INFLUENCE OF EXTRACTIVES ON THE POROSITY OF OIL PALM
(Elais guineensis Jacq.) STEM

BALKIS FATOMER BINTI A. BAKAR

IPTPH 2014 2
INFLUENCE OF EXTRACTIVES ON THE POROSITY OF OIL PALM
(Elais guineensis Jacq.) STEM

By

BALKIS FATOMER BINTI A. BAKAR

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

May 2014
COPYRIGHT

All material contained within the thesis, including without limitation text, logos, icons, photographs and all other artwork, is copyright material of Universiti Putra Malaysia unless otherwise stated. Use may be made of any material contained within the thesis for non-commercial purposes from the copyright holder. Commercial use of material may only be made with the express, prior, written permission of Universiti Putra Malaysia

Copyright © Universiti Putra Malaysia
To my beloved husband

Nizam Hakim Md. Ishak

My beloved parents
Hj. A. Bakar Othman
Hjh. Farida Amin

My beloved sisters and brother
Suhailey Bakar
Nathrah Bakar
Ghazaly Bakar

Thank you for being the people that encouraged me the most.
Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Master of Science

INFLUENCE OF EXTRACTIVES ON THE POROSITY OF OIL PALM (*Elaeis guineensis* Jacq.) STEM

By

BALKIS FATOMER A. BAKAR

May 2014

Chairman : Professor Paridah Md. Tahir, PhD

Institute : Institute of Tropical Forestry and Forest Products (INTROP)

In this study, an investigation was conducted to determine the basic properties (moisture content and density) of the oil palm stem and amount of extractives content that can be extracted from the sample. Porosity studies were also conducted on the oil palm stem in different exposure conditions (dried and green) and the influence of extractive on the porosity was examined. Oil palm trees were selected randomly from the species *Elaeis guineensis* Jacq. from Taman Pertanian Universiti located in Universiti Putra Malaysia, Serdang, Malaysia. Each of the tree were cut along the tree height into three main parts namely bottom, middle and top. Each part was further cut into three sections labelled as outer, inner and centre across the transverse direction of oil palm stem. Technical Association of the Pulp and Paper Industry (TAPPI) standards were employed for water extractives (cold water and hot water) and also acetone extractives. The green moisture content of the oil palm stem was found higher at the middle with average of 221.8% and lowest was at bottom with 158.4%. Across the transverse direction, centre section always had higher moisture content regardless of the tree height and the lowest was found at outer section with average of 260.7% and 115.3%, accordingly. The density of oil palm stem was found inversed with moisture content as the highest density was found at bottom with average of 0.46 g/cm³ and the lowest was at middle with 0.37 g/cm³. Outer consistently gave higher density compared to centre section with 0.55 g/cm³ and 0.30 g/cm³. The coefficient of determination ($R^2$) obtained between moisture content and density was high with 0.83. In non-sequential method, hot water extractives gave higher results compared to other solvents with average of 26.8% of total extracted compounds. Whereas in the sequential method, cold water was found higher with average of 21.3%. Comparing the methods, sequential extraction method gave greater amount of extractives as the samples had gone through three different solvents continuously. Whilst, parenchyma cells is proven to contribute three times higher of extractives content than vascular bundles.
For theoretical porosity in dried and green condition, samples taken from centre section at middle part had highest average percentage of 79.4% and 78.2%, respectively and the least was found at outer section at bottom part with 71.7% and 69.0%, accordingly. Whereas, experimental porosity was found higher at centre section at top part for dried condition and at centre section of middle part along the oil palm tree height for green condition. Experimental porosity surpassed the theoretical porosity values as a result from the effects of condition exposure of the samples at the upper part of the oil palm tree (middle and top). However, there is no dependency of extractives content towards porosity found in this study. This study concluded that moisture content and density of oil palm stem was affected by the location (longitudinal and transverse direction) of the sample taken. Extractives content was found higher at sample which consist higher portion of parenchyma cells. Oil palm stem sample in green condition resulted higher experimental porosity compared to dried condition. Porosity of oil palm stem has low influence by its extractives content rather than its anatomical structure. The study suggests that oil palm stem can be treated by impregnation or preservation process in green condition.
Abstrak thesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Master Sains

PENGARUH EKSTRAKTIF TERHADAP KELIANGAN BATANG KELAPA SAWIT (Elaeis guineensis Jacq.)

Oleh

BALKIS FATOMER A. BAKAR
Mei 2014

Pengerusi : Profesor Paridah Md Tahir, PhD
Institut : Institut Perhutanan Tropika dan Produk Hutan (INTROP)

Dalam kajian ini, satu ujikaji telah dijalankan untuk menentukan sifat-sifat asas (kandungan air dan ketumpatan) daripada batang kelapa sawit dan juga jumlah kandungan ekstraktif yang boleh diekstrak daripada sampel tersebut. Kajian keliangan juga dijalankan pada batang kelapa sawit dan pengaruh ekstraktif pada keliangan kayu dikaji. Pokok kelapa sawit telah dipilih secara rawak daripada spesies Elaeis guineensis Jacq. dari Taman Pertanian Universiti yang terletak di Universiti Putra Malaysia, Serdang, Malaysia. Setiap pokok dipotong kepada tiga bahagian utama iaitu bahagian bawah, tengah dan atas disepanjang ketinggian pokok. Setiap bahagian pula dipotong menjadi tiga bahagian kecil yang dilabel sebagai luar, dalam dan pusat di arah melintang batang kelapa sawit. Piawaian (Persatuan Teknikal Industri Pulpa dan Kertas) TAPPI digunakan untuk eksperimen keterlarutan air (air sejuk dan air panas) dan juga aseton ekstraktif. Kandungan lembapan hijau batang kelapa sawit didapati lebih tinggi di tengah dengan purata 221.8% dan terendah adalah di bahagian bawah dengan 158.4%. Pada arah melintang, bahagian pusat sentiasa mempunyai kandungan lembapan yang lebih tinggi tanpa mengira ketinggian pokok itu dan yang paling rendah didapati di bahagian luar dengan purata 260.7% dan 115.3%. Ketumpatan batang kelapa sawit didapati songsang dengan kandungan lembapan sebagai kepadatan paling tinggi didapati di bahagian bawah dengan purata 0.46 g/cm³ dan yang paling rendah adalah di tengah dengan 0.37 g/cm³. Bahagian luar secara konsisten memberikan kepadatan yang lebih tinggi berbanding dengan bahagian tengah dengan 0.55 g/cm³ dan 0.30 g/cm³. Pekali penentuan (R²) diperolehi antara kandungan lembapan dan ketumpatan adalah tinggi dengan 0.83. Dalam kaedah tidak berurutan, keterlarutan air panas memberikan jumlah yang lebih tinggi berbanding dengan pelarut lain dengan purata sebanyak 26.8% daripada jumlah sebatian yang diekstrak. Manakala, dalam kaedah berurutan, kelerutan air sejuk didapati lebih tinggi dengan purata 21.3%. Apabila membandingkan kaedah, kaedah pengekstrakan berurutan memberikan jumlah yang lebih besar kerana sampel batang kelapa sawit telah melalui tiga pelarut yang berbeza dalam satu proses.
Tambahan lagi, sel parenkima terbukti menyumbang tiga kali lebih tinggi kandungan ekstraktif berbanding daripada berkas vaskular.

Untuk teori keliangan dalam keadaan kering dan hijau, sampel yang diambil daripada bahagian pusat di bahagian tengah mempunyai peratusan tertinggi purata 79.4% dan 78.2% masing-masing dan yang paling didapati di bahagian luar di bahagian bawah dengan 71.7% dan 69.0%. Manakala, eksperimen keliangan didapati lebih tinggi pada bahagian tengah di bahagian atas bagi keadaan kering dan di bahagian tengah bahagian tengah di sepanjang ketinggian pokok kelapa sawit bagi keadaan hijau. Eksperimen keliangan melepas nilai teori keliangan sebagai hasil dari kesan pendedahan keadaan sampel pada bahagian atas pokok kelapa sawit (tengah dan atas). Walau bagaimanapun, tidak ada pergantungan kandungan ekstraktif terhadap keliangan didapati dalam kajian ini. Kajian ini mendapati bahawa kandungan lembapan dan ketumpatan batang kelapa sawit berubah mengikut lokasi sampel (arah ketinggian kelapa sawit dan melintang) yang diambil. Kandungan ekstraktif didapati lebih tinggi pada sampel yang mempunyai sel parenkima yang tinggi. Sampel batang kelapa sawit dalam keadaan hijau menghasilkan bacaan keliangan experiment yang lebih tinggi berbanding keadaan sampel yang dikeringkan. Keliangan batang kelapa sawit mempunyai pengaruh yang rendah oleh jumlah ekstraktif berbanding dengan struktur anatomi. Kajian ini juga mencadangkan bahawa batang kelapa sawit boleh dirawat dalam keadaan hijau.
ACKNOWLEDGEMENTS

All praises are due to Allah SWT who had given me blessing, strength and knowledge in finishing this thesis.

Special notes of gratitude to my main supervisor, Professor Dr Paridah Md Tahir, without whom my research would not have been possible and completed. I would also like to thank her for all the guidance and encouragement that she has shown me throughout the period of this research as a supervisor. To all my committee members Professor Dr Alinaghi Karimi, and Associate Professor Dr Edi Suhaime Bakar, I extend to you my warmest thanks for being patient, understanding and providing me invaluable guidance. I would like to also say thank you to Professor Dr Zaidon Ashaari, Professor Dr Salim Hiziroglu and Dr Mohd Khairun Anwar Uyup for your willingness to spend some time to sharing knowledge with me and guiding me in writing this thesis.

Special thanks to my Head of Department of Forest Production, Dr. Rasmina Halis and Dean of Faculty of Forestry, Prof. Datin Dr. Faridah Hanum Ibrahim for the approval of my study leave and all the assistance and advice given. I would also like to extend my appreciation to all the staff of the Faculty of Forestry and the Institute of Tropical Forestry and Forest Products, especially Mr Azam, Mr Fakruddin, Mr Zamani for all their help during my labwork.

To my fellow researchers, Dr Adrian Choo Cheng Yong, Dr. Juliana Halip, Aisyah Humaira, Norul Izani, Nor Hafizah, Husna, Lukman, all my ex-UiTM comrades and other colleagues, I sincerely appreciate all the help that you guys have given to me and I truly cherish our friendship.

My greatest and deepest gratitude goes to my parents, my parents in law and siblings for being understanding and supportive through the years. To my husband Hakim, thank you for always being there for me, being a good listener and encouraging me through the trials I faced in completing this thesis. I dedicate this thesis to all of you.

Balkis
I certify that an Examination Committee has met on 27th May 2014 to conduct the final examination of BALKIS FATOMER A. BAKAR on her MASTER IN SCIENCE thesis entitled “INFLUENCE OF EXTRACTIVES ON THE POROSITY OF OIL PALM (Elaeis guineensis Jacq.) STEM” in accordance with Universiti Pertanian Malaysia (Higher Degree) Act 1980 and Universiti Pertanian Malaysia (Higher Degree) Regulations 1981. The Committee recommends that the student be awarded the relevant degree.

Members of the Examination Committee were as follows:

Azmah Hanim binti Mohamed Ariff, PhD
Faculty of Engineering
Universiti Putra Malaysia
(Chairman)

Rasmina binti Halis, PhD
Faculty of Forestry
Universiti Putra Malaysia
(Internal Examiner)

Rosfarizan binti Mohamad, PhD
Associate Professor
Faculty of Biotechnology and Biomolecular Sciences
Universiti Putra Malaysia
(Internal Examiner)

Rokiah Hashim, PhD
Professor
School of Industrial Technology
Universiti Sains Malaysia
(External Examiner)

PROF. DR. ZULKARNAIN ZAINAL, PhD
Professor and Deputy Dean
School of Graduate Studies
Universiti Putra Malaysia

Date:
This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfillment of the requirement for the degree of Master of Science. The members of the Supervisory Committee were as follows

**Paridah Md Tahir, PhD**  
Professor  
Institute of Tropical Forestry and Forest Products  
Universiti Putra Malaysia  
(Chairman)

**Alinaghi Karimi, PhD**  
Professor  
Institute of Tropical Forestry and Forest Products  
Universiti Putra Malaysia  
(Member)

**Edi Suhaimi Bakar, PhD**  
Associate Professor  
Faculty of Forestry  
Universiti Putra Malaysia  
(Member)

---

**BUJANG BIN KIM HUAT, PhD**  
Professor and Dean  
School of Graduate Studies  
Universiti Putra Malaysia

Date:
DECLARATION

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.: _________________________________________
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:________________________ Signature:________________________
Name of Chairman of Supervisory Committee:________________________
Name of Member of Supervisory Committee:________________________

Signature:________________________
Name of Chairman of Supervisory Committee:________________________
# TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>Chapter</th>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>DEDICATION</td>
<td></td>
<td>i</td>
</tr>
<tr>
<td>ABSTRACT</td>
<td></td>
<td>ii</td>
</tr>
<tr>
<td>ABSTRAK</td>
<td></td>
<td>iv</td>
</tr>
<tr>
<td>ACKNOWLEDGEMENTS</td>
<td></td>
<td>vi</td>
</tr>
<tr>
<td>APPROVAL</td>
<td></td>
<td>vii</td>
</tr>
<tr>
<td>DECLARATION</td>
<td></td>
<td>ix</td>
</tr>
<tr>
<td>LIST OF TABLES</td>
<td></td>
<td>xiii</td>
</tr>
<tr>
<td>LIST OF FIGURES</td>
<td></td>
<td>xiv</td>
</tr>
<tr>
<td>LIST OF ABBREVIATIONS</td>
<td></td>
<td>xvii</td>
</tr>
<tr>
<td><strong>CHAPTER 1</strong></td>
<td><strong>INTRODUCTION</strong></td>
<td></td>
</tr>
<tr>
<td>1.1</td>
<td>General view</td>
<td>1</td>
</tr>
<tr>
<td>1.2</td>
<td>Problem Statement</td>
<td>2</td>
</tr>
<tr>
<td>1.3</td>
<td>Objectives</td>
<td>3</td>
</tr>
<tr>
<td><strong>CHAPTER 2</strong></td>
<td><strong>LITERATURE REVIEW</strong></td>
<td></td>
</tr>
<tr>
<td>2.1</td>
<td>Introduction</td>
<td>4</td>
</tr>
<tr>
<td>2.2</td>
<td>General Description of Oil Palm</td>
<td>4</td>
</tr>
<tr>
<td>2.3</td>
<td>Oil Palm Biomass</td>
<td>7</td>
</tr>
<tr>
<td>2.4</td>
<td>Morphology Characteristics of Oil Palm Stem</td>
<td>8</td>
</tr>
<tr>
<td>2.5</td>
<td>Anatomical Features of Oil Palm Stem</td>
<td>8</td>
</tr>
<tr>
<td>2.5.1</td>
<td>Vascular Bundles</td>
<td>10</td>
</tr>
<tr>
<td>2.5.2</td>
<td>Parenchyma</td>
<td>10</td>
</tr>
<tr>
<td>2.6</td>
<td>Physical Properties of Oil Palm Stem</td>
<td>11</td>
</tr>
<tr>
<td>2.6.1</td>
<td>Density</td>
<td>12</td>
</tr>
<tr>
<td>2.6.2</td>
<td>Moisture Content</td>
<td>13</td>
</tr>
<tr>
<td>2.7</td>
<td>Chemical Composition of Oil Palm Stem</td>
<td>14</td>
</tr>
<tr>
<td>2.7.1</td>
<td>Extractives</td>
<td>15</td>
</tr>
<tr>
<td>2.7.2</td>
<td>Extractives Content in Oil Palm Stem</td>
<td>15</td>
</tr>
<tr>
<td>2.7.3</td>
<td>Classification of Wood Extractives</td>
<td>16</td>
</tr>
<tr>
<td>2.7.4</td>
<td>Techniques of Extraction</td>
<td>17</td>
</tr>
<tr>
<td>2.8</td>
<td>Porosity</td>
<td>18</td>
</tr>
<tr>
<td>2.8.1</td>
<td>Fluid Flow in Lignocellulosic Materials</td>
<td>18</td>
</tr>
<tr>
<td>2.8.2</td>
<td>Moisture in Oil Palm Stem</td>
<td>21</td>
</tr>
<tr>
<td>2.8.3</td>
<td>Determination of Porosity</td>
<td>23</td>
</tr>
<tr>
<td>2.8.4</td>
<td>Effect extractives content towards porosity</td>
<td>23</td>
</tr>
<tr>
<td><strong>CHAPTER 3</strong></td>
<td><strong>METHODOLOGY</strong></td>
<td></td>
</tr>
<tr>
<td>3.1</td>
<td>Material Selection</td>
<td>25</td>
</tr>
<tr>
<td>3.2</td>
<td>Experimental Design</td>
<td>26</td>
</tr>
<tr>
<td>3.3</td>
<td>Determination of Moisture Content</td>
<td>28</td>
</tr>
</tbody>
</table>
3.4 Determination of Density 28
3.5 Determination of Extractives Content 28
  3.5.1 Acetone Extractives 30
  3.5.2 Cold Water Extractives 30
  3.5.3 Hot Water Extractives 31
  3.5.4 Non-Sequential and Sequential Extraction 31
  3.5.5 Non-sequential extraction of Vascular Bundles and Parenchyma 31
3.6 Porosity of Oil Palm Stem 32
3.7 Statistical Analysis 34

4 RESULTS AND DISCUSSION 35
  4.1 Moisture Content and Density of Oil Palm Stem 35
    4.1.1 Moisture Content 35
    4.1.2 Density 37
  4.2 Extractives Content in Oil Palm Stem for Non-Sequential Extraction Process 39
    a) Acetone Extractives 40
    b) Water Extractives (Cold and Hot Water Solubility) 41
  4.3 Extractives Content in Oil Palm Stems for Sequential Extraction Process 44
    a) Cold Water Extractives 45
    b) Hot Water Extractives 46
    c) Acetone Extractives 48
  4.4 Determination of Extractives Content in Vascular Bundles and Parenchyma 51
  4.5 Investigation on Oil Palm Stem Porosity 52

5 CONCLUSION AND RECOMMENDATIONS 67
  5.1 Conclusion 67
  5.2 Recommendations 68

REFERENCES 69
APPENDICES 81
BIODATA OF STUDENT 88
LIST OF PUBLICATIONS 89
## LIST OF TABLES

<table>
<thead>
<tr>
<th>Table</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.1</td>
<td>Oil palm taxonomy</td>
<td>4</td>
</tr>
<tr>
<td>2.2</td>
<td>Properties of a 27 year old oil palm stem at various sections and height of the stem.</td>
<td>11</td>
</tr>
<tr>
<td>2.3</td>
<td>Chemical composition in different wood species</td>
<td>14</td>
</tr>
<tr>
<td>2.4</td>
<td>Techniques of extractions and corresponding extracted compounds</td>
<td>17</td>
</tr>
<tr>
<td>3.1</td>
<td>Summaries of replicates used for the experimental work</td>
<td>26</td>
</tr>
<tr>
<td>4.1</td>
<td>Analysis of variance of the effect between height and section on the density and moisture content of oil palm stem</td>
<td>35</td>
</tr>
<tr>
<td>4.2</td>
<td>Comparison of moisture content of oil palm tree at different ages (14, 25 and 32 years)</td>
<td>36</td>
</tr>
<tr>
<td>4.3</td>
<td>Analysis of variance for the effects of tree height and sections on the yields of different types of extractives</td>
<td>39</td>
</tr>
<tr>
<td>4.4</td>
<td>Analysis of variance of extractives yields for different height and sections within the stem using 3 different solvent using sequential extraction method</td>
<td>45</td>
</tr>
<tr>
<td>4.5</td>
<td>Analysis of variance (ANOVA) for theoretical porosity and experimental porosity of oil palm stem</td>
<td>52</td>
</tr>
</tbody>
</table>
# LIST OF FIGURES

<table>
<thead>
<tr>
<th>Figure</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.1</td>
<td>Transverse section of oil palm stem</td>
<td>5</td>
</tr>
<tr>
<td>2.2</td>
<td>Sample taken along the transverse direction of oil palm stem indicated as a) outer section b) inner section and c) centre section.</td>
<td>6</td>
</tr>
<tr>
<td>2.3</td>
<td>Estimated percentage of oil palm biomass</td>
<td>7</td>
</tr>
<tr>
<td>2.4</td>
<td>Sample was taken from bottom part. Darker section is represent as outer which having compact vascular bundles and lighter colour at centre section where the parenchyma is dominant</td>
<td>9</td>
</tr>
<tr>
<td>2.5</td>
<td>Vascular bundles and parenchyma of oil palm stem (5x magnification)</td>
<td>9</td>
</tr>
<tr>
<td>2.6</td>
<td>Schematic diagram of density variation in oil palm stem</td>
<td>12</td>
</tr>
<tr>
<td>2.7</td>
<td>Extractives classification</td>
<td>16</td>
</tr>
<tr>
<td>2.8</td>
<td>Samples were cut into two to observed the penetration of acid fuchsin after 16 h of immersion</td>
<td>19</td>
</tr>
<tr>
<td>2.9</td>
<td>SEM images showing the differences anatomical structure of a) hardwood, b) softwood, c) oil palm stem</td>
<td>20</td>
</tr>
<tr>
<td>2.10</td>
<td>The three principal axes of wood</td>
<td>22</td>
</tr>
<tr>
<td>3.1</td>
<td>Schematic labelling of oil palm stem</td>
<td>25</td>
</tr>
<tr>
<td>3.2</td>
<td>General view of experimental design in this study</td>
<td>27</td>
</tr>
<tr>
<td>3.3</td>
<td>Sample preparation from oil palm billet to form a board</td>
<td>29</td>
</tr>
<tr>
<td>3.4</td>
<td>The oil palm billet was cut into stick form (2 x 2 x length in diameter)</td>
<td>29</td>
</tr>
<tr>
<td>3.5</td>
<td>Oil palm stem particles weighted 2 g each for extraction process</td>
<td>30</td>
</tr>
<tr>
<td>3.6</td>
<td>Vascular bundles and parenchyma cells were separated for further experiment</td>
<td>32</td>
</tr>
<tr>
<td>3.7</td>
<td>Schematic diagram to prepare blocks in two different condition</td>
<td>32</td>
</tr>
<tr>
<td>3.8</td>
<td>Sample size (2 x 2 x 2 cm) of oil palm stem</td>
<td>32</td>
</tr>
<tr>
<td>Section</td>
<td>Description</td>
<td>Page</td>
</tr>
<tr>
<td>---------</td>
<td>-----------------------------------------------------------------------------------------------</td>
<td>------</td>
</tr>
<tr>
<td>3.9</td>
<td>Summary of process flow for porosity test</td>
<td>33</td>
</tr>
<tr>
<td>4.1</td>
<td>Moisture content in longitudinal and transverse sections of oil palm stem</td>
<td>36</td>
</tr>
<tr>
<td>4.2</td>
<td>Density in longitudinal and transverse sections of oil palm stems</td>
<td>38</td>
</tr>
<tr>
<td>4.3</td>
<td>Correlation between density and moisture content of oil palm stem</td>
<td>39</td>
</tr>
<tr>
<td>4.4</td>
<td>Extractives in longitudinal and transverse directions of oil palm stem dissolved in acetone</td>
<td>40</td>
</tr>
<tr>
<td>4.5</td>
<td>Extractives in longitudinal and transverse directions of oil palm stem dissolved in cold water</td>
<td>41</td>
</tr>
<tr>
<td>4.6</td>
<td>Extractives in longitudinal and transverse directions of oil palm stem dissolved in hot water</td>
<td>42</td>
</tr>
<tr>
<td>4.7</td>
<td>Mapping of the distribution of extractives content in the oil palm stem using a) acetone, b)</td>
<td>44</td>
</tr>
<tr>
<td></td>
<td>cold water and c) hot water</td>
<td></td>
</tr>
<tr>
<td>4.8</td>
<td>Extractives in longitudinal and transverse directions of oil palm stem dissolved in cold water</td>
<td>45</td>
</tr>
<tr>
<td></td>
<td>for sequential extraction</td>
<td></td>
</tr>
<tr>
<td>4.9</td>
<td>Distribution of vascular bundles and parenchyma cells in a) outer and b) centre section of</td>
<td>46</td>
</tr>
<tr>
<td></td>
<td>bottom part of oil palm stem</td>
<td></td>
</tr>
<tr>
<td>4.10</td>
<td>Extractives in longitudinal and transverse directions of oil palm stem dissolved in hot water</td>
<td>47</td>
</tr>
<tr>
<td></td>
<td>for sequential extraction</td>
<td></td>
</tr>
<tr>
<td>4.11</td>
<td>Starch found in parenchyma cells at a) bottom outer and b) top centre section of oil palm stem</td>
<td>48</td>
</tr>
<tr>
<td>4.12</td>
<td>Extractives in longitudinal and transverse directions of oil palm stem dissolved in acetone</td>
<td>49</td>
</tr>
<tr>
<td></td>
<td>for sequential extraction</td>
<td></td>
</tr>
<tr>
<td>4.13</td>
<td>Extractives content in average percentage between non-sequential and sequential extraction</td>
<td>50</td>
</tr>
<tr>
<td>4.14</td>
<td>Extractives in vascular bundles and parenchyma cells using three different solvents</td>
<td>51</td>
</tr>
<tr>
<td>4.15</td>
<td>Theoretical porosity in oil palm stem (longitudinal and transverse) as function of conditions</td>
<td>53</td>
</tr>
<tr>
<td>4.16</td>
<td>Crack occurred and hollow space observed at parenchyma cells of oil palm stem using Dino Light</td>
<td>54</td>
</tr>
<tr>
<td></td>
<td>with 65x magnification</td>
<td></td>
</tr>
</tbody>
</table>
4.17 Experimental porosity in oil palm stem (longitudinal and transverse) as function of condition

4.18 Comparison between theoretical and experimental porosity for bottom height along the transverse direction of oil palm stem in dried condition

4.19 Difference occurrence of vascular bundles at outer section taken from bottom (left) and middle (right) with sample size 2x2x2 cm each

4.20 Comparison between theoretical and experimental porosity for bottom height along the transverse direction of oil palm stem in green condition

4.21 Comparison between theoretical and experimental porosity for middle height along the transverse direction of oil palm stem in dried condition

4.22 Comparison between theoretical and experimental porosity for middle height along the transverse direction of oil palm stem in green condition

4.23 Comparison between porosity and free water for top height along the transverse direction of oil palm stem in dried condition.

4.24 Effect of drying process on oil palm samples across the transverse direction of the stem

4.25 Outer section at top height sample shows some of the defects resulted from drying

4.26 Comparison between theoretical and experimental porosity for top height along the transverse direction of oil palm stem in green condition

4.27 Starch granule in the top part of oil palm stem

4.28 Correlation between theoretical porosity and extractives content of oil palm stem in dried condition

4.29 Correlation between theoretical porosity and extractives content of oil palm stem in green condition

4.30 Correlation between experimental porosity and extractives content of oil palm stem in dried condition

4.31 Correlation between experimental porosity and extractives content of oil palm stem in green condition
### LIST OF ABBREVIATIONS

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>(-OH)</td>
<td>Hydroxyl groups</td>
</tr>
<tr>
<td>ANOVA</td>
<td>Analysis of variance</td>
</tr>
<tr>
<td>CPO</td>
<td>Crude palm oil</td>
</tr>
<tr>
<td>EFB</td>
<td>Empty fruit bunch</td>
</tr>
<tr>
<td>EMC</td>
<td>Equilibrium moisture content</td>
</tr>
<tr>
<td>FSP</td>
<td>Fibre saturation point</td>
</tr>
<tr>
<td>GBP</td>
<td>Gympsum-bonded particleboard</td>
</tr>
<tr>
<td>ha</td>
<td>Hectares</td>
</tr>
<tr>
<td>Lmw PF</td>
<td>Low molecular weight phenol formaldehyde</td>
</tr>
<tr>
<td>LSD</td>
<td>Least significant difference</td>
</tr>
<tr>
<td>LVL</td>
<td>Laminated veneer lumber</td>
</tr>
<tr>
<td>MDF</td>
<td>Medium-density fibreboard</td>
</tr>
<tr>
<td>MF</td>
<td>Mesocarp fibre</td>
</tr>
<tr>
<td>MIDA</td>
<td>Malaysian Industrial Development Authority</td>
</tr>
<tr>
<td>MPOB</td>
<td>Malaysian Palm Oil Board</td>
</tr>
<tr>
<td>PKO</td>
<td>Palm kernel oil</td>
</tr>
<tr>
<td>PKS</td>
<td>Palm kernel shells</td>
</tr>
<tr>
<td>POME</td>
<td>Palm oil mill effluent</td>
</tr>
<tr>
<td>R²</td>
<td>Coefficient of determination</td>
</tr>
<tr>
<td>SAS</td>
<td>Statistical analysis variance</td>
</tr>
<tr>
<td>TAPPI</td>
<td>Technical Association of the Pulp and Paper Industry</td>
</tr>
<tr>
<td>TPU</td>
<td>Taman Pertanian Universiti</td>
</tr>
</tbody>
</table>
CHAPTER 1

INTRODUCTION

1.1 General View

Since early 1960’s, the cultivation of oil palm plantation increased at a fast pace in line with the government’s agricultural diversification program, which was introduced to reduce the country’s economic dependence on rubber and tin (Rasiah and Shahrin, 2004). Later in the 1960’s, the government introduced land settlement schemes for planting oil palm tree to eliminate poverty for the landless farmers and smallholders. Initially, oil palm tree was planted to harvest the palm oil from its fruits. The latest statistical data extracted from MPOB (2014) had reported that there was 5.23 million ha of oil palm plantation in 2013 compared to 5.08 million ha in 2012. The largest oil palm plantation was dominated by Peninsular Malaysia with 2.59 million ha, followed by Sabah (1.48 million ha) and Sarawak (1.16 million ha) (MPOB, 2014).

In spite of substantial plantation, ample oil palm stems are available during replanting process which happens after the trees reach 25 to 30 years. The stems generated approximately 15.39 million tonnes of lignocellulosic materials annually (Hartono, 2012). Previously, the discarded stems were burnt in the field as disposal of the wastes (Lim and Gan, 2005) or were left at the oil palm plantation as natural compost.

With proper treatment against bio-deteriorating agents, the oil palm stems have been proven to be used in various applications such as laminated veneer lumber (LVL) and plywood (Loh et al., 2011; Sulaiman et al., 2008; Nordin et al., 2004) are used as the core materials to produce framing materials for the manufacture of furniture. Oil palm stem usage is extended as well as to other composite panels, such as particleboard, medium-density fibreboard (MDF) and wood cement board. Rahim and Khozirah (1991) had introduced gypsum-bonded particleboard (GBP) by using fresh oil palm stem chips. Additionally, recent works done by several authors (Hoong et al., 2013; Nor Hafizah et al., 2012; Loh et al., 2011) had produced high grade oil palm plywood and veneers by impregnated low molecular weight phenol formaldehyde (LmwPF) into the samples.

However, there is no economic value of oil palm stem from structural point of view (Abdul Khalil, 2006), and the maximum utilization of oil palm stem still constrained with several factors such as variation in density (Loh et al., 2011; Choo et al., 2010; Bakar et al., 2008; Lim et al., 2003), high moisture content (Bakar et al., 2008; Shirley, 2002), high extractives content (Darmawan, 2006) and low dimensional stability (Bakar et al., 2008; Ibrahim, 1989). Therefore, various techniques have been implemented to enhance the properties of oil palm stem end products through polymer injection (Zugenmaier, 2006; Ibrahim, 1989), thermal treatment (Fukuta, 2008; Higashihara et al., 2000), chemical modification (Mahlberg et al., 2001; Xie et al., 2007) and resin impregnation (Nor Hafizah et al., 2014; Bakar et al., 2013 and
In general, such processes aim to improve the weather and decay resistance, dimensional stability, strength, colour and paintability properties of materials (Herajarvi, 2009).

Most of the treatments particularly using chemical treatments are related to the basic properties of the woody or lignocellulose such as porosity and permeability value. Like wood, oil palm stem is a porous material (Kollmann and Cote, 1968) which composed of cell wall substances and cavities containing air and extractives (Tsoumis, 1991). The specific gravity of the cell wall practically constant for all woody material with value of 1.53 g/cm$^3$ on an oven dry mass and volume basis, and the cell wall materials are completely non-porous (Dinwoodie, 1981). What make oil palm stem differ from other wood such as rubberwood is it belongs to monocotyledon plants which means oil palm stem does not possess any vascular cambium, secondary growth, growth rings, ray cells, sapwood and heartwood, branches and knots (Killmann and Lim, 1985) compared to dicotyledon plants. Flow of fluid in oil palm stem is mainly through metaxylem vessels in vascular bundles (Shirley, 2002) and several researchers also found that parenchyma contributes to absorb more liquid as it have thin walled and high absorbency rate (Nordin, 2012; Paridah et al., 2006).

Moreover, oil palm stem is a much more porous, cellular and anisotropic in nature. Thus liquid such as water and low molecular weight compounds can rapidly absorbed and flow into the cell wall and lumen (Loh et al., 2011). Basically, wood porosity can ranged from 46 to 80% of total wood volume which can give significant effect to the depth and direction of fluid flows like preservatives and adhesives in treatment process (Vick, 1999). During the treatment process, penetration of liquid in wood pores depends on surface roughness, density, extractives content and properties of the liquid itself (Nor Hafizah et al., 2012). Oil palm stem also has been reported to contain high extractives content (10%) compared to other wood (Darmawan, 2006), and Olsson et al. (2001) believed that extractives are one of the main reasons for reduced transverse permeability of pine heartwood.

1.2 Problem Statement

Lignocellulosic material is chemically heterogeneous and its components can be divided into two groups; structural components of high molecular weight which includes cellulose, hemicellulose and lignin that contributes to the major cell wall components; and non-structural components of low molecular weight (extractives and inorganic components). The extractives are non-polymeric and may be separated from the insoluble cell wall materials by solving them in water or organic solvents (Vaicklenionis and Vaickelioniene, 2006). In general, the overall percent of the extractives in wood varies from 2 to 10% and oil palm stem consists the highest extractives content among other monocotyledon plants (Darmawan, 2006). The effects of extractives resulted in corrosion of metals in contact with wood, inhibition of setting of concrete, glue and finishes (David and Nobuo, 2001). During the drying process, extractives that presence in wood are transported to the surface in a heterogeneous distribution and deposited as solids when the water evaporates causing the interference with absorption and curing process of the substances.
Contamination of wood surface by having heavy deposits of extractives may reduce bonding strength by blocking the reaction sites and prevent true wetting by the adhesives (Hse and Kuo, 1988).

Moreover, Behr et al. (2011) stated that in Scots pine, extractives are believed to be one of the main reason for the reduced transverse permeability of pine heartwood. A small amount of distributed extractives is enough to encrust the bordered pits permanently and block them for liquids as extractives were related to reduce wood treatability (Zimmer et al., 2009). A vast number of experimental results have shown that the removal of extractives increases the dimensional changes of wood (Adamopoulos and Voulgaridis, 2012; Stamm and Loughborough, 1942). In study done by Adamopoulos and Voulgaridis (2012) on Black Locust wood had found that removal of extractives also resulted to a slight gradual increase in radial and tangential dimensional changes of the wood. Furthermore, Darmawan et al. (2012) reported that wood extractives and silica have a potential adverse effect on tool wear.

As in wood, the most crucial properties determining the ease of drying and treatment in oil palm stem is its porosity. Porosity is the fractional of void volume of wood and to be a permeable, a solid must be porous (Siau, 1984). However, having high porosity values does not mean that the material will have higher permeability values as a result from blockage or cell ruptured. The knowledge of porosity is important as a factor influencing the amount of liquid that can be absorbed in a given block volume and influenced the way preservative retention is expressed (Usta, 2006). For instance, the maximum amount of treating solution that can be injected into wood can be determined. Research on porosity has always been highlighted on the hardwoods and softwoods as compared to monocotyledons (Nordin, 2012; Plotze and Niemz, 2011). Only limit information has been found for porosity of oil palm stem and it is not sufficient to help boost the effect of the treatment that using liquid. Thus, hypothesis for this study is wood extractives that are presence in oil palm stem may block the voids in liquid absorption of oil palm stem.

1.3 Objectives

The main objective of this study was to evaluate the influence of extractives on the porosity of oil palm stem.

Specific objectives of the work were:

a) To determine the moisture content and density of oil palm stem along the tree height and transverse section.

b) To evaluate the extractives content in longitudinal and transverse section of oil palm stem.

c) To determine the porosity relationships with extractives content of oil palm stem along the tree height and transverse direction.
REFERENCES


