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This issue of *Palm Oil Engineering Bulletin* presents useful information on oil palm fruit ripeness, oil palm biomass treatment and particulate matters emission control. Presently, management of palm oil production and waste is becoming the main priority in palm oil mills. To enhance oil quality and quantity, understanding in oil palm fruit development is necessary to improve harvesting operation. In general practice of mills, fresh fruit bunches (FFB) of different degree of ripeness are received for palm oil processing. Thus, this issue includes effect of various degree of fruit ripeness on oil content of the palm fruits, changes in free fatty acid (FFA) composition and quality of oil extracted. Comparison of results with other oil palm cultivar is also reported.

Conversion of waste, such as oil palm biomass, into value-added product is one of the profitable ways for waste management. Oil palm biomass has great potential to be used as new resources for bio-based materials production. With lignocellulosic content as the main component and suitable treatment process, oil palm biomass can be transformed into valuable substrate for applications in food, chemical and pharmaceutical industries. Hence, an insight review and description of various oil palm biomass treatment processes and discussion on their advantages and disadvantages are highlighted in this issue.

Another highlight in this issue is the emission of particulate matters from palm oil mills. Boilers are known as contributor to air pollution through incineration of fibre, shell and empty fruit bunches (EFB) generating hazardous particulate matters which create environmental issue and affect human health. Therefore, monitoring and control of particulates are of great concern to the country and palm oil industry. This issue presents existing technologies which have been applied in palm oil mills to control emission of...
particulate matter. It also provides options to the millers as alternatives to overcome problems related to particulate matter. The information shared in this issue of *Palm Oil Engineering Bulletin* is expected to encourage the involvement of palm oil millers in improving their mills operation as well as to gain knowledge on new findings which are beneficial to the industry.

**CALL FOR ARTICLES**

Personnel of the palm oil mills are invited to send in articles of relevance to the palm oil industry in Malaysia for publication in *Palm Oil Engineering Bulletin*. By sharing your expertise, you will be helping the industry and the nation as a whole. The topics of interest are:

1. Plant modifications done in your mill that resulted in improvements in milling operation or maintenance.

2. Innovations done in your mill that produced improvements in the operation of the mill and that you are willing to share them with others.

3. Any special work done in your mill that directly resulted in improvements in OER and product quality.

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## MPOB TRAINING PROGRAMME SCHEDULE 2019

<table>
<thead>
<tr>
<th>CODE NO.</th>
<th>COURSES</th>
<th>DATE</th>
<th>VENUE</th>
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<tr>
<td>A1</td>
<td>OIL PALM</td>
<td></td>
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### A1.1 KURSUS & PEPELIKSAAN KEMAHIRAN MENGGREB BUAH SAWIT

| Wilayah Sabah | 19 - 21 Feb | Plasma Lahad Datu, Sabah |
| Wilayah Selatan | 19 - 21 Mar | Kulai, Johor |
| Wilayah Tengah | 16 - 18 April | Selangor |
| Wilayah Sarawak | 18 - 20 Jun | Kuching, Sarawak |
| Wilayah Utara | 2 - 4 July | Perak |
| Wilayah Timur | 16 - 18 July | Terengganu |

### A1.2 INTENSIVE DIPLOMA IN OIL PALM MANAGEMENT AND TECHNOLOGY (IDOPMT)

| Semester 1 | 15 July – 1 Aug | MPOB, Head Office |
| Estate Attachment | 5 – 9 Aug | |
| Semester 2 | 19 Aug – 13 Sept | |
| Semester 3 | 23 Sept– 4 Oct | Convocation: 11 Oct |

### A1.3 KURSUS OPERASI MEKANISASI LADANG (KOML)

| Wilayah Sarawak | 26 – 27 Feb | Sibu, Sarawak |
| Wilayah Timur/Selatan | 23 – 24 April | Kuantan, Pahang |
| Wilayah Utara | 16 – 17 July | Gurun, Kedah |
| Wilayah Sabah | 6 – 7 Aug | PLASMA Lahad Datu, Sabah |
| Wilayah Tengah | 24 – 25 Sept | Port Dickson, Negeri Sembilan |

### A1.4 KURSUS PENGURUSAN DAN PENYELENGGARAAN NURSERI SAWIT

| Wilayah Sarawak | 26 – 27 Feb | Sibu, Sarawak |
| Wilayah Timur/Selatan | 23 – 24 April | Kuantan, Pahang |
| Wilayah Utara | 16 – 17 July | Gurun, Kedah |
| Wilayah Sabah | 6 – 7 Aug | PLASMA Lahad Datu, Sabah |
| Wilayah Tengah | 24 – 25 Sept | Port Dickson, Negeri Sembilan |

### A1.5 KURSUS PENGURUSAN DAN PENYELENGGARAAN NURSERI SAWIT (Kursus Tambahan atas Permintaan Industri 2019)

| Wilayah Sabah (Sawit Kinabalu) | 19 – 20 Feb | Sawit Kinabalu Seeds, Tawau, Sabah |
### A  COURSES

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<td>Kursus Penyelia Bengkel Kilang Sawit</td>
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<td>2.7</td>
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### B  MPOB CONFERENCES AND SEMINARS

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<td>Palm Oil Economic Review &amp; Outlook Seminar 2019</td>
<td>17 Januari</td>
<td>Le Meridien Hotel, Putrajaya</td>
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<td>3</td>
<td>TOT Seminar</td>
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<td>4</td>
<td>GSAS Seminar</td>
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<td>5</td>
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<td>*</td>
<td>KLCC, Kuala Lumpur</td>
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<td>6</td>
<td>PIPOC 2019</td>
<td>19 - 21 November</td>
<td>KLCC, Kuala Lumpur</td>
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Note: *To be confirmed.

For any enquiry or further information, please contact:

Training and Conference Management Unit
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Content and Quality Characteristics of Oil Obtained Under Different Treatment at Various Palm Fruits Ripeness

Nurul Hasimah Kasmin*; Azwan Mat Lazim* and Roila Awang**

ABSTRACT

This study evaluates the chemical changes that occur as oil palm fruits ripen in the bunch in terms of changes in oil content, chemical composition of fatty acid (FA), free fatty acid (FFA), deterioration of bleachability index (DOBI) and carotenes content. Oil was extracted from fruits with different ripeness, using different extraction techniques. It was found that oil content in fruit increased over the ripening period, reaching the maximum oil content of 34.7% in ripe fruit which can be related to the optimal time for fruit harvesting based on colour. Results showed that the main changes in FA occurred in terms of palmitic, oleic and linoleic acids content. Meanwhile, FFA, DOBI and carotenes content increased as oil palm fruits ripen and the value remained nearly constant.

INTRODUCTION

The oil palm has the highest oil yield per hectare of all oil crops and is now one of the top edible oils in the world. In optimal harvest time, oil content of the fruit is between 40.5% while its fibre content is about 20% (Macaire et al., 2010). The amount of crude palm oil (CPO) extracted from the mesocarp of the palm fruit is significantly reduced if the fruits are not harvested at the right stage of ripeness or maturity. According to Tan et al. (2010), oil extracted from fruits harvested five days before ripeness can cause reduction in oil content up to 7.7%. Thus, harvesting fruits at the appropriate time will ensure maximum oil yield and oil of good quality.

* Malaysian Palm Oil Board, 6, Persiaran Institusi, Bandar Baru Bangi, 43000 Kajang, Selangor, Malaysia. E-mail: nurulhasimah@mpob.gov.my
** School of Chemical Sciences and Food Technology, Faculty of Science and Technology, Universiti Kebangsaan Malaysia, 43650 Bangi, Selangor, Malaysia.
In general, mills receive fruits of different degree of ripeness for CPO production. Thus, study in CPO production from fresh fruit bunch (FFB) of different ripeness is needed to increase the understanding of fruit development, which is crucial for optimal harvest. According to the FFB ripeness classification established by Malaysian Palm Oil Board (MPOB), FFB ripeness can be classified into five main classes, i.e. unripe, under ripe, ripe, over ripe and rotten.

The degree of ripeness may be estimated from the physical appearance such as colour, size and texture of the fruits. Colour is the most commonly used for ripeness determinant. Although it may be helpful, this technique has limitation as oil palm from different varieties gives divergent colour. There is very little information or reports regarding the ripeness of fruit based on colour and its relation with fruits ripening. Moreover, information on oil yields of FFB based on ripening of fruits is also lacking. As such, this work was conducted to identify and distinguish the effect of various degree of fruit ripeness in terms of oil content of the palm fruits, changes in FA composition and the quality of oil extracted.

**MATERIALS AND METHODS**

**Determination of Palm Fruit Ripeness**

Oil palm fruits (*Elaeis guineensis* of tenera) of various stages of ripeness were used in the following experiments. As the flowers were not hand pollinated, thus fruit ripeness was estimated based on colour and number of loose fruits present on the ground. Over riped fruits are fruits taken from spikelet of over riped bunch which is harvested when the bunch is orange in colour and there are more than five loose fruits present on the ground. A ripe bunch is defined as a bunch which is harvested when the bunch is orange in colour and there are two to five loose fruits present on the ground. Under riped fruits are from under ripe bunch, harvested without any sign of loose fruit on the ground.

**Processing of Palm Fruitlets**

The palm fruits were sterilised at 90°C for 90 min. The heated oil palm fruits were peeled and the nuts were removed from the mesocarp. The peeled mesocarp was later extracted for its oil by way of solvent extraction.

**Soxhlet Extraction**

The peeled mesocarp was subjected to hexane extraction for 6 hours by using soxhlet extractor, at fruit to solvent ratio 1:4 (w/v). The solvent was then removed from the oil by using rotary evaporator.

**Cold Extraction**

The peeled mesocarp was immersed in hexane for 24 hr at fruit to solvent ratio 1:1.5 (w/v) and later pressed using fruit press expeller. The extraction solution was filtered through a Whatman filter paper. The solvent was then removed from the oil by using rotary evaporator. The oil content of oil palm extract was determined using equation below.

\[
\% \text{ oil content} = \frac{X \times 100\%}{Y} \quad (1)
\]

where, \(X = \text{mass of oil extracted (g)}\)
\(Y = \text{mass of oil palm fruits (g)}\)

Following this procedure, the following mesocarp oils were prepared:
1. Under ripe fruits and soxhlet extraction (US)
2. Ripe fruits and soxhlet extraction (RS)
3. Over ripe fruits and soxhlet extraction (OS)
4. Under ripe fruits and cold extraction (UC)
5. Ripe fruits and cold extraction (RC)
6. Over ripe fruits and cold extraction (OC)

**Physicochemical Analysis of Extracted Oil**

Determination of FFA, DOBI, carotenes contents and fatty acid composition were carried out using *MPOB Test Methods* (2005).
RESEARCH FINDINGS

Oil Content in Fresh Fruits during Ripening of Fruits

Table 1 shows the comparison of oil content in palm fruit from this study and other cultivars reported by Prada et al. (2011). It was found that the oil content increased as fruits ripened, ranging from 16.1% to 34.7%. In this study, it was obvious that ripe fruit showed maximum oil content compared to under ripe and over ripe fruits. Ripe fruits (RS and RC) contain 34.7% and 27.4% oil, while over ripe fruits (OS and OC) contained 30.0% and 25.6% of oil. Under ripe fruit (US and UC) contained only 25.1% and 16.1% oil, respectively. As in agreement with the research reported by Prada et al. (2011), under ripe fruits in this study can be assumed to be 18 week after anthesis (WAA) and ripe fruits 20 to 22 WAA.

According to Prada et al. (2011), lipid synthesis starts at 16 WAA and increased rapidly within the next six weeks. Based on their research, the highest oil content was at 22 or 24 WAA. Thus, Prada et al. (2011) suggested from their study that the maximum lipid accumulation in fresh fruits of Elais guineensis occurred after 20 WAA. Another study reported that commercial tenera palms from Malaysia reached the maximum accumulation of total lipids at 20 WAA, while for Nigeria palms, the accumulation occurred between 18 to 22 WAA (Sambanthamurthi et al., 2000). The trend observed from the results in Table 2 is similar to those observed from Table 1.

Characteristics of Oil Extraction

Table 3 summarises the FA composition obtained in previous studies and the present study. Oils in young fruits contained a higher amount of unsaturated fatty acids than oils from older fruits. Polyunsaturated fatty acids (PUFA) of under ripe fruits obtained in this study were much lower than that reported by Ōo et al. (1987) at 16 to 20 WAA.

TABLE 1. CHANGES IN OIL CONTENT (%) IN FRESH FRUITS DURING RIPENING OF FRUITS

<table>
<thead>
<tr>
<th>Tenera cultivars</th>
<th>12</th>
<th>14</th>
<th>16</th>
<th>18</th>
<th>20</th>
<th>22</th>
<th>24</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Deli x La Me</td>
<td>4.7</td>
<td>6.1</td>
<td>4.6</td>
<td>15.8</td>
<td>29.6</td>
<td>46.6</td>
<td>40.7</td>
<td>Prada et al. (2011)</td>
</tr>
<tr>
<td>Deli x Ekona</td>
<td>3.9</td>
<td>7.9</td>
<td>3.3</td>
<td>13.2</td>
<td>28.1</td>
<td>41.9</td>
<td>39.4</td>
<td></td>
</tr>
<tr>
<td>Deli x AVROS</td>
<td>-</td>
<td>1.0</td>
<td>1.1</td>
<td>8.4</td>
<td>22.9</td>
<td>37.9</td>
<td>43.2</td>
<td></td>
</tr>
<tr>
<td>Malaysia</td>
<td>25.1</td>
<td>16.1</td>
<td>34.7</td>
<td>27.4</td>
<td>30.0</td>
<td>25.6</td>
<td></td>
<td>Present work</td>
</tr>
</tbody>
</table>

TABLE 2. CHANGES IN TOTAL LIPID (OIL) IN MESOCARP DURING RIPENING OF FRUITS FROM DELI x LA ME, DELI x EKONA, AND DELI x AVROS CULTIVARS

<table>
<thead>
<tr>
<th>WAA</th>
<th>Total lipid (g/100 g of fresh mesocarp)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Deli x La Me</td>
</tr>
<tr>
<td>12</td>
<td>6.2</td>
</tr>
<tr>
<td>14</td>
<td>7.8</td>
</tr>
<tr>
<td>16</td>
<td>5.9</td>
</tr>
<tr>
<td>18</td>
<td>20.3</td>
</tr>
<tr>
<td>20</td>
<td>36.3</td>
</tr>
<tr>
<td>22</td>
<td>54.7</td>
</tr>
<tr>
<td>24</td>
<td>49.3</td>
</tr>
</tbody>
</table>

Source: Prada et al. (2011).
### TABLE 3. CHANGES IN MAIN FATTY ACID COMPOSITION (wt % as Methyl Esters) DURING RIPENING OF FRUITS

<table>
<thead>
<tr>
<th>WAA</th>
<th>14:0</th>
<th>16:0</th>
<th>16:1</th>
<th>18:0</th>
<th>18:1</th>
<th>18:2</th>
<th>18:3</th>
<th>20:0</th>
<th>Others</th>
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<tr>
<td>8</td>
<td>1.0</td>
<td>27.5</td>
<td>-</td>
<td>4.4</td>
<td>22.2</td>
<td>24.0</td>
<td>13.6</td>
<td>-</td>
<td>7.3</td>
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<tr>
<td>12</td>
<td>1.0</td>
<td>27.0</td>
<td>-</td>
<td>4.5</td>
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<td>18.0</td>
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<tr>
<td>16</td>
<td>0.4</td>
<td>35.2</td>
<td>-</td>
<td>5.4</td>
<td>42.6</td>
<td>13.9</td>
<td>0.8</td>
<td>-</td>
<td>1.8</td>
<td>Oo et al. (1986)</td>
</tr>
<tr>
<td>20</td>
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<td>40.8</td>
<td>-</td>
<td>5.0</td>
<td>35.9</td>
<td>11.3</td>
<td>0.0</td>
<td>-</td>
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<td>Over ripe</td>
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<td>44.2</td>
<td>-</td>
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<td>12.5</td>
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<td>0.1</td>
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<td>0.8</td>
<td>43.8</td>
<td>0.2</td>
<td>3.5</td>
<td>40.3</td>
<td>11.1</td>
<td>0.1</td>
<td>0.2</td>
<td>-</td>
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<tr>
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<td>39.4</td>
<td>0.2</td>
<td>4.4</td>
<td>41.7</td>
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<td>0.2</td>
<td>0.3</td>
<td>-</td>
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<tr>
<td>22</td>
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<td>0.1</td>
<td>4.7</td>
<td>38.8</td>
<td>10.6</td>
<td>0.1</td>
<td>0.3</td>
<td>-</td>
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<td>14</td>
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<td>29.9</td>
<td>4.5</td>
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<td>33.3</td>
<td>10.2</td>
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<td>4.4</td>
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<td>40.7</td>
<td>1.2</td>
<td>4.7</td>
<td>39.4</td>
<td>13.7</td>
<td>0.4</td>
<td>-</td>
<td>-</td>
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<tr>
<td>22</td>
<td>0.9</td>
<td>44.2</td>
<td>1.3</td>
<td>5.0</td>
<td>37.3</td>
<td>11.6</td>
<td>0.3</td>
<td>-</td>
<td>-</td>
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<tr>
<td>24</td>
<td>1.1</td>
<td>44.9</td>
<td>1.3</td>
<td>4.8</td>
<td>36.8</td>
<td>11.3</td>
<td>0.3</td>
<td>-</td>
<td>-</td>
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<tr>
<td>US</td>
<td>0.8</td>
<td>41.8</td>
<td>-</td>
<td>4.2</td>
<td>44.1</td>
<td>8.9</td>
<td>0.2</td>
<td>-</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>UC</td>
<td>0.9</td>
<td>41.4</td>
<td>0.1</td>
<td>4.2</td>
<td>44.6</td>
<td>8.7</td>
<td>0.2</td>
<td>-</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>RS</td>
<td>1.2</td>
<td>47.1</td>
<td>0.1</td>
<td>4.0</td>
<td>37.3</td>
<td>10.1</td>
<td>0.2</td>
<td>-</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>RC</td>
<td>1.0</td>
<td>44.1</td>
<td>0.1</td>
<td>4.1</td>
<td>40.3</td>
<td>10.2</td>
<td>0.3</td>
<td>-</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>OS</td>
<td>0.5</td>
<td>43.9</td>
<td>0.1</td>
<td>3.4</td>
<td>40.1</td>
<td>11.6</td>
<td>0.4</td>
<td>-</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>OC</td>
<td>0.9</td>
<td>44.5</td>
<td>0.6</td>
<td>3.3</td>
<td>38.6</td>
<td>11.8</td>
<td>0.3</td>
<td>-</td>
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</tr>
</tbody>
</table>

### TABLE 4. CHANGES IN QUALITY OF OIL PALM DURING RIPENING OF FRUITS

<table>
<thead>
<tr>
<th>Parameter</th>
<th>FFA (%)</th>
<th>DOBI</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Under ripe</td>
<td>0.65-1.15</td>
<td>2.45-4.12</td>
<td>Junaidah et al. (2015)</td>
</tr>
<tr>
<td>Ripe</td>
<td>0.89-1.95</td>
<td>0.99-2.96</td>
<td>Junaidah et al. (2013)</td>
</tr>
<tr>
<td>Overripe</td>
<td>1.71-2.43</td>
<td>2.53-6.69</td>
<td></td>
</tr>
<tr>
<td>Loose fruit</td>
<td>3.2-3.6</td>
<td>2.19-2.53</td>
<td></td>
</tr>
<tr>
<td>US</td>
<td>0.76</td>
<td>3.01</td>
<td>Present work</td>
</tr>
<tr>
<td>UC</td>
<td>0.88</td>
<td>3.09</td>
<td></td>
</tr>
<tr>
<td>RS</td>
<td>1.27</td>
<td>4.46</td>
<td></td>
</tr>
<tr>
<td>RC</td>
<td>1.27</td>
<td>4.61</td>
<td></td>
</tr>
<tr>
<td>OS</td>
<td>1.01</td>
<td>3.86</td>
<td></td>
</tr>
<tr>
<td>OC</td>
<td>1.01</td>
<td>4.14</td>
<td></td>
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</tbody>
</table>
Moreover, for both oil extracted, the oleic acid content were higher, ranging from 44.1%-44.6%. A comparison was made with previously reported FA composition. It was found that the main changes in FA occurred in palmitic, oleic and linoleic acids. The results were in agreement with other researchers as reported in Table 3. Prada et al. (2011) reported that PUFA values decreased whereas monoson saturated fatty acids (MUFA) and saturated fatty acids (SFA) values increased during fruit development.

Oil extracted from under ripe, ripe and over ripe fruits show slight difference in the percentage of FFA, DOBI and carotene content. The FFA, DOBI and carotene content of under ripe fruits were lower than ripe and over ripe fruit for both types of extraction. The FFA content in this study ranged from 0.76%-1.27% (Table 4). These results were supported by research done by Junaidah et al. (2015). In this study, low FFA content of under ripe fruits was due to high unsaturated fatty acid levels. DOBI value throughout this study ranged from 3.01 to 4.61 (Table 4). DOBI obtained from this study is in the range of fair to good DOBI grade.

Similar result for DOBI was also recorded by Junaidah et al. (2013). Ripe fruits recorded higher DOBI than under ripe fruits due to the rich and deep orange colour found in ripe oil palm fruits, indicating high carotene content as shown in Table 5. DOBI depends on the carotenes content, but is more affected by oxidation state of the oil. In this study, results showed that the carotenes content was higher when oil was solvent extracted. Table 5 shows carotene contents of CPO extracted from under ripe, ripe and over ripe fruits with carotenes content ranging from 327 ppm to 645 ppm. An increase in concentration of carotenes during ripening of the fruit coincide with the time when lipids were synthesised (Tan et al., 1997; Prada et al., 2011).

**CONCLUSION**

The results of oil content, FA composition, FFA, DOBI and carotenes content of CPO extracted from palm fruits of different ripeness were analyses and compared with CPO extracted from other cultivars. It was found that the oil content present in this study reached maximum values when ripe fruits were harvested. At this stage, oil content in the fruits was between 27.4%-34.7%, major fatty acid being palmitic, oleic, linoleic and stearic acid. Ripe fruits showed higher FFA, carotenes content and DOBI value compared to over ripe and under ripe fruits.

**REFERENCES**


---

**TABLE 5. CAROTENES CONTENT VARIATION DURING RIPENING OF FRUITS (ppm)**

<table>
<thead>
<tr>
<th>Tenera cultivars</th>
<th>WAA 12</th>
<th>14</th>
<th>16</th>
<th>18</th>
<th>20</th>
<th>22</th>
<th>24</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Deli x La Me</td>
<td>7135</td>
<td>536</td>
<td>586</td>
<td>831</td>
<td>573</td>
<td>808</td>
<td></td>
<td>Prada et al., (2011)</td>
</tr>
<tr>
<td>Deli x Ekona</td>
<td>1335</td>
<td>424</td>
<td>756</td>
<td>514</td>
<td>905</td>
<td>1531</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Malaysia</td>
<td>US</td>
<td>UC</td>
<td>RS</td>
<td>RC</td>
<td>OS</td>
<td>OC</td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>356</td>
<td>327</td>
<td>645</td>
<td>593</td>
<td>641</td>
<td>588</td>
<td></td>
<td>Present work</td>
</tr>
</tbody>
</table>


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**ANALYSIS RESULTS**

<table>
<thead>
<tr>
<th>Type of Test</th>
<th>Test Methods</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>pH VALUE</td>
<td>APHA 4500-B</td>
<td>4.73@25.6°C</td>
</tr>
<tr>
<td>Biochemical Oxygen Demand (3 Days @ 30°C), mg/L</td>
<td>DL-LAB-TM01 (based on MN Method 8-22)</td>
<td>48.100</td>
</tr>
<tr>
<td>Chemical Oxygen Demand, mg/L</td>
<td>DL-LAB-TM02 (based on MN Method 0-25; 0-28; 0-29)</td>
<td>78,000</td>
</tr>
<tr>
<td>Ammonial Nitrogen (NH3-N), mg/L</td>
<td>DL-LAB-TM03 (based on MN Method 1-05)</td>
<td>70</td>
</tr>
<tr>
<td>Total Nitrogen, mg/L</td>
<td>DL-LAB-TM04 (based on MN Method 0-88)</td>
<td>590</td>
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<tr>
<td>Oil and Grease, mg/L</td>
<td>DOE (M) Reference Method</td>
<td>13,812</td>
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<tr>
<td>Suspended Solids, mg/L</td>
<td>DOE (M) Alternative Method</td>
<td>24,600</td>
</tr>
<tr>
<td>Total Solids, mg/L</td>
<td>APHA 2540 B</td>
<td>49,750</td>
</tr>
</tbody>
</table>

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Physico-chemical Treatment of Oil Palm Biomass into Applicable Feedstock

Fatiha Ismail*; Noorshamsiana Abdul Wahab*; Nur Eliyanti Ali Othman* and Astimar Abdul Aziz*

INTRODUCTION

The depletion of fossil fuels and natural raw materials has encouraged the search for new resource materials for the production of bio-based materials (Alekhina et al., 2014). Oil palm biomass (OPB) is classified as lignocellulosic residues comprised mainly of cellulose, hemicellulose, and lignin in their cell walls (Raveendran et al., 1995). This lignocellulosic material can be converted into valuable feedstock for the production of biosugar, biocompost, biochemical and bioethanol. Due to the lignocellulosic nature of OPB, countless research and development activities were undertaken by various agencies in order to improve the transformation of OPB into more valuable substrate for producing a variety of chemicals that will have huge potential in food, chemical and pharmaceutical industries. The chemical constituents in OPB varied considerably due to their diverse origins and types (Chew and Bhatia, 2008). The chemical composition of different OPB is shown in Table 1.

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Cellulose forms a major constituent of OPB. Only cellulose and hemicellulose can be converted into fermentable sugars. These lignocellulosic chemicals are reinforced in a lignin matrix similar to that of other natural fibres. Recovery of these components from the OPB requires some kind of pre-treatment. The pathway of different pre-treatments on OPB to extract lignocellulosic chemicals and production of fermentable sugars is shown in Figure 1. A pre-treatment method needed to remove lignin, reduce crystallinity of the cellulose and increase the porosity of lignocellulosic materials in order to make cellulose and hemicellulose more amenable to hydrolysis and fermentation processes that are used to convert these lignocellulosic chemicals to fermentable sugars in higher yield (Moiser et al., 2005; Balat, 2011). Various pre-treatment methods have been developed to extract these lignocellulosic chemicals.

Oil palm biomass were subjected to physico-chemical treatment in order to cleave the cellulosic matrix into individual component for effective chemical or biological process. The increased in surface
area of material would shorten the reaction time, hence the conversion of oil palm biomass into various higher value products is technically feasible and economically viable. Figure 1 illustrates the cleavage of lignocellulosic matrix when subjected to physico-chemical treatment.

**Types of Treatment**

The physico-chemical processes are improvement of existing chemical processes, to reduce reaction time and improve the efficiency of the process. In order to enhance the removal of lignin and increase their efficiency, physical parameters such as pressure and temperature are added to the established chemical pre-treatment. In previous studies, various types of physico-chemical pre-treatments for oil palm lignocellulosic biomass were used. These include pre-treatments such as ultrasonic, microwave, ball milling, superheated and chemical thermo-mechanical. An insight review and description of various treatment processes, and discussion on their advantages and disadvantages are given below:

i) **Ultrasonication process**

Ultrasonic treatment is a relatively newer method in lignocellulosic biomass pre-treatment technology which is more
applicable at laboratory scale. The significant use of ultrasound on lignocellulosic biomass is to enhance the extractability of main component such as hemicelluloses, cellulose and lignin. Pre-treatment using ultrasound enhanced the hydrolysis yields from lignocellulosic biomass. Ultrasonic interactions with lignocellulose for degradation of lignin shows the key ultrasonic effects on lignocellulose. First, ultrasound increased the cleavage of bonds within lignin as well as the bonds between lignin and hemicellulose. The cleavage reactions were enhanced by radicals produced by ultrasound and the shear forces from ultrasonic mixing improved the degradation of polymer (Bussemaker and Zhang, 2013).

According to Asakura et al. (2008), ultrasound is also used to clean cellulosic fibre from used paper and to improve the susceptibility of lignocellulosic materials to biodegradation. In another study, Toma et al. (2007) found that by increasing the accessible surface area and influencing the crystallinity, it can generate a pre-treated substrate to be more easily hydrolysed. Previous research done by Robiah et al. (2010) have found that the ultrasonicated oil palm empty fruit bunch (OPEFB) fibre has achieved maximum xylose yield which occurred at low temperature. Thus, ultrasonication is an emerging and very effective mechanical pretreatment method by disrupting the physical, chemical and biological properties of the lignocellulosic biomass. Figure 2 shows a set-up of ultrasonic treatment for oil palm biomass.

ii) Microwave process

The treatment of biomass using microwaves has been in use since 1970s (Dominguez et al., 2006). The microwave treatment of cellulose and wood has been optimised for the production of chemicals in the synthesis of natural products (Sarotti et al., 2007). Microwave energy can cause a heating effect through ionic conduction where the electric field generates ionic motion causing rapid heating and reduce reaction time (Kappe, 2004). Factors such as starting material particle size, microwave power, irradiation time and source of biomass are all considered to have effect on the efficiency of microwave interactions.

Therefore, many studies have been carried out to investigate the appropriate operational parameters of the microwave pre-treatment in order to optimise the conditions for a further efficient hydrolysis of biomass. In general, the treatment of oil palm biomass commonly uses the microwave assisted-alkaline and microwave-assisted acid treatments. The combined microwave-chemical treatment of different feedstock resulted in higher sugar
recovery. Several chemicals were used in microwave/chemical pre-treatment such as microwave-assisted dilute ammonia (Chen et al., 2012) and microwave-assisted FeCl₃ (Lu and Zhou, 2011). In previous research carried out by Komolwanich et al. (2014), pre-treatment on OPEFB was done using the combination of microwave and NaOH which removed lignin and hemicellulose, thus enhancing the cellulose accessibility during the pre-treatment. In 2005, Guanben and co-workers demonstrated that microwave drying with proper selection of power input, weight of drying material and drying time could increase the drying rate. When compared with the conventional drying methods, microwave drying could save up to 50% of energy and significantly decreases the volatile organic compound emissions. This view is supported by Ethaib et al. (2015) who concluded that although the energy consumption of microwave is relatively higher than that of oven drying, it could save more time and thus the total energy consumed is significantly lower than that of conventional methods. Figure 3 illustrates the working mechanism of microwave process and a photo of actual machine available.

**iii) High-energy ball milling process**

Ball milling has been recognised as one of the proven treatment through its mechanical activation processes. Besides material synthesis, high-energy ball milling is a process to modify the conditions of chemical reactions by changing the reactivity of the solids (mechanical activation - increasing reaction rates, lowering reaction temperature of the ground powders) or by inducing chemical reactions during milling (mechanochemistry). Its function is mainly to increase the surface area of lignocellulosic biomass. During ball milling process, the particle sizes and crystallinity index values of the OPB were significantly reduced with extended ball mill processing time. This indicates that the particle size of treated OPB has been reduced after undergone the ball milling treatment. Zakaria et al. (2014) claims that the yield of glucose and xylose has increased when OPF fibre and OPEFB were pre-treated through ball mill. This makes ball milling a good and economical choice as a preliminary pre-treatment method for a wide variety of lignocellulosic feedstocks. Figure 4 illustrates the rotation of the milling bowl and the beads during the ball milling reaction. Inside a ball mill, the balls move around in a circle movement as the mill turns, crushing the particle into powder form.

**iv) Superheated steam process**

Superheated steam (SHS) is a technology created to convert oil palm biomass into bio-composite material. Through this technology, it can effectively remove hemicellulose from oil palm biomass (OPB) fiber, which leads to surface modification of the fiber. This is because SHS treatment is conducted at high temperature and has a long retention time which causes the removal of cellulose. Previously, Warid et
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al. (2016) conducted a study to optimise the SHS treatment temperature and retention time for three types of OPB fibers which are oil palm mesocarp fiber (OPMF), oil palm empty fruit bunch (OPEFB), and oil palm frond (OPF). The study successfully maintained the cellulose degradation below 5% while the removal of hemicellulose was in the average range of 65%.

SHS can be an advantageous treatment method for oil palm biomass as it is conducted at atmospheric pressure compared to steam explosion. The SHS treatment does not require hazardous chemicals for operation and it is a safe, non-hazardous, green technology. The entire SHS procedure is cost-savvy as it is operated at atmosphere pressure and prevents the abrasive wear and damage of the extruder screw. In addition, Bahrin et al. (2012) have claimed that their research on SHS treatment of OPEFB for fermentable sugars production is the first to be reported. In another major study, Ahamad Nordin et al. (2013) found that the utilisation of SHS for surface modification may contribute to the eco-friendly and sustainable treatment. Figure 4 shows the photo of steam supply control system of the SHS oven.

v) Chemithermomechanical process

The other alternative for pre-treatment of lignocellulosic biomass is via combination of chemical, thermal and mechanical treatments as one treatment process. There are various of treatment methods that can be used for removal of unwanted particles from the surface of OPEFB fibres; heat treatment, chemical treatment and mechanical treatment. The CTMP fractionation process would simultaneously remove lignin and disintegrate the microfibrils of the fibres, hence increasing the surface area of the fibres for the enzymatic saccharification. On the other hand, Rosman et al. (2013) treated the OPEFB using alkali followed by silane treatment and found that the surface treatment of OPEFB fibres increased the compactibility with the matrix, thus producing superior mechanical properties of the reinforced polymer composite.

The modifications of OPEFB fibres treated with sodium hydroxide and succinic acid increased the availability of functional groups through chemical modification and interacted strongly with the matrix polymer to get better interfacial bonding between fibres and
TABLE 2. ADVANTAGES AND DISADVANTAGES OF DIFFERENT TREATMENT METHODS ON OIL PALM BIOMASS

<table>
<thead>
<tr>
<th>Treatment Types</th>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ultrasonic</td>
<td>• Green and sustainable treatment</td>
<td>Partial cleavage of the lignin-carbohydrate matrix</td>
</tr>
<tr>
<td>Microwave</td>
<td>• Less inhibitor formation</td>
<td>High energy consumption</td>
</tr>
<tr>
<td></td>
<td>• High reaction rate and yields</td>
<td></td>
</tr>
<tr>
<td>Ball milling</td>
<td>• Green and sustainable treatment</td>
<td>Partial cleavage of the lignin-carbohydrate matrix</td>
</tr>
<tr>
<td>Superheated steam process</td>
<td>• A cost-effective operation</td>
<td>• Partial disintegration of hemicelluloses</td>
</tr>
<tr>
<td></td>
<td>• Transformation of lignin and hemicelluloses</td>
<td>• Acid catalyst needed to make process solubilisation efficient</td>
</tr>
<tr>
<td></td>
<td>• High yield of glucose and hemicellulose</td>
<td>with high lignin content material</td>
</tr>
<tr>
<td>Chemithermomechanical</td>
<td>• Green and sustainable treatment</td>
<td>• Toxic compound generation in two-step process</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Involve more than two steps for pre-treatment</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Require more reaction time</td>
</tr>
</tbody>
</table>
matrix (Bhat et al., 2011). Zawawi et al. (2015) reported that the effect of pre-treatments on the surfaces of EFB fibres are subjected to thermomechanical pulping (TMP) process. For fibres treated with NaOH, the SEM images showed that the alkali treatment made the fibre surface rougher with less amount of silica bodies (Figure 7). Most of the lignin and small amount of silica bodies were removed resulting in a rough surface. A study carried out by Ariffin et al. (2008) claimed that the combination of physical, chemical and thermal treatments have successfully altered the physical structure and chemical composition of the OPEFB, as well as reducing sugar production. OPEFB treated by chemical treatment followed by thermal is the best treatment for production of reducing sugars as compared to reversed treatment technique.

Summary of Oil Palm Biomass Treatments

The main goal of numerous treatment strategies that have been developed for OPB is to enhance the reactivity of cellulose and to increase the yield of fermentable sugars. The advantages and disadvantages of different treatment methods are listed in Table 2.

CONCLUSION

The important insights of this article is the objective of biomass treatment before biochemical conversion of lignocellulosic biomass into applicable feedstock, i.e. in biofuels and biorefinery applications. The treatment is depended on the choice of the optimum pretreatment process where it is a crucial step in order to enhance and activate the reactivity of cellulose. Therefore, the choice of a treatment method should also focus on important parameters such as economic viability and environmental impact, and not only on its potential yield.

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LuengnaruemitchaI, A and Wongkasemjit, S (2014). Comparative potentiality of Kans grass (Saccharum spontaneum) and Giant reed (Arundo donax) as lignocellulosic feedstocks for the release of monomeric sugars by microwave/chemical pretreatment. J. Cellulose, 21(3): 1327-1340.


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CEREX Metering Pump Type P

**Features:**
- API 675 compliance
- Hydraulic Actuated Double PTFE Diaphragm
- Diaphragm condition monitoring with pressure gauge
- Double ball check valves
- NPT OR Flange connections
- Liquid-wetted metallic material SS316 or higher
- Manual linear stroke adjustment from 0 to 100%
- Motor suiting safe area or hazardous area
- Standard paint system

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- Palm Oil Refinery and Oleochemicals
- Boiler Feed Water Treatment
- Oil & Gas Additives Dosing
- Industrial Water and Waste Water Treatment
- Chemicals Dosing

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**Features:**
- Capacity up to 600m³/hr (360 CFM) special range for palm oil industry application.
- Vacuum Level up to 33 mabrA
- Material of construction available in SS316, SS304, Bronze and Cast Iron.
- Come with reinforced stainless steel shaft and sealed bearing
- Can provide 20,000 hours of maintenance-free operation
- Pedestal design, accepts most C-Faced motors

**Applications:**
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- Vacuum system for drying, bleaching and neutralisation process

Model: NASH 2AV2 110 ~ 161

Water in Oil Monitor EASZ-2

**Features:**
- Highly accurate measuring system up to ± 0.05% with response time 1s
- Digital RS485 and analogue 4 - 20 mA communication
- CE Compliant
- Ingress protection IP66
- ATEX available (EASZ - 2Ex - For Hazardous Areas)
  II 1/2 G Ex ia/ib IIC T4 Ga/Gb
- High visibility OLED display and LED status background
- Sensor pipe all in 316 stainless steel
- A wide range of pipe sizes, pressure ratings and connection options available: Threaded G½" - G3", Flanged 1" - 48", PN10 - PN40 (150 - 1500 ANSI)

To monitor water in oil in order to prevent loss of revenue by averting potential problems such as, additive depletion, oil oxidation, corrosion, reduced lubricating film thickness, accelerated component wear rates and microbiological growth.
INTRODUCTION

The Malaysian palm oil industry is a large sector contributing to the economic growth of the country. As the world’s second largest palm oil producer with millions of hectares of plantations, approximately 20 million tonnes of crude palm oil (CPO) was produced in 2014 from 439 palm oil mills (MPOB, 2014). As a result, the palm oil industry is identified as a major contributor to water and air pollution. The sources of air pollution in the palm oil mills are mainly from boilers using fibres and shells as fuel, and incinerators burning empty fruit bunches (Abdullah et al., 2007).

The main pollutants in boiler exhaust emission are particulates together with small amount of carbon monoxide (CO), nitrogen oxide (NO) and traces of sulphur gases, which are harmful to the environment and community’s health. Therefore, monitoring and control of these pollutants particularly particulates are of great concern for the country. Particulates exist in the form of smoke and dust emissions originated from incomplete combustion of solid waste materials (DOE, 1999).

Particulate emission has gained serious attention from local authorities since most of the palm oil mills in Malaysia are constructed in rural areas. As time goes on, the residential areas gradually expand to the suburbs until these areas spread to the vicinity of the industrial area. With the formation of a phenomenon called urban heat island, the emission of particulate matter from the palm oil mills remained suspended within the low level of air turbulence and thus hindering vertical motion for pollutants dissipation. Under this blanket layer, the accumulated particulate matter begins to grow in size. As relative humidity is more than 70%, the coagulated particles start to scatter sun rays which in turn impair visibility causing opaque atmosphere known as haze. Apart from that, particulate matter is also capable of damaging respiratory system of animals and human being.

According to the record obtained from the Department of Environment (DOE) for the entire country between 1993 until 1998, it was found that the emission of particulate from industrial processes were the largest contributors to pollution. In those six years, the highest amount of particulate emission from industrial processes was recorded in...
1994 at 85.54% of total particulates produced in that year which is equivalent to 153,890 metric tonnes. The second highest emission of particulate matter came from industrial fuel used in palm oil mills (Abdullah et al. 2007).

The main objective of the Environment Quality (Clean Air) Regulations 1978 was to prevent, abate and control air pollution as well as to enhance the quality of the environment while allowing development to progress in an environmentally friendly way. The control of black smoke emission comes under Regulations 15 and 16, while the maximum limit for dust emission/particulate is 0.4 g Nm$^{-3}$. This limit remained unchanged for the last 30 years, and the DOE is currently in the process of implementing more stringent regulations regarding particulate emission not exceeding 0.15 g Nm$^{-3}$. The existing dust control system such as multicyclone, can only cope with the existing boiler operation and managed to control particulate matter in the range of 0.32 to 0.46 g Nm$^{-3}$. Therefore, it is essential to study the palm oil mill management control, combustion and boiler control, and more efficient dust control system in order to comply with the stringent regulation on particulate matter emission.

**Existing Technologies in Palm Oil Mills to Control Particulate Matter Emission**

Boilers and incinerators are the two sources of particulate emission from palm oil mills. Boilers utilise palm oil fibres and shells as fuels, while incinerators burn empty fruit bunches (EFB) for recovery and use of potash as fertiliser substitute (DOE, 1999). Boilers air emission mainly appear as dark smoke due to the presence of soot following the incomplete combustion of biomass fuels. Several degrees of control of fuel combustion and smoke emission are currently accomplished for steady-state conditions for boilers.

There are a few control measures comprising the use of appropriate indicative boiler instrumentations, automated fuel feed, and boiler modifications. These modifications involve prevention of air leakage from the boiler furnace door, large capacity of draught fans to increase air injection, installation of air nozzles for secondary air supply, replacement of manual with automated fuel feed and improved pollutant dispersion by increasing stack height. The reduction of particulate emission is also feasible through utilisation of control devices and dust collectors.

Among the control devices used in the palm oil mills as shown in Figure 1 are (a) cyclone separators, (b) bag filters and (c) wet scrubbers. Each device applies different mechanical means of collecting dust in the air emission system before being released into the environment. The most commonly applied technology in the mills is cyclone separators which is more reliable in the long run for palm oil mill operations, with high efficiency and less maintenance (PlasTEP, 2011).

Cyclone and multi-cyclones are the most basic form of external particulate emission control for combustion chamber and heat exchanger of boiler. Particulates are removed through centrifugal forces and gravity (Wakefield, 2013). On the other hand, flue gases pass through fine woven media inside the bag filters where particulates are retained by impingement and located in local exhaust ventilation systems. Wet scrubbers, however, have different mechanism in operation unlike the two dry collectors. They filter particulates via impingement with water droplets (Dauber et al., 2017).

Cyclones or multi-cyclones are popular devices used in the industry primarily because they occupy relatively small spaces compared to other devices, and able to tolerate high-temperature exhaust flue gas compared to bag filters which have certain limitations depending on the type of fabric made (Turner, 1998). Besides that, bag filters are usually additional devices added after a pre-cleaning device like the cyclone. They also require additional fan power due to
high pressure drop across the filter media, and occupy a large space area. However, fine-dust-removal efficiency of cyclones is typically below 70%, whereas electrostatic precipitator (ESP) and bag filters can have removal efficiency of more than 99.9% (World Bank Group, 1998). Hence, cyclones are generally used as the first-stage cleaning device before subsequent processes are done to further improve the final exhaust emissions.

Technologies Advancement

Recent years have seen numerous technologies advancements in relation to particulate reduction. Some reuse the fundamental principle of technology such as hurricane/recyclone, while others come up with latest process such as electrostatic precipitator (ESP) to facilitate the reduction of harmful emission.

Cyclone-based Technology

Dry particulate reduction technology, such as cyclone, utilises the fundamental idea of gravity and vortex to separate the particles from flue gas stream. The flue gas is forced to change direction through a cylinder casing which creates a centrifugal force drawing particles towards the wall of the cyclone. Inertia of the particles causes them to remain in the original direction and be separated from the gas stream. When particulate matter hit the wall, it loses velocity and lifted, and thus falls into a collection hopper at the bottom of the cylinder unit (Habib, 2017). Clean air exits the top of the unit flowing upward in a spiral vortex.

Palm oil mills utilise this technology as basis for the application of multi-cyclone units to reduce particulates emissions. The multi-cyclones incorporate many cyclones in one device for successive reduction of particulates through each unit of cyclone until the targeted air quality is achieved. However, the device is still very inefficient in reducing particulate matter compared to more expensive method such as bag filters.

A modification of the existing multi-cyclones was carried out by Chong et al. (2013) as shown in Figure 2, which focused on recirculation of duct partially extracted flue gas from the bottom of the multi-cyclones by means of an external induced (ID) fan. The fan was utilised to create a slightly negative pressure at the dust hopper, and thus increase the collection of particulates. It also extracted part of the particulates back into the inlet of the multi-cyclones Chong et al. (2013).

A new technology called Hurricane or ReCyclone has been introduced and explored. This system is said to be contrary to the traditional claim that cyclones are inefficient dust collectors and able to replace bag filters in many demanding operating processes (Advanced Cyclone Systems, 2014). It is also more efficient than the common multi-cyclone systems, and has lower operational costs compared to bag filters. Researchers have been investigating how cyclones work, culminating on how particle agglomeration affect the efficiency of particle collection (Paiva et al., 2010).

This system assists in building efficiency...
Hurricane system as portrayed in Figure 3(a) features higher efficiency than traditional cyclones, down to 10%-20% of the emissions of cyclones, very low emissions (25-45mg Nm^{-3}) with no temperature restriction while maintaining the robustness and low cost of the cyclone system. Meanwhile, ReCyclone as shown in Figure 3(b) showcases a system made up of a hurricane and a particle separator in the form of a straight-through cyclone which is placed at the downstream of the cyclone called recirculator.

Hurricane has been invented to give insights on particle agglomeration, while ReCyclone system has been built based on the technology. The main purpose of the recirculator in a ReCyclone system is to reintroduce the fine particles that are not captured back into the cyclone after they have been driven to the outer walls of the recirculator by centrifugal forces. This is accomplished through an additional fan since the tangential gas stream is enriched in...
particles which means the axial gas stream exhaust to the stack is free from particles (Advanced Cyclone Systems, 2014).

Since recirculation system only separates instead of collecting dust, the particles are exclusively collected in the cyclone and the need of rapping mechanisms is thus avoided. The ReCyclone system has very high efficiency due to recirculation and agglomeration of very small particles with larger particles coming directly from the process. It decreases the emissions of Hurricane cyclones by 40% to 60%. The system is robust with almost zero maintenance and downtime cost as well as low in operational and investment cost due to absence of temperature restriction and moving part that requires frequent replacement.

**Electrostatic Precipitator (ESP)**

An electrostatic precipitator (ESP) is a particle control device that uses electric fields to separate particles from the gas stream to the collector plates from which the particles can be removed (Biomass Energy Resource Center, 2011). The first commercial ESP was a wet ESP installed in 1907 for acid mist control, while the first dry ESP was commercialised in 1910’s in non-ferrous metals and cement industry (Seetharama et al., 2013). While the wet and dry ESP retain similar high voltage and collection system and also share similar physical characteristics, there are many inherent differences attributed mainly to the existing design of technology for various size particles. Figure 4(a) shows the wet ESP, while Figure 4(b) illustrates the dry ESP. The wet ESP uses similar working principle as the dry ESP, but it is specifically developed to achieve high yield for water-soluble aerosols, which are more difficult to separate using dry ESP (EMIS-VITO, 2015). Table 1 summarises the differences between these two types of ESPs.

Research performed by Yang et al. (2000) incorporated a wet tubular ESP which has perforated plates to ensure even distribution of gas flow across the entire cross section of the wet tubular ESP tower. Figure 5 shows the schematic layout of the system (Yang et al., 2000). Results from the setup and testing showed 63% reduction in particulate matter.

Another study reported by Manuzon et al. (2014) used CFD simulation to design and develop an optimised ESP based on previous studies. The ESP unit was tested in a mechanically ventilated poultry layer facility housing 200 000 layer hens and the resulting particulate matter showed reduction of more than 80%. Figure 6 illustrates the optimised ESP design and ESP module.

**RESEARCH RECOMMENDATIONS**

Even with the advancement in technologies, there is still lack of sufficient experimental data to show the effect of utilising these devices in palm oil mills. There are many factors that may affect the final emission from these devices if and after implementation. While Hurricane and ReCyclone system are perceived to reduce particulate emission, real data in application of these systems in palm oil mills to support the claims are not yet available. This is similar with ESP where most studies are only involved in coal power plants or similar systems. In fact, ESP is the dominant technology currently applied in coal-fired power plants in Alberta which achieve 99.9% particulate removal (Chambers, 2006).

It is of interest to set up, test and further improve current technologies so that palm oil mills may achieve the new emission standards to be imposed by the DOE. It would even be more appealing to combine the two technologies for the palm oil industry in Malaysia to achieve that goal.

**CONCLUSION**

Several technologies have been discussed in this article and it is found that bag filters and scrubbers are able to achieve high particulate removal from flue gas emission. On the other hand, the selection of cyclone systems is due to robustness and low costs.
Figure 4. Electrostatic precipitator; (a) Wet ESP and (b) Dry ESP.

TABLE 1. DIFFERENCES BETWEEN DRY AND WET ESP

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Dry ESP</th>
<th>Wet ESP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Purpose</td>
<td>Primary PM control device</td>
<td>Polishing device</td>
</tr>
<tr>
<td>Location</td>
<td>First APC device</td>
<td>Last APC device</td>
</tr>
<tr>
<td>Configuration</td>
<td>Horizontal plate</td>
<td>Vertical tubular or Horizontal/ vertical plate</td>
</tr>
<tr>
<td>Humidity</td>
<td>5-20%</td>
<td>100%</td>
</tr>
<tr>
<td>Temperature</td>
<td>120°C-425°C</td>
<td>&lt;150°F (&lt;65°C)</td>
</tr>
<tr>
<td>High PM loading</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>FPM10 removal</td>
<td>High</td>
<td>Limited</td>
</tr>
<tr>
<td>FPM2.5 removal</td>
<td>Moderate</td>
<td>High</td>
</tr>
<tr>
<td>PM condensable removal</td>
<td>No</td>
<td>High</td>
</tr>
<tr>
<td>H₂SO₄ removal</td>
<td>No*</td>
<td>High</td>
</tr>
<tr>
<td>Mercury removal</td>
<td>No*</td>
<td>Moderate</td>
</tr>
<tr>
<td>SCA</td>
<td>300-800</td>
<td>50-200</td>
</tr>
<tr>
<td>Gas velocity</td>
<td>3-5 feet/sec</td>
<td>6-10 feet/sec</td>
</tr>
<tr>
<td></td>
<td>0.9-1.5 m/sec</td>
<td>1.8-3.0 m/sec</td>
</tr>
<tr>
<td>Pressure drop</td>
<td>&lt; 2 in.w.c. (0.5 kPa)</td>
<td>&lt; 2 in.w.c. (0.5 kPa)</td>
</tr>
<tr>
<td>Water usage</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Waste water treatment</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Resistivity issue</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Back corona</td>
<td>Possible</td>
<td>No</td>
</tr>
<tr>
<td>Re-entrainment</td>
<td>Possible</td>
<td>No</td>
</tr>
<tr>
<td>Materials of construction</td>
<td>Carbon steel</td>
<td>Stainless steel, minimum</td>
</tr>
<tr>
<td>Cost</td>
<td>Low/moderate</td>
<td>Moderate/high</td>
</tr>
</tbody>
</table>

Note: Unless treated with sorbent injection; PM = particulate matters; APC = air pollution control.
Figure 5. Schematic layout of wet tubular electrostatic precipitator.

Figure 6. (a) Optimised wire-plate ESP design, and (b) ESP module.
Nevertheless, new design of cyclones has been invented to overcome the low efficiency of existing cyclones compared to other technologies based on research that have been done. Electrostatic precipitator (ESP) is also found to remove dust and ashes significantly between 60% to 90% from the particulate emission.

REFERENCES


INTRODUCING NEW EFB BOILER FUEL FIBRE PRESS

- **NEW MODEL**
  - KH-777-8

- **FUNCTION**
  - A Single Step machine for Press and Cut

- **CAPACITY**
  - 6-8MT of EFB/Hour

- **MOISTURE CONTENT**
  - 38% - 45% (after press)

- **OIL CONTENT IN FIBRE**
  - 1% - 1.5% on sample (wet basis)

- **FIBRE LENGTH**
  - 1”-6” long (after press) for boiler fuel preparation

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- OIL CONTENT IN FIBRE
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  1"-6" long (a/f ter press) for boiler fuel preparation

- FUNCTION
  A Single Step machine for Press and Cut

- NEW MODEL
  KH-777-8

- MOISTURE CONTENT
  38% - 45% (a/f ter press)

- CAPACITY
  6-8MT of EFB/Hour

- HIGHER CAPACITY
  Up to 35MT/day for 1st Press and 22MT/day for 2nd Press

- MAINTENANCE FRIENDLY
  Easy to dismantle in shorter time

- BETTER WORKING ENVIRONMENT
  With the new body design, the machine is tested to be Low Noise and Low Vibrations

- COST SAVING
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DESLUDGING & DEWATERING

<table>
<thead>
<tr>
<th>Dimension (mm)</th>
<th>5100(L) x 2525(W) x 2560(H)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power Consumption (hp)</td>
<td>8</td>
</tr>
<tr>
<td>DS Standard Treatment Capacity</td>
<td>390–480 kg/hr</td>
</tr>
<tr>
<td>Influent Treatment Capacity</td>
<td>15–30 m³/hr</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Belt Width (mm)</th>
<th>1500</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power Consumption (hp)</td>
<td>5</td>
</tr>
<tr>
<td>DS Standard Treatment Capacity</td>
<td>180–308 kg/hr</td>
</tr>
<tr>
<td>Inlet Capacity (S.S. 1.5%-2.5%)</td>
<td>12–20.5 m³/hr</td>
</tr>
</tbody>
</table>

PREVENTIVE MAINTENANCE PROGRAM

A software that assist maintenance team to operate, control and monitor the maintenance management. To verify the regulatory compliance and produce reports and summaries for all maintenance activities, scheduling maintenance program.

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- Increase profits
- Improve control
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- The dust laden flue gas flows through a system which consists of collecting electrodes and discharge electrodes.
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- The charged dust particles will migrate to collecting electrodes and dust layer will accumulated and formed.
- The accumulated dust layer will remove to the hopper by the rapping system.

SOLID REMOVAL & OIL RECOVERY SYSTEM

Recover over 75% of Oil Loss in Raw Sludge

COD/BOD of discharge is reduced by 65% to 75%. Increase Oil Extraction Rate (OER) of mill 0.4% - 0.6%.
SOPHISTICATED SIMPLICITY

High Efficiency Dust Collectors for Biomass Boilers
Erratum to:
Data on Biomass Boilers

Ir Ravi Manon*

The following data on biomass boilers were gathered and published in PIPOC 1999 by John de Kock and David Yap of Flosep Sdn Bhd. These data should be of interest to those who would like to venture into designing devices for trapping particulates to meet with the emission level of 0.15 g Nm$^{-3}$.

TABLE 1. FLUE GAS CHARACTERISTICS IN A TYPICAL PALM OIL MILL BOILERS

<table>
<thead>
<tr>
<th>Description</th>
<th>Units</th>
<th>Study 1(a)</th>
<th>Study 1(b)</th>
<th>Study 2</th>
<th>Study 3</th>
<th>Study 4</th>
<th>Study 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Boiler Capacity</td>
<td>t hr$^{-1}$</td>
<td>27</td>
<td>27</td>
<td>11</td>
<td>18</td>
<td>13.6</td>
<td>13.6</td>
</tr>
<tr>
<td>Steam turbine output</td>
<td>kW</td>
<td>640</td>
<td>650</td>
<td>290</td>
<td>480</td>
<td>n/a</td>
<td>300</td>
</tr>
<tr>
<td>Inlet dust load</td>
<td>g Nm$^{-3}$</td>
<td>3.98</td>
<td>3.2</td>
<td>4.3</td>
<td>3.8</td>
<td>2.76</td>
<td>1.49</td>
</tr>
<tr>
<td>Outlet dust load</td>
<td>g Nm$^{-3}$</td>
<td>1.95</td>
<td>0.24</td>
<td>1.7</td>
<td>1.15</td>
<td>0.52</td>
<td>0.24</td>
</tr>
<tr>
<td>Inlet particle size</td>
<td>D$_{v,0.5}$</td>
<td>40.92</td>
<td>44.88</td>
<td>38.41</td>
<td>56.7</td>
<td>46.43</td>
<td>38.24</td>
</tr>
<tr>
<td>Outlet particle size</td>
<td>D$_{v,0.5}$</td>
<td>36.8</td>
<td>4.48</td>
<td>n/a</td>
<td>34.4</td>
<td>8.53</td>
<td>4.11</td>
</tr>
<tr>
<td>Type of dust collector$^1$</td>
<td>MULTI CYCLONE</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>FLOSEP TAS50</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>MULTI CYCLONE</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>MULTI CYCLONE</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>FLOSEP TAS100</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>FLOSEP TAS50</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Emission factor</td>
<td>kg t$^{-1}$</td>
<td>3.25</td>
<td>0.4</td>
<td>3.026</td>
<td>1.5</td>
<td>0.65</td>
<td>0.42</td>
</tr>
</tbody>
</table>

All dust collectors in this study were single stage.

* Ravindranathan Palmtech Solutions
  No. 77 Jalan 22/37
  47400 Petaling Jaya, Selangor
  E-mail: nravimenon41@gmail.com
# TABLE 2. BOILER FLUE GAS CHARACTERISTICS UNDER DIFFERENT CONDITIONS

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Units</th>
<th>Normal Condition</th>
<th>Overload Condition</th>
<th>Racking in Progress</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Inlet</td>
<td>Outlet</td>
<td>Inlet</td>
<td>Outlet</td>
</tr>
<tr>
<td>Flue gas temperature</td>
<td>°C</td>
<td>214</td>
<td>167</td>
<td>236</td>
</tr>
<tr>
<td>Dust concentration</td>
<td>g Nm⁻³</td>
<td>1.75</td>
<td>0.40</td>
<td>2.60</td>
</tr>
<tr>
<td>Moisture content</td>
<td>% V/V</td>
<td>7.40</td>
<td>7.35</td>
<td>7.96</td>
</tr>
<tr>
<td>Particle size (median)</td>
<td>µm</td>
<td>52.02</td>
<td>6.66</td>
<td>6.89</td>
</tr>
<tr>
<td>Below 10 µm</td>
<td>% Mass</td>
<td>7.90</td>
<td>64.3</td>
<td>57.60</td>
</tr>
<tr>
<td>Below 1 µm</td>
<td>% Mass</td>
<td>0.64</td>
<td>18.2</td>
<td>15.20</td>
</tr>
</tbody>
</table>

The original article was published in *Palm Oil Engineering Bulletin, Issue No. 127* (Apr – Jun 2018). Unfortunately, the original version of this article contained errors. Data for flue gas characteristics in a typical palm oil mill boilers were previously incorrect. The correct data are shown as above.
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Rohaya M Halim  Tel: 03-8769 4457 • Lim Soo Chin  Tel: 03-8769 4676
E-mail: milleng@mpob.gov.my

Advertising Schedule for MPOB Palm Oil Engineering Bulletin

<table>
<thead>
<tr>
<th>Issue</th>
<th>Quarter</th>
<th>Deadline for Registration</th>
<th>Deadline for Submission of Artwork</th>
</tr>
</thead>
<tbody>
<tr>
<td>131</td>
<td>Apr - June 2019</td>
<td>28 April 2019</td>
<td>31 May 2019</td>
</tr>
<tr>
<td>132</td>
<td>July - Sept 2019</td>
<td>31 July 2019</td>
<td>30 Aug 2019</td>
</tr>
<tr>
<td>134</td>
<td>Jan - Mar 2020</td>
<td>31 Jan 2020</td>
<td>27 Feb 2020</td>
</tr>
</tbody>
</table>

REPLY-SLIP

Rohaya M Halim/Lim Soo Chin
Engineering and Processing Division
Palm Oil Engineering Bulletin
Malaysian Palm Oil Board (MPOB)
6, Persiaran Institut
Bandar Baru Bangi
43000 Kajang, Selangor

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Tel: 03-8769 4400     Fax: 03-8926 2971

Rohaya M Halim   Tel: 03-8769 4457  or  e-mail: rohaya@mpob.gov.my
Lim Soo Chin          Tel: 03-8769 4676  or  e-mail: milleng@mpob.gov.my

REPLY SLIP

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Engineering and Processing Division
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Boiler suppliers  Heat exchanger  Steam turbines/generators/spares
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Signature: ____________________________
Name: _______________________________
Date: _______________________________

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The Editorial Board
Palm Oil Engineering Bulletin
Malaysian Palm Oil Board
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Malaysia
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<th>ADVERTISEMENT PACKAGES</th>
</tr>
</thead>
<tbody>
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<td>Platinum</td>
<td>1. Souvenir Programme Book</td>
</tr>
<tr>
<td>Three patrons</td>
<td>2. Mini Programme Book (Pocket Size)</td>
</tr>
<tr>
<td>Gold</td>
<td>3. Notepad</td>
</tr>
<tr>
<td>Unlimited</td>
<td>4. Conference Bag</td>
</tr>
<tr>
<td>Silver</td>
<td>5. Lanyard</td>
</tr>
<tr>
<td>Unlimited</td>
<td>6. Pen</td>
</tr>
<tr>
<td>Bronze</td>
<td>7. Banner/ Hanging Sign</td>
</tr>
<tr>
<td>Unlimited</td>
<td>8. Golf Tournament Merchandise</td>
</tr>
</tbody>
</table>

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