose from different raw materials and its reinforcement potential. *Carbohydrate Polymers*, *79*, 1086–1093.

Zudaire, L., Viñas, I., Abadias, M., Simó, J., & Aguiló-aguayo, I. (2018). LWT - Food Science and Technology E ffi cacy of chlorine , peroxyacetic acid and mild-heat treatment on the reduction of natural micro fl ora and maintenance of quality of fresh-cut calçots (Allium cepa L.). *LWT - Food Science and Technology*, *95*(May), 339–345.

Zugenmaier, P. (2008). *Crystalline Cellulose and Cellulose Derivatives* (1st ed.). New York: Springer-Verlag Berlin Heidelberg.

BIODATA OF STUDENT

Liana Noor Megashah was born on November 5, 1993. She attended her primary school at Sekolah Kebangsaan (SK) Bakri Batu 2 in Muar, Johor for six years. She continued her secondary education at Sekolah Menengah Kebangsaan (SMK) Convent, Muar, Johor (2006 – 2007), SMK Padang Midin, Kuala Terengganu (2007 – 2008), SMK Munshi Abdullah, Melaka (2009) and there she sits for Lower Secondary Evaluation (PMR). At fifth form of secondary school, she went to SMK Puteri, Kota Bharu, Kelantan and completed her Malaysian Certificate of Education (SPM). She got an offer by Majlis Amanah Rakyat (MARA) to pursue a foundation program at Kolej MARA Kuala Nerang (KMKN), Kedah for the year 2011. After completion, she pursued a four-year Bachelor of Chemical Engineering Technology (Hons.) in Bioprocess program at Universiti Kuala Lumpur Malaysian Institute of Chemical and Bio-Engineering Technology (UniKL MICET) in Melaka. Her final year project was on cultivation of soil bacteria and exploitation of its capability for the biodegradation of used engine oil in the environment. She underwent a four-month industrial training program at Melaka Biotechnology Corporation. Her job scope included food testing laboratory focusing on food nutritional fact, antioxidant test and alcohol detection, allowing her to understand on what consumers are concerned about their food products. Later in 2016, she started her Master's degree in the field of Environmental Biotechnology in Universiti Putra Malaysia (UPM), under the supervision of Professor Ts. Dr. Hidayah Ariffin. Her research interests are in developing sustainable methods for commercialize nanocellulose from oil palm waste. During her postgraduate studies, she gets an offer for research attachment at Kyushu Institute of Technology, Japan in May 2017; July – October 2017. Later in 2018, she managed to convert from Master's degree course to Doctor of Philosophy. During the course of her PhD study, she managed to publish several publications in journals and books namely *Cellulose*, *Asia-Pacific Journal of Molecular Biology and Biotechnology,* book chapter in Lignocellulose for Future Bioeconomy, and several conference-proceedings.

LIST OF PUBLICATIONS

The following papers is based on the work contained in this dissertation:

Liana Noor Megashah, Hidayah Ariffin, Mohd Rafein Zakaria, Mohd Ali Hassan, Yoshito Ando, Farah Nadia Mohd Padzil (2020). Modification of cellulose degree of polymerization by superheated steam treatment for versatile properties of cellulose nanofibril film. *Cellulose*, *27*(13), 7417–7429.

Liana Noor Megashah, Hidayah Ariffin, Mohd Ali Hassan & Farah Nadia Mohd Padzil (2019). Chapter 3 - Multistep, Nonchlorinated Treatment for Cellulose Isolation From Oil Palm Fronds. In H. Ariffin, S. M. Sapuan, & M. A. Hassan (Eds.), *Lignocellulose for Future Bioeconomy* (pp. 31–40). Elsevier.

Liana Noor Megashah, Hidayah Ariffin, Mohd Rafein Zakaria & Mohd Ali Hassan (2018). Multi-step pretreatment as an eco-efficient pretreatment method for the production of cellulose nanofiber from oil palm empty fruit bunch. *Asia-Pacific Journal of Molecular Biology and Biotechnology*, *26*(2), 1–8.

Liana Noor Megashah, Hidayah Ariffin, Mohd Rafein Zakaria & Mohd Ali Hassan (2018). Properties of Cellulose Extract from Different Types of Oil Palm Biomass. *IOP Conference Series: Materials Science and Engineering*, *368*, 012049.

Liana Noor Megashah, Hidayah Ariffin, Mohd Rafein Zakaria & Yoshito Ando (2018). Characteristics of cellulose from oil palm mesocarp fibres extracted by multi-step pretreatment methods Characteristics of cellulose from oil palm mesocarp fibres extracted by multi-step pretreatment methods. *IOP Conf. Ser. Mater. Sci. Eng.*, *368*, 012001.

The presentation of papers in conferences/symposiums included in this dissertation was as follows:

Liana Noor Megashah, Hidayah Ariffin, Mohd Rafein Zakaria, Yoshito Andou (2017). Multiple Stage Pretreatment Affecting the Properties of Nanocellulose from Oil Palm Frond. *In International Symposium on Applied Engineering and Sciences (SAES2017).* Universiti Putra Malaysia.

Liana Noor Megashah, Hidayah Ariffin, Mohd Ali Hassan, Mohd Rafein Zakaria, Yoshito Andou (2017). Effect of Pretreatment Concatenation on the Characteristic of Nanocellulose. *In Wood and Biofiber International Conference 2017 (WOBIC2017).* Hotel Bangi-Putrajaya, Malaysia.

Liana Noor Megashah, Hidayah Ariffin, Mohd Rafein Zakaria, Yoshito Andou (2017). Isolation of Cellulose from Oil Palm Empty Fruit Bunch by Multi-step, Totally Chlorine-Free Treatment Method for Cellulose Nanofibril Production. *In International Symposium on Applied Engineering and Sciences (SAES2018).*Kyushu Institute of Technology, Kitakyushu, Japan.

Hidayah Ariffin, Liana Noor Megashah, Siti Shazra Shazleen Shamsudin, Mohd Ali Hassan. Depolymerization of Cellulose with Superheated Steam Improving the Properties of Cellulose Nanofiber (2018). *5th Global Conference on Polymer and Composite Materials (PCM 2018).* Kitakyushu City, Kokura region, Japan.

Liana Noor Megashah, Hidayah Ariffin, Mohd Ali Hassan, Mohd Rafein Zakaria, Yoshito Andou (2019). Characteristic of Oil Palm Empty Fruit Bunch Nanocellulose Film. *In International Symposium on Applied Engineering and Sciences (SAES2019).* Universiti Putra Malaysia.

Liana Noor Megashah, Hidayah Ariffin, Mohd Ali Hassan, Mohd Rafein Zakaria, Yoshito Andou (2019). Versatile Properties of Nanocellulose Film from Oil Palm Empty Fruit Bunch by Superheated Steam Pretreatment. *In Wood and Biofiber International Conference 2019 (WOBIC2019).* Promenada Hotel, Kota Kinabalu, Sabah, Malaysia.

Hidayah Ariffin, Liana Noor Megashah, Mohd Ali Hassan. Steam Pretreatment Enhancing Productivity of Cellulose Nanofibrils from Oil Palm Biomass (2019). *2019 International Conference on Nanotechnology for Renewable Materials*. TAPPI Nano. Chiba, Japan.

The contribution of this work to the copyright included in this dissertation was as follow:

Hidayah Ariffin, Mohd Nor Faiz Norrahim, Liana Noor Megashah, Mohd Ali Hassan. Training module of cellulose isolation from lignocellulose. Copyright no.: LY2017004130.