Design and performance of a mobile coconut husk fibre separator
(Reka bentuk dan prestasi alat pemisah bergerak serat sabut kelapa)

Abstract
A mobile coconut husk fibre separator has been successfully designed and developed. The coconut husks can be easily extracted to separate the coco peat and coir fibre by using the mobile separator which is powered by 6.5 kW diesel engine. The machine has beating blades, combing device and filtering system to complete the operation. The beating blades are installed in helical arrangement on a rotary drum (diameter, 50 cm and length, 100 cm) to break and soften the coconut husks after manual loading. The combination of the beating and combing mechanism will split the coco peat and coir fibre from the coconut husks and then screened by a filter to separate each output to different collecting bins. The beating device is covered by a semi-cylindrical housing to increase efficiency of the extracting process. The mobile separator has a capacity of 500 kg/h to process either dry or wet husks. This machine is very useful and economical for the smallholders to process the coconut husks and add values to the products. It can be attached to a mini tractor to process the coconut husks in the field for production of coir fibre and coco peat. The economical break even point of the mobile separator is projected after 110 h of operation. The estimated cost of the mobile separator is RM21,000 per unit. The machine has been patented in Malaysia and the patent number is MY138315-A.

Introduction
Coconut is the fourth important crop in terms of acreage in Malaysia. A total area of 106,312.4 ha has been planted with coconut in Malaysia including Sabah and Sarawak with total production of 562,556.6 mt in 2011 (Anon 2011; Junus 2013). The crop has significant socio-economic implications as it provides a source of revenue and generates employment to households. Coconut is a special crop, with almost every part of the plant can be used as food and non-food products. A lot of agro wastes are produced during harvesting and processing activities of coconut such as coconut husks, shells and fronds. These agro wastes can be processed to produce value added products. One of the agro wastes is the coconut husks. The main products from the coconut husks are coir fibre and coco peat. In Malaysia, processing of coconut husks for fibre is still a small scale industry. The coir production process in Malaysia is the dry milling type in which the coconut husks are directly fed into the machine without soaking in water. The moisture content of the coconut husks, however, must be about 25 – 30% (wet basis) to avoid machine damage (Md. Akhir et al. 2006).
Production of coir fibre from coconut husks produces dusts in the factory. This condition can be controlled by using dust vacuum and water sprayer. The ratio of coir fibre to coco peat in one coconut husk is 75:25. This means that one tonne of husk will produce 750 kg coir fibre and 250 kg coco peat. The coir fibre can be used as impervious stuff. The coco peat can absorb water 8 times its own weight. This character can be manipulated in agriculture industries for improvement of soil structure and water holding capacity. Coco peat has also found a good niche in agricultural industries such as the fertigation system where it is used as a planting medium (Md. Akhir et al. 2009). Coir fibre can also be used in agriculture as supporting baskets and replacement for plastic polybags.

Transportation of the coconut husks to the factory is expensive because it is bulky. Each one-tonne lorry can only be loaded with 4,000 – 6,000 units of coconut husks (with 30% moisture). The price of the husks is also very low. The factory would pay two cents per unit husk collected at the farm. To avoid high transportation cost, alternative ways are needed to overcome the problem. Thus, a portable and environmentally friendly mobile machine was developed to separate the coco peat and coir fibre, the two main products from the coconut husks (Md. Akhir and Dhiauddin 1992; Mohd Taufik and Md. Akhir 2009).

**Machine conceptual design**

The mobile coir fibre separator consists of a feed hopper, rotary drum with a helically arranged blades, combing device, filter rods, coir fibre and coco peat outlets, power transmission unit, the main frame to support these components and a pair of wheels. The coconut husks were fed through the feed hopper at a uniform rate. The husks were beaten by a 50 cm diameter rotational drum fitted with helically arranged blades and combing devices at both sides of the frame. The blades will beat the husks and then swing pass through the combing devices to separate the coir fibre and coco peat. The coir fibre will be blown out at the front outlet while the coco peat will be screened by filter rods and collected at the bottom outlet. The front and side elevation of the mobile coconut husk fibre separator is given in Figures 1 and 2. The complete prototype mobile coco peat and coir fibre separator is shown in Plate 1. This machine has been patented and the patent number is MY138315-A.

This machine was designed with an estimated processing capacity of 500 kg/h of coconut husks. It is operated by a 6.5 kW diesel engine. A mini tractor can be used to pull the machine to any suitable location such as into the farm. The coconut husk separator can be operated directly in the farm because it does not depend on electricity to run. The design details of the coco peat and coir fibre separator are shown in Figures 1 and 2. The coir fibre and coco peat can be directly separated during the process. Both products can be packed in plastic bags or gunny sacks for marketing purposes.

**Feed hopper**

The feed hopper was designed to facilitate continuous feeding of the coconut husks into the rotary drum with the feeding hood holding the husks at 45° vertically. The feeding mount hopper is rectangular in shape with 30 cm wide x 40 cm long x 60 cm deep.

**Rotary drum with blades**

The rotary drum was made of 50 cm diameter cylindrical pipe with 100 cm length and welded with 33 beating blades in helical arrangement on the drum surface. There were three helical lines which consist of 11 beating blades in each line. The rotary drum was fitted to a central shaft by means of a circular plate slot on both sides inside the cylindrical drum. Both side shafts were fitted with pillow blocks and ball bearings to allow free rotation of both drum and shaft. The diameter of the shaft was 62 mm. The size of the beating blades was 60 mm x 30 mm x 14 mm. The blades spacing were 49 mm between blades and were helically arranged along the drum surface. Four bolts and nuts at 20 mm diameter were used to fix the pillow block (R-120 mm) to the frame. The completed rotary
Figure 1. Side view of the mobile coconut husk fibre separator

Figure 2. Front view of the mobile coconut husk fibre separator

Figure 3. Side and front view of the rotary drum and beating blades
drum as shown in Figure 3 had to be balanced so as to reduce the vibration during high speed rotation which is powered by the 6.5 kW diesel engine at a speed of 1600 rpm.

**Drum cover**
A drum cover plate was provided at the top of rotary drum and fitted to the side frame by bolts and nuts. The main purpose of this cover was to protect the husks from flying out during the beating process. The diameter of the top half of the cover plate was 100 cm. The top left side cover was cut in rectangular shape 30 cm x 40 cm and welded to the feeding hopper.

**Combing device**
The combing device was designed for combing the husks. The device has a total of 18 blades welded at both sides of the frame, one side with 7 blades whilst the balance was at the other side. The permanent comb is used to comb the beaten husks during the operation. The size of the combing blades is 30 mm x 13 mm x 70 mm and spaced at 50 mm. The spacing of the combing blades is arranged properly so as to synchronize with the rotary drum blades to prevent them from colliding with each other. Both blades work as scissors. During the slashing operations there is a 5-mm spacing between the beating and combing blades which prevent the fibre from being cut and damaged.

**Filtering rods**
The filter was made of iron rods 10 mm in diameter and 850 mm long. The rods were installed on the half round frame of 580 mm diameter in parallel arrangement at 10 mm apart. The filter rods were fitted at the bottom of the rotary drum and clamped together with the half circular drum cover at the top, to make a complete circular drum cover. The filter rods were used to filter the coir fibre and coco peat during processing operation.

**Main frame and wheels**
The main frame was fabricated using 38 x 6 mm, mild steel L-angle, a pair of wheels and a 6.5 kW engine. The frame was designed to support the components of the rotational drum shaft and pulleys. The dimensions of the frame were 1.5 m long, 1.3 m wide and 1.0 m high. For better mobility, the frame was supported by standard wheels 13R 155. At the front of the frame, a 1.0 m long horizontal drawbar was fitted for towing purpose. The back of the frame was extended up to 0.5 m long and 1.3
m wide for mounting the engine. At the centre of the towing bar, a jack, for adjusting the machine, was fixed in a horizontal position during operation.

**Power transmission**

The power was transmitted from the diesel engine or motor shaft by means of pulleys. The diameter of the shaft (drive) pulley was kept constant and the diameter of driving pulley was calculated according to the speed required. The speed of the driving pulley is calculated from the following formula (Joseph and Larry 2001):

\[
\begin{align*}
N_1 D_1 &= N_2 D_2 \\
N_2 &= \frac{(N_1 D_1)}{D_2}
\end{align*}
\]

Where

- \(N_1\) is the speed of the engine, rpm
- \(N_2\) is the speed of the driving shaft, rpm
- \(D_1\) is the diameter of the pulley mounted on engine shaft, cm
- \(D_2\) is the diameter of the pulley mounted on the drive shaft, cm

Therefore, the speed of the drive shaft \((N_2) = 3000 \times (10/20) = 1500\) rpm

The shaft was made of mild steel and subjected to a combination of bending and twisting movements. It was subjected to fluctuating loads since the blades were fed into the drum in helical arrangement at regular time intervals. Hence the shock and fatigue factors were taken into account when calculating the twisting and bending movements. The diameter of the shaft was calculated using the following formula (Joseph and Larry 2001):

\[
T_{\text{max}} = \frac{P}{\omega} = \frac{p \times 60}{2\pi N_2}
\]

Power engine constant output

- 5700 Watt at 3000 RPM Min.
- 6300 Watt at 3600 RPM Max.

\[
= \frac{(6300 \times 60)}{2\pi 1500} = 40.10\ Nm
\]

Where,

- \(P\), power transmitted by the shaft, W
- \(N\), speed of the shaft, rpm

Maximum bending movement for a shaft loaded on both ends was given by,

\[
M = W x L = 600\ N \times 1285 = 771.0\ Nm
\]

Where,

- \(W\), was the load acting on the shaft and shafts itself, (600 N).
- \(L\), was the length of the shaft, (1285 mm)

The equivalent twisting movement equation (Joseph and Larry 2001),

\[
Te = \sqrt{(Km \times M)^2 + (Kt \times T)^2}
\]

\[
= \sqrt{(1.5 \times 771.0)^2 + (1.5 \times 40.1^2) = 1158.06\ Nm}
\]

Where,

- \(Km\) = combined shock and fatigue factor for bending, 1.5
- \(Kt\) = combined shock and fatigue factor for torsion, 1.5

But equivalent twisting movement equation,
$$T_e = \pi \frac{1}{16} \times \tau \times d^3$$

$$d = \left( \frac{T_e}{\pi \frac{1}{16} \times \tau} \right)^{1/3}$$

$$= (18.529 \times 10^3/\pi \times 220.63 \times 10^6)^{1/3}$$

$$= 0.02989 \text{ m}$$

$$= 30 \text{ mm} \text{ but choose standard shaft 45 mm for safety.}$$

Where,

- $\tau$, maximum allowable shear stress steel shaft = 220.63 MPa,
- $d$, was the diameter of the shaft, mm
- $S_f$ = chosen shaft/calculation shaft
- $S_f$ = 1.5 design safety

Based on the above calculation, the diameter of the solid shaft is 30 mm but 45 mm was chosen for safety for a shaft length of 1285 mm.

**Performance evaluation of the mobile coconut husk fibre separator**

The prototype mobile coconut husk fibre separator is shown in *Plate 1*. It was tested in the field using wet and dry husks. A total of 50 batches of samples of wet and dry husks with a total load of 10 kg for each sample were used for the machine performance evaluation. During the evaluation process, husk numbers, product quantity and processing time were recorded. The fuel consumption was measured based on 100 kg samples. The physical conditions of the products such as cleanliness and product size distribution were also evaluated. A tachometer was used to measure the initial speed of the rotational shaft at minimum speed of 1500 rpm by adjusting the throttle fuel combustion. The feeding process of each sample batch was manually done and continuously conducted until all samples were processed. The coir fibre and coco peat separated by this prototype machine are shown in *Plate 2*.

**Processing of dry coconut husks**

Processing of husks at dry basis is done when the moisture content of the husks is less than 15%. The mobile separator was able to process 1,152 dry coconut husks (500 kg) within 7,081 s (1.97 h) (*Table 1*). *Figure 4* indicates that the average number of husks for 10 kg sample is 23 pieces. The husk number for 50 batches of samples varies from 17 to 25 pieces. The data normality analysis in *Figure 5* shows that the $P$-value is less than 0.005 which means the husk number for each sample is not following the normal distribution at 95% confidence intervals (Ronald and Raymond 1978; SAS Inst. 2002; Anon. 2012). The main factors that contribute to this scenario are the size and percentage

*Plate 2. Coco peat (a) and coir fibre (b) from coconut husks after separating process using mobile coconut husk separator*
Table 1. Fuel consumption for dry processing of coconut husks (<15% moisture content)

<table>
<thead>
<tr>
<th></th>
<th>Group 1</th>
<th>Group 2</th>
<th>Group 3</th>
<th>Group 4</th>
<th>Group 5</th>
<th>Total</th>
<th>Ave</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of husks</td>
<td>204</td>
<td>237</td>
<td>242</td>
<td>243</td>
<td>226</td>
<td>1152</td>
<td>230.4</td>
</tr>
<tr>
<td>Process time (s)</td>
<td>1416</td>
<td>1657</td>
<td>1261</td>
<td>1441</td>
<td>1306</td>
<td>7081</td>
<td>1416.2</td>
</tr>
<tr>
<td>Fuel consumption (ml)</td>
<td>878</td>
<td>970</td>
<td>718</td>
<td>845</td>
<td>732</td>
<td>4143</td>
<td>828.6</td>
</tr>
<tr>
<td>Fuel consumption (litre/h)</td>
<td>2.23</td>
<td>2.11</td>
<td>2.05</td>
<td>2.11</td>
<td>2.02</td>
<td>10.52</td>
<td>2.10</td>
</tr>
</tbody>
</table>

Figure 4. Number of dry coconut husks (MC <15%) processed in 50 batches of samples

Figure 5. Normality analysis for number of dry coconut husks processed
of moisture content of the husks. Basically, husks with bigger size and higher moisture content will contribute to bigger mass and less quantity. Conversely, husks with smaller size and lower moisture content will result in smaller mass and higher quantity.

The processing duration for each sample also varied from 115 s to 188 s due to several factors (Figure 6). Based on the data normality analysis in Figure 7, the results are also not following the normal distribution curve due to the $P$-value which was less than 0.005. The main reason contributing to this issue is the human factor including the operator’s skills and attitudes. The skill of the operator is very important in feeding the husks into the separating chamber without clogging the feeding port. If clogging occurs then the operator has to solve the problem before continuing feeding new husks into the machine. This will cause the processing time to become longer even though the number of husks is less. Besides that, the operator’s attitude also affects the processing time, whereby the feeding rate of husks will vary either slow or fast. The operator’s attitude is related to the level of commitment in completing the tasks. Those operators with high commitment and disciplines will feed the husks at specific speed consistently.

During the trial run, the fuel consumption was also recorded for every 100 kg sample (Table 1). The average rate of fuel consumption for dry basis processing was 2.1 litres/h. During processing, observation was also done on the surrounding of the working area and products. It was observed that processing of husks at dry basis generated floating dust particles in the working areas that can cause an unhealthy working environment. Operators have to use personal protection equipment (PPE), such as face masks, for their convenience during processing.

**Processing of wet coconut husks**

Processing of husks at wet basis is done when the moisture content of husks is less than 50%. The machine was able to separate coir fibre and coco peat from 581 wet coconut husks (500 kg) within 3,668 (1.02 h) (Table 2). The average number of husks for 10 kg sample is only 11 pieces (Figure 8). The number of husks processed is less than processing at dry basis due to the higher percentage of moisture content in the husk. The husks were submerged in water for 24 h prior to processing to enable water absorption.

The data normality analysis in Figure 9 indicates that the $P$-value is less than 0.005 which means that the husk number for each sample is not following the normal distribution curve at 95% confidence intervals. The husk number for 50 batches of samples varied from 8 to 14 pieces (Figure 8). This happened probably due to the inconsistent rate of water absorption by the husks during submerging process. Therefore, husks with higher moisture content will have bigger mass and less quantity to achieve the 10 kg sample weight.

The processing duration for each sample also varied from 55 s to 94 s due to several factors (Figure 10). The normality test on the processing data in Figure 11 was also not following the normal distribution curve due to a $P$-value of less than 0.005. The main factors influencing the result are similar to those highlighted in the dry basis processing. However, the operator needs to wear proper attire for their convenience during handling of wet husks.

The average fuel consumption rate for processing of wet husks was 2 litres/h (Table 2). Processing of husks at wet basis is better because no floating dust particles are generated during the processing operation. However, operators are encouraged to wear their personal protection equipment (PPE) for safety.

**Cost analysis**

*Table 3* shows a simple economic analysis by assuming annual working hours as 800 hours (William et al. 2005). The cost of the machine cum diesel engine is RM21,000. Obsolescence life of machine is estimated for 10 years after which the value of the machine will depreciate to an estimated value of RM2,000. Annual depreciation rate is RM1,900. Interest charge rate on machine is 10% per year.
Figure 6. Processing time of 50 batches of dry (MC <15%) coconut husk samples

Figure 7. Normality analysis for processing time of dry coconut husks
Table 2. Fuel consumption for wet processing of coconut husks (<50% moisture content)

<table>
<thead>
<tr>
<th></th>
<th>Group 1</th>
<th>Group 2</th>
<th>Group 3</th>
<th>Group 4</th>
<th>Group 5</th>
<th>Total</th>
<th>Ave</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of husks</td>
<td>101</td>
<td>116</td>
<td>124</td>
<td>124</td>
<td>116</td>
<td>581</td>
<td>116.2</td>
</tr>
<tr>
<td>Process time (s)</td>
<td>711</td>
<td>853</td>
<td>690</td>
<td>750</td>
<td>664</td>
<td>3668</td>
<td>733.6</td>
</tr>
<tr>
<td>Fuel consumption (ml)</td>
<td>376</td>
<td>470</td>
<td>380</td>
<td>450</td>
<td>365</td>
<td>2041</td>
<td>408.2</td>
</tr>
<tr>
<td>Fuel consumption (litre/h)</td>
<td>1.90</td>
<td>1.98</td>
<td>1.98</td>
<td>2.16</td>
<td>1.98</td>
<td>10.01</td>
<td>2.00</td>
</tr>
</tbody>
</table>

Figure 8. Number of wet husks (MC <50%) processed in 50 batches of samples

Figure 9. Normality analysis for number of wet coconut husks processed
Figure 10. Processing time of 50 batches of samples at wet basis (MC <50%)

Figure 11. Normality analysis for processing time of wet coconut husks
If the machine is continuously runs for an hour a day, the income generated will be RM188.35/h or RM1506.80 for 8 h working day. The economic return of the mobile separator is projected after 110 h of continuous machine operation.

**Conclusion**

The mobile coconut husk fibre separator which has been patented (Patent No. MY138315-A) can be used to process both wet and dry husks at a capacity of 500 kg/h. It is very useful and economical for the coconut growers to collect and process the coconut husks into higher value added products such as coco peat and coir fibre. The estimated cost of the mobile separator is RM21,000 per unit. It can be attached to a mini tractor to process the coconut husks in the fields. The economic return of the mobile separator is projected after 110 h of continuous machine operation. The coir fibre and coco peat are very useful for various applications and there is high demand for these products.

**Acknowledgement**

The authors would like to thank all parties that contribute either directly or indirectly in conducting the design and development of bio-fibre extractor. Special thanks are also extended to Mr. Mohd Shahmihaizan, Mr. Mohd Nadzim and Mr. Wan Mohd Faris for their contribution during the performance evaluation of the extractor.

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**Table 3. Cost analysis for operating mobile coconut husk fibre separator**

<table>
<thead>
<tr>
<th>Particular</th>
<th>Annual cost (RM)</th>
<th>Cost/hour</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Fixed cost</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Depreciation</td>
<td>(21,000 – 2,000)/10 = 1,900</td>
<td>2.38</td>
</tr>
<tr>
<td>Interest @ 10% of ave. price</td>
<td>[(21,000 + 2,000)/2] x 0.10 = 1150</td>
<td>1.44</td>
</tr>
<tr>
<td>Insurance (1% of purchase price)</td>
<td>[(21,000 + 21,000)/2] x 0.01 = 210</td>
<td>0.26</td>
</tr>
<tr>
<td>Taxes (1% of purchase price)</td>
<td>21,000 x 0.01 = 210</td>
<td>0.26</td>
</tr>
<tr>
<td><strong>Total fixed cost (A)</strong></td>
<td><strong>4.34</strong></td>
<td></td>
</tr>
<tr>
<td>2. Variable cost</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Repair and maintenance</td>
<td>10% of purchase price</td>
<td>2.10</td>
</tr>
<tr>
<td>Labour cost</td>
<td></td>
<td>6.25</td>
</tr>
<tr>
<td>Fuel @ 1.80/litres (2 l/h)</td>
<td></td>
<td>3.60</td>
</tr>
<tr>
<td>Lubrication, 10% of fuel cost</td>
<td></td>
<td>0.36</td>
</tr>
<tr>
<td>Raw materials (husk) 5 cents/kg</td>
<td>400 tonnes = 20,000</td>
<td>25.00</td>
</tr>
<tr>
<td><strong>Cost of operation (B)</strong></td>
<td><strong>37.31</strong></td>
<td></td>
</tr>
<tr>
<td>3. Selling cost</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Coir fibre products (RM700/tonne)</td>
<td>120 tonnes = 84,000.00</td>
<td>105.00</td>
</tr>
<tr>
<td>Coco peat products (RM500/tonne)</td>
<td>200 tonnes = 100,000.00</td>
<td>125.00</td>
</tr>
<tr>
<td><strong>Total selling cost (C)</strong></td>
<td><strong>230.00</strong></td>
<td></td>
</tr>
<tr>
<td>4. Profit cost (D)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>D = C – (A + B)</td>
<td></td>
<td>188.35</td>
</tr>
</tbody>
</table>

Calculated by assuming annual working hours as 800 h (William et al. 2005)
References

Abstrak