Palm fiber and nut separation by air classifier system

Ahmad Hafizuddin Zakaria\textsuperscript{1,a}, Mohamad Amran Mohd Salleh\textsuperscript{1,2,b}, Mohd Halim Shah Ismail\textsuperscript{1,2} and Mustafa Kamal Abdul Aziz\textsuperscript{3}

\textsuperscript{1}Chemical Engineering Department, Universiti Putra Malaysia  
\textsuperscript{2}Institute of Advanced Technology, Universiti Putra Malaysia  
\textsuperscript{3}Center of Lipids Engineering and Applied Research, Universiti Teknologi Malaysia

\textsuperscript{a}arfizz@gmail.com, \textsuperscript{b}asalleh@upm.edu.my

ABSTRACT
Air classification to separate mesocarp fibers and nuts has been used in the palm oil industry to replace manual separation. However, the design of the air classifier in the palm oil mill usually based on know-how and lack scientific data to support. This study attempt to establish relationship between parameters in the operation of air classifier. The result show direct relationship between air velocity and efficiency of separation. This preliminary study will create a foundation for improved understanding in the fundamental of air classification and improve its design efficiency.

Keywords: Air classification, Palm fiber and nuts, Air velocity.

1. Introduction

Oil palm fiber is general terms for fiber being extracted from oil palm. Oil palm fiber can be further classified EFB (empty fruit bunch) fiber, shredded fiber, oil palm fruit mesocarp fiber as well as oil palm trunk fiber (Hoong Chan Trading, 2009). In crude palm oil mill, fresh fruit bunch is received to be processed. After bunch sterilization process, palm oil bunch will go through a fruit detachment where threshing process is conducted to separate palm fruit lets and EFB (Maycock, 1985).
Fig. 1 Palm fruit layer

Fig. 1 showed the palm fruit figure and the position of the mesocarp that covered fruit nuts. In the palm fruit oil extraction processes, mesocarp and palm kernel nut is the left byproduct which is then separated from palm kernel nut by separation process. Mesocarp fiber is elongated cellulose with 30 – 50 mm length with constitute 15.7% of FFB. Mesocarp fiber has shorter fiber length then shredded EFB fiber and usually used for fuel, matters fiber board, cushion and carpet. Fig. 2 shows overview of palm oil processing (Ologunagba et al., 2010).

Palm kernel nut contain highly kernel oil will be cracked down to kernel and kernel shell. The kernel will be extracted for kernel oil and kernel shell will become by product for this process. Palm kernel oil widely used in manufacturing of soap, toiletries, surface active ingredient, baking coatings, whipped creams and sugar confectioneries (Owolarafe et al., 2005).

Fig. 2 Palm Oil Processing Diagram

Fig. 3 show mixture mesocarp and nuts after palm fruits pressing process. To get all the palm fiber mentioned before, the mesocarp and palm kernel nut will go through fiber and nut process separation. The mesocarp fiber can be separated from palm kernel nut by the air classifier separation machine. The current issue and difficulties that have been faced by the
industry is the inefficient of separation. The current standard parameters that have been set up on the air classifier machine are believed one of the main factors that contribute to the inefficient result. This is due to lack of fundamental understanding of air classification process. This study will examine the relationship between air velocity and separation efficiency of fiber and nuts in air classification process.

![Fig. 3 The mixture of fiber and nuts (with cracked mix)](image)

### 1.1. The air classifier

Air Classifier is industrial equipment which can sort materials by size, shape and density. The process works by injecting material stream that must be sorted into a chamber which contain column of rising air. Inside the separation chamber, air drag on the objects result in the upward force which counter the force of gravity and lift the material if the upward force is greater than the gravitational force (Owolarafe et al., 2005). Air classifiers are commonly employed in industry process where large volumes of mixed material with different physical characteristic need to be sorted quickly and efficiently. Figure 4 shows the simplified schematic of an air classifier.

### 2. Material and method

#### 2.1 Industrial air classifier prototype

In this study an industrial air classifier prototype is used to find the relation between the different velocity levels, discharge opening, temperature, separation time and percentage of separation. Current prototype has the maximum of air velocity of 11 m/s, maximum of 45°C of temperature at full speed and fixed discharge opening. It was built and design by Sawipac Sdn. Bhd one which is one of the machine manufacture for palm oil industry in Malaysia. Fig. 5 show the actual rigs in the study.

The study was conducted in University Putra Malaysia laboratories. This industrial prototype mainly consist of the blower to generate the air flow through the separation column, heater rod located at the bottom of the prototype machine where its deliver the temperature to the air separation column through the air flow, a controller box which design to control the blower speed and the temperature. To attain a fully developed flow in the separation column, the distance from bottom to the top of discharge opening was 12050mm. A 2500mm2 and
9150mm long clear column was used. The transparent air separation column provides a good visibility when fiber separation process takes place. To ensure no obstacle to the air flow during experiment, the discharge opening will be left wide open because any particle or material that left on the discharge opening area will disturb the air flow.

![Air classifier schematic](image)

**Fig. 4 Air classifier schematic**

![Industrial prototype of air classifier photo](image)

**Fig. 5 Industrial prototype of air classifier photo**

### 2.2 Separation of fiber and nuts

The mixture of palm fiber and nuts was produced at local palm oil mill by using the press mechanism. The palm fruit will be undergoing the sterilizer, stripper and digester process.
before it can be pressed to gain the oil (Owolarafe et al., 2005). Usually the initial moisture content of this fiber is around 40% (Maycock, 1985). The fiber and nuts were weighed to 50 grams and put into plastic bags. Each experiment was repeated 3 times. The control panel of the industrial air classifier prototype was used to control the air velocity. An initial velocity was set at 5 m/s. The percentage of separation is calculated by the weight of leftover fiber from original. The air velocity was measured using a calibrated hand-held anemometer (AVM-07, Prova).

2.3 Terminal velocity
Terminal velocity is the maximum falling down velocity of an object or material. If the upward air classification velocity is the same as terminal velocity, the material will float [http://en.wikipedia.org/wiki/Terminal_velocity]. In this study if the air classifier velocity is larger than the terminal velocity of fiber or nuts, they will leave the reactor at the top. To provide efficient separation, the velocity chosen must be higher than fiber terminal velocity but lower than nuts terminal velocity (Tejas et al., 2012).

2.3.1 The density
To obtain accurate terminal velocity of palm mesocarp fiber and kernel shell, the density of each particle has to be measured. Because of properties of kernel shell that have significant volume, the traditional method to obtain its volume will be applied by putting the kernel shell inside the cylinder measurement that contain certain amount of water where the difference between the initial and final water level is equal to the object volume. As for the mesocarp fiber, the physical characteristic of each individual mesocarp fiber that had fine and light weight is impossible to submerge into the water to obtain its volume. So another approach is applied to ensure the volume can be obtained from the mesocarp fiber. In this study the mesocarp fiber volume are determined by using ellipsoid approximation. Based on 2-D image that was captured, the estimated dimension was calculated after length and major and minor diameter is measured (Cassandra et al., 2012).

\[ V_{\text{ellipsoid}} = \pi \times \frac{L \times D_1 \times D_2}{6} \]  

Where \( V_{\text{ellipsoid}} \) is volume of mesocarp fiber, \( L \) is a mesocarp fiber length, \( D_1 \) and \( D_2 \) are major and minor diameter.

After collecting all the sample palm mesocarp fiber and kernel shell volume, the sample now can be estimated by using equation (2).

\[ P_s = \frac{m}{V} \]  

Where \( P_s \) is object density, \( V \) is object volume and \( m \) is object mass which we measured by using weight apparatus that available in the lab.
2.3.2 Object free fall

Object speed, \( v \) is measure by using object free fall test where the selected object will be drop to the ground from a certain height. To ensure an accurate time recording a camera is used to record the experiment. Then the experiment result will be applied into equation (3).

\[
v = \frac{d}{t}
\]  

(3)

Where \( v \) is average speed, \( d \) is total distance of traveled object and \( t \) is time until object reach the ground. A graph will be plot to see any significant different between mesocarp fiber and kernel shell.

2.3.3 Force balance

![Object force balance](image)

Fig. 6 Object force balance

When object drop through fluid (air) until it reach the ground, there are three forces are involve which is \( F_G \) gravity force (weight of object that acting downward through the fluid), \( F_B \) buoyancy force (acting to move particle upward through the fluid) and lastly \( F_D \) drag force (acting opposite to the relative motion). The gravity force can be determined by using equation (4).

\[
F_G = v \times P_s \times g
\]  

(4)

Where \( v \) is object volume, \( P_s \) is object density and \( g \) is acceleration due to gravity. Because \( F_G \) is downward direction it will cause the object to settle. The buoyancy force is a weight of fluid that is displace by the particle act in opposite direction. So the buoyancy force can be determined by using equation (5).

\[
F_B = v \times P \times g
\]  

(5)

In this calculation, \( P \) is the density of the fluid that objects moving through. \( F_G \) and \( F_B \) act in opposition the net force on the object (\( F'_G \)):

\[
F'_G = F_G - F_B = \frac{\pi}{6} P_s gd^3 - \frac{\pi}{6} pgd^3 = \frac{\pi}{6} (P_s - p) gd^3
\]  

(6)
When object density bigger then fluid density, it will settle through the fluid because \( F_G > F_B \). The expression on the right side is termed the submerged weight of object. Stroke law derivation base on the 2 forces act on the object (submerge weight and weight forces). When the object is settling at its terminal velocity no net force will act on it. During object reaches its terminal velocity the drag force \( F_D \) equal to \( F_G \) in magnitude and act in opposition direction (\( F_D \) is upward and \( F_G \) downward). So when the object reached its terminal velocity drag force is expressed by the following equation (7).

\[
F_D = F_G - F_B \tag{7}
\]

The drag coefficient is a dimensionless quantity that used to quantify the resistance of the object in fluid environment such as water or air. The drag coefficient always connected with the surface area. Drag coefficient defined as following equation (8):

\[
C_D = \frac{F_D}{\frac{1}{2} \rho v^2 A} \tag{8}
\]

Where \( F_D \) is the drag force, \( \rho \) is the density of the fluid, \( v \) is the speed of object and \( A \) is surface area.

Equation (9) showed that when terminal velocity reached its object weight and then balanced by the upward buoyancy force and drag force.

\[
V_t = \sqrt{\frac{4gd}{3C_D}} \left( \frac{P_s - P}{P} \right) \tag{9}
\]

2.4 Sample and analysis

The study was conducted by collecting 3 sample of each level velocity where the weight of the sample remains the same at 50 grams. The sample was a mixture of fiber and nuts (with cracked mix) where it was obtained after press process. So the moisture contain of this sample usually was around 40%. The experiment was carried out at University Putra Malaysia using the industrial air classifier prototype that was developed and design by Sawipac Sdn Bhd. All data was recorded during experiment execution. Moisture contain was determined using oven where the weight before and after heating. Figure 7 shows sample in the bottom of column.
3. Result and discussion

3.1 Object free fall

Fig. 8 Graph Time vs height of palm mesocarp fiber and kernel shell

Result on the figure 8 shows the time taken to drop the object (mesocarp fiber and kernel shell) from a certain height to the ground. Mesocarp fibers show the significant different result from the kernel shell because it’s had much lighter density that took more time to reach the ground. But kernel and shell show the slightly different due to density of these two objects is not much different.
3.2 Terminal velocity

Based on the fig. 9, histogram shows the different level of terminal velocity of mesocarp fiber and kernel shell. It is highly possible to separate mesocarp fiber from the kernel shell using air classifier due to the different level of the terminal velocity between mesocarp fiber and kernel shell is much significant.

Fig. 9 Graph of terminal velocity of mesocarp fiber and kernel shell.
### 3.3 Object shape factor

Table 1 Object shape factor

<table>
<thead>
<tr>
<th>$d_v$ volume diameter (mm)</th>
<th>$d_A$ projected diameter (mm)</th>
<th>Shape factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.65387</td>
<td>0.2994</td>
<td>0.2160</td>
</tr>
<tr>
<td>3.03924</td>
<td>0.3429</td>
<td>0.2483</td>
</tr>
<tr>
<td>5.47896</td>
<td>0.6182</td>
<td>0.9717</td>
</tr>
<tr>
<td>2.67638</td>
<td>0.3020</td>
<td>0.1590</td>
</tr>
<tr>
<td>2.78316</td>
<td>0.3140</td>
<td>0.1780</td>
</tr>
<tr>
<td>2.22441</td>
<td>0.2510</td>
<td>0.1563</td>
</tr>
<tr>
<td>3.40279</td>
<td>0.3839</td>
<td>0.1742</td>
</tr>
<tr>
<td>2.25278</td>
<td>0.2542</td>
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<tr>
<td>2.90964</td>
<td>0.3283</td>
<td>0.1508</td>
</tr>
<tr>
<td>2.71533</td>
<td>0.3064</td>
<td>0.1621</td>
</tr>
<tr>
<td><strong>Mean</strong></td>
<td><strong>0.3400</strong></td>
<td><strong>0.2555</strong> (fiber)</td>
</tr>
<tr>
<td>19.04800</td>
<td>1.9672</td>
<td>6.2689</td>
</tr>
<tr>
<td>18.01760</td>
<td>1.7931</td>
<td>5.1562</td>
</tr>
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<td>9.77142</td>
<td>1.8887</td>
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</tr>
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<td>20.95735</td>
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</tr>
<tr>
<td>26.21946</td>
<td>2.4323</td>
<td>7.1026</td>
</tr>
<tr>
<td><strong>Mean</strong></td>
<td><strong>1.8980</strong></td>
<td><strong>5.6632</strong> (kernel)</td>
</tr>
<tr>
<td>9.77142</td>
<td>0.9608</td>
<td>2.8259</td>
</tr>
<tr>
<td>8.73982</td>
<td>1.2791</td>
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<td>6.17999</td>
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<td>6.17999</td>
<td>1.2103</td>
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<td>1.0084</td>
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<td>3.1555</td>
</tr>
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<td>8.73982</td>
<td>1.2129</td>
<td>3.4650</td>
</tr>
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</tr>
<tr>
<td>4.36991</td>
<td>0.9752</td>
<td>2.7018</td>
</tr>
<tr>
<td><strong>Mean</strong></td>
<td><strong>1.1304</strong></td>
<td><strong>3.1618</strong> (shell)</td>
</tr>
</tbody>
</table>
A sample containing 10 particles of each type selected randomly was photographed and projected diameter and shape factor has been determined using Image J software. These two quantities are defined as:

Projected diameter formula

\[ d_A = \frac{1}{N} \sqrt{\frac{4}{\pi} \sum A_i} \]  

(10)

Shape factor

\[ \Phi = \frac{1}{N} \sum \frac{4\pi A_i}{L_i^2} \]  

(11)

Shape factor shows the significant difference between these three types of objects, indicating that each type had different air resistance properties (Arsenijevic et al., 1999).

3.4 Initial result of separation

Table 2 Initial result of the study

<table>
<thead>
<tr>
<th>Input</th>
<th>Output</th>
</tr>
</thead>
<tbody>
<tr>
<td>MC %</td>
<td>Temp (°C) (35-45)</td>
</tr>
<tr>
<td>37%</td>
<td>42</td>
</tr>
<tr>
<td>37%</td>
<td>43</td>
</tr>
<tr>
<td>34%</td>
<td>40</td>
</tr>
<tr>
<td>34%</td>
<td>40</td>
</tr>
<tr>
<td>37%</td>
<td>42</td>
</tr>
<tr>
<td>34%</td>
<td>41</td>
</tr>
<tr>
<td>37%</td>
<td>36</td>
</tr>
</tbody>
</table>
Fig. 10 Percentage of separation vs. air velocity

Fig. 11 Process time vs. air velocity
The result of the experiment (Figure 10) show that air classifier can perform more than 70% of separation above 9 m/s of air velocity. It’s indicated higher flow rate at 10 m/s produced better performance at more than 90% of separation. During the experiment fiber sometimes tend to sticky too each other due to moisture contain and cause hard to separate even at high flow rate. So as show in figure 8 the time is inconsistent that it’s consume more time to separate even at high flow rate. The result also show separation still take place at lower velocity indication that the fiber has a distribution of size. The moisture contain does not affect the separation significantly but it can be seen that the find moisture contain is lower at higher velocity as drying took place.

3.4.1 Mixture ratio added on the study

![Graph](image)

Fig. 12 Percentage of separation vs setting run time at 15.68m/s

On this study mixture ratio of palm mesocarp fiber and kernel shell was added as input parameter. The purpose of this experiment is to study whether the rate of the fiber within the 50 grams of sample might affect output where it can improve the understanding of air separation. Based on the figure 12, the graph represents percentage of separation versus setting time where it set to run at 15m/s of air velocity. In this experiment we purposely divided the ratio of fiber into 4 categories which is 20% of fiber, 40% of fiber, 60% of fiber and 80% of fiber within 50 grams of sample. As for setting time, started at 30 second and it’s increased by one minute for each level until 5 minute. This result shows that reduction of mesocarp fiber in the mixture increased the separation result where it’s due to low quantity mean less obstruction during separation process. Another thing is all mixture ratio start to slowdown the separation at 60 second due initial air velocity that going to the separation column can act as initial force where it’s helped the separation process to achieved high percentage of separation within 60 second time.
Figure 13 The velocity vs % of separation at 300sec run time

Fig. 13 is a graph that represents the velocity versus percentage of separation within 300 second of setting time. This experiment was conducted to study the relation between the percentage of separation and level of velocity within 300 second of setting time. Note that the different of this experiment (fig. 13) from the initial result on table 4 are the increasing of blower capacity that provided more air velocity into the separation column and mixture ratio as input parameter. The air velocity was categorized into several levels from low to high. The initial air velocity was set at 5 m/s and its increased level by level until 15 m/s.

From the graph (fig. 13) is understood that increasing air velocity going through the separation column affected the separation result where it’s increased the percentage of separation mean more mesocarp fiber will separate from the kernel shell. At 14 m/s of air velocity, the separation percentage started to increased rapidly because this level of velocity is capable to float the clod of mesocarp fiber due to moisture content (which is become one of the obstruction in this experiment due to fiber tend to stick to each others) where at lower level of air velocity this clod will stayed at bottom of the separation column with nuts kernel shell. The risk of using such a high velocity is it’s also capable to float the kernel shell.
3.4.2 Particle size distribution

Fig. 14 show the average particle size versus air velocity. This experiment to improve the understanding of separation result related to air velocity. In this experiment, eight level of air velocity was determined based on previous experiment. To ensure more accurate data 15 sample of mesocarp fiber was individually selected randomly for each level of velocity. The result shows that increasing of air velocity is capable to float bigger size of mesocarp fiber during separation. Different length of mesocarp fiber will had different characteristic of its air resistance as the length is influenced by its shape characteristic, projection area, mass as well as density.

4. Conclusions

The different density and size of fiber and nuts kernel shell make it possible to separate by air flow. Some study has been done show that because of fiber can be float by the air around 1 - 2 m/s but due to quantity, cross sectional area and fiber properties higher flow rate is needed to ensure the successful of the separation. In future, another parameter will be add-in such as ratio moisture content reduction, temperature level, disturbing system (agitation introduction, pulse and auxiliary flow) and nut and fiber properties. This is to ensure more accurate data will be obtained.
Reference
Maycock, J. H. Laboratory and milling control, Jan 1986.
Available online: http://en.wikipedia.org/wiki/Terminal_velocity