Development of a Motorized Soybean Dehulling Machine for Small Scale Farmers

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Abstract: Soybean has been recognized as so versatile that can be processed into a wide variety of food products the soybean can be dried and wet processed. Soybean is also a valuable source of edible oil and excellent source of protein useful for both human and animal feeding. Protein is very important and is required for growth, repair of muscles and nutritional balance. The intake of soybean that is gaining acceptability both by the rural and urban dwellers calls for development of de-hulling machine to reduce the drudgery that involved in traditional method of de-hulling the beans. The de-hulling of soybean machine was based on abrasion between the beans and the wall of the de-hulling chamber and between the beans. The machine consists of the inlet hopper, the de-hulling chamber which included the barrel and the auger specially designed to create abrasion on the beans as it is carrying them towards the outlet end, 1HP geared motor with pulley and belt to make up the transmission unit. The overall dimensions of the machine are 460mm x 750mm x 250mm. The machine has de-hulling capacity of 40.00 to 54.55 Kg/hr and efficiency of 87% to 93% with the highest efficiency gotten when 2Kg of the samples were soaked for five hours before dehulling. The output result falls within economic range, therefore it is recommended for small soybeans processors.

I. INTRODUCTION

Soybean [Glycine max (L.) Merr.] is an important oil seed belonging to the family leguminosae is usually grown as a food crop1. The oil is produced almost entirely for human consumption, while the meal is mainly used as animal feed2. Soybean is mainly cultivated for its seeds, used commercially as human food and livestock feed and for the extraction of oil2. The oil is produced almost entirely for human consumption, while the meal is mainly used as animal feed1. The unit operation involved in traditional method are soaking, de-hulling, milling, cooking, flaking e.t.c as shown in figure 1, but de-hulling tends to be the most tedious and time consuming in the unit operation. De-hulling involves removal of the fibrous seed coat that tightly envelops the cotyledons. In other words, de-hulling may be described as the efficient and complete removal of the outer layers enveloping the cotyledons from the kernel leaving a seed coat free cotyledon3. Mortar and pestle, hand rubbing and grinding stone are used in the olden days to de-hull the seed which thereby give room for a better way of de-hulling which brings about the mechanical way. Many mechanical machinery have been done in the past, example are attrition-type de-hullers4, abrasive de-hullers such as the tangential abrasive de-hulling device5.
II. MATERIAL AND METHODS

Design Considerations
The factors considered for selection of materials for the fabrication included the cost of the machine, so as to enhance its use of materials, power sustainability, reliability, workability requirement and the efficiency labour requirement in operating the machine. Also, considered in the design was the ease of replacement of component parts in case of damage or failure and the durability of the materials, corrosion resistance, rigidity, strength and rust. The materials selected to suite the design considerations are shown in Table 1.

<table>
<thead>
<tr>
<th>S/N</th>
<th>MACHINE COMPONENTS</th>
<th>SUITABLE ENGINEERING MATERIAL</th>
<th>CRITERIA FOR MATERIAL SELECTION</th>
<th>MATERIAL SELECTED</th>
<th>REMARKS</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.</td>
<td>Medium carbon steel</td>
<td>Availability, cost and strength</td>
<td>Angle Iron</td>
<td>Medium carbon steel</td>
<td>Strength</td>
</tr>
<tr>
<td>3. Pulley</td>
<td>Cast iron, mild steel, wood forged iron and aluminum</td>
<td>Strength, availability, and cost</td>
<td>Cast iron</td>
<td>Strong and readily available</td>
<td></td>
</tr>
<tr>
<td>4. Belt</td>
<td>Rubber and leather</td>
<td>Strength and flexibility</td>
<td>Rubber</td>
<td>Flexibility and strength</td>
<td></td>
</tr>
<tr>
<td>5. Bearing</td>
<td>P205</td>
<td>Axial loading and radial loading</td>
<td>Pillow bearing</td>
<td>Accommodate both axial and radial loading</td>
<td></td>
</tr>
</tbody>
</table>

Machine conception
The motorized soybean de-hulling machine developed, is sub-divided in four units namely; the hopper, de-hulling chamber, the outlet and the power unit.

Mode of operation of the machine
The motorized soybean de-hulling machine was developed using abrasion force. The machine consists of a two hopper (water inlet and seed inlet), two semi-concentric cylinders (one perforated to allow the hull to pass through it and the other not perforated) and a driving mechanism. De-hulling takes place in the annular space between rotating shaft and stationary cylinder.

Design Calculations
The Hopper Design: The hopper was designed based on the volume of frustum of a pyramid (Figure 1). The volume of the frustum of a pyramid can be obtained as follows:
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**Figure 2:** Shape of the hopper

Volume of the big pyramid = \( \frac{1}{3}c^2(h + y) \) \hspace{1cm} (1)

Volume of the small pyramid = \( \frac{1}{3}k^2y \) \hspace{1cm} (2)

Volume of the frustrum = \( \frac{1}{3}[c^2(h + y) - k^2y] \) \hspace{1cm} (3)

Where:
- \( h \) = Height of frustum (250 mm)
- \( y \) = Height of small pyramid
- \( c \) = Length of one side of the square base of the big pyramid (250 mm)
- \( k \) = Length of one side of the square base of the small pyramid (100 mm)

**Capacity of Hopper**

\[ \text{Capacity of Hopper} = \frac{\text{Volume of Hopper}}{\text{Volume of Soybean}} \] \hspace{1cm} (4)

**The pulley**

To determine the speed of the driven pulley, the relationship given by \(^8\) was adopted

\[ nd = ND \] \hspace{1cm} (5)

Where
- \( d \) = diameter of the small pulley
- \( n \) = speed of the small pulley
- \( N \) = desired speed of the big pulley
- \( D \) = desired diameter of the big pulley

**Belt Length**

The length of the belt will be determined using the equation below:

\[ L = 2C + \frac{\pi}{2}(D_1 + D_2) - \frac{(D_2 - D_1)^2}{4C} \] \hspace{1cm} (6)

Where:
- \( L \) = total length of the belt (mm)
- \( D_1 \) = diameter of driven pulley (mm)
- \( D_2 \) = diameter of driving pulley (mm)
- \( C \) = distance between the centers of the two pulleys (mm)

**The Belt Drive**

Belts are used to transmit power in equipment. It requires close spacing and centre distance. It transmits power from motor to the shaft making the center distance between motor and shaft to be adjustable.

The twisting moment \((T)\) was given as:

\[ T = (T_1 - T_2)R \] \hspace{1cm} (7)

Where:
- \( T_1 \) = Tension in the tight side
- \( T_2 \) = slack side of the belt
- \( R \) = Radius of the pulley

Tension ratio for an open belt was calculated using equation (8)

Let \( 2.3\log \left( \frac{1}{T_2} \right) = \mu \) \hspace{1cm} (8)

Where: \( \mu \) is the coefficient of friction between rubber belt and mild steel pulley given by 0.3.

**The Shaft:**

The shaft was made from mild steel with the following parameters:
- Yield strength of the material, \( Y = 320 \text{ N/mm}^2 \)
- Ultimate tensile strength, \( S_{ut} = 580 \text{ N/mm}^2 \)
Since the loading of soybeans seed is not strong, it was assumed that load was applied gradually. The combined shock and fatigue factor applied to bending moment, \( K_m = 1.0 \)
The combined shock and fatigue factor applied to torsional moment, \( K_t = 1.5 \)
The motor rating is 750 W at 1440 rpm.
And if keyways are present, it will reduce to 23% and the shear stress of the shaft will be 84MPa = 84Nmm².
The co-efficient fraction between the belt and pulley is 0.3 and the angle of lap of the belt is 180°.The diameter of the pulley is 130mm.
\[
T = \frac{66 \times P}{2 \pi x N}
\]  
(9)
Where:
\( T \) = Twisting moment
\( P \) = Power rating of the motor
\( N \) = Speed of the shaft

**Critical speed of the shaft (\( \omega_s \)):**
The critical speed of the shaft was determined by equation (10) given by \(^8\)
\[
\omega_s = \frac{4BEI}{ML^2}
\]  
(10)
Where:
\( E \) is the Modulus of elasticity of steel
\( I \) is the moment of inertia given by \((\pi d^4)/64\)
\( L \) is the shaft length.

**Dehulling chamber design**
The dehulling chamber was assumed to be a thin walled cylinder, the tangential stress perpendicular to the axis of the cylinder is given in equation (11) as:
\[
\sigma = \frac{pd_{dc}}{2t}
\]  
(11)
Where:
\( \sigma \) = perpendicular of hoop stress, assumed to be the maximum tensile stress the cylinder is subjected to at failure by yield.
\( P \) = Internal pressure
\( t \) = Thickness of dehulling chamber
\( d_{dc} \) = internal diameter of dehulling chamber
Also, \( \sigma = S_{all} = \frac{0.5S_y}{N} \)  
(12)
Where:
\( S_{all} \) = allowable shear stress
\( N \) = factor of safety
\( S_y \) = Yield stress

**Volume of dehulling chamber**
This is given by
\[
V_{dc} = \pi r_{dc}^2 l_{dc}
\]  
(13)
Where: \( r_{dc} \)=radius of dehulling chamber
\( l_{dc} \)= length of dehulling chamber

**Machine Parts**
**The Hopper:** it consists of two hoppers (one for water and the other is for the seed). This is where the soybean and the water are conveyed into the dehulling chamber. It is made of plate of thickness 2mm in a pyramid shape.

**The Dehulling Chamber:** It contains the shaft coupled with auger which will dehull the soybean. The dehulling chamber consist of two half cylinders fabricated together. The first half cylinder is perforated with a 7mm drill bit to allow the chaff to move out through the side outlet.

**The Outlet Unit:** The machine has two outlets; one at rear side and the other located in the front of the machine. The side outlet will convey the chaff out of the machine and the front outlet will convey the dehulled soybean out of the machine.

**The Power Unit:** An electric motor is used to power this machine. It will be connected to the power source (electricity) and also connected to the machine through a v-belt through the pulley system.
Test procedure

The soybean dehulling machine was fabricated and tested in order to know the capacity and the efficiency of the machine. Three different quantities of soybean (1.5Kg, 2Kg and 2.5Kg) were soaked for 3 hours, 4 hours and 5 hours. After that, it was fed into the dehulling chamber of the machine. The efficiency and machine capacity was determined for each quantity of soybean and each soaking time as shown in equation (14) and (15) respectively given by.

\[ \text{The efficiency} = \frac{\text{Total number of dehulled seeds}}{\text{Sum total number of seeds}} \times 100\% \quad (14) \]

\[ \text{The machine capacity} \left( \frac{\text{Kg}}{\text{hr}} \right) = \frac{\text{Throughput}}{\text{Time taken to dehull}} \quad (15) \]

III. RESULT

The soybean dehulling machine was fabricated and the materials of construction have been listed. Figure 3a and 3b shows the orthographic projection of the machine.

Figure 3a: Orthographic projection (side view) of the soybean dehulling machine. (All dimensions in mm).

Figure 3b: Orthographic projection (End view) of the soybean dehulling machine. All dimension in mm.
IV. DISCUSSION

The soybean dehulling machine was tested and the result was shown in Table 2.

Table 2: Performance evaluation of the soybean dehuller showing efficiency and machine capacity.

<table>
<thead>
<tr>
<th>Test</th>
<th>Quantity of soybean (Kg)</th>
<th>Soaking time (hr)</th>
<th>Dehulling time (s)</th>
<th>Percentage of dehulled soybean (%)</th>
<th>Machine capacity (Kg/hr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1.5</td>
<td>3</td>
<td>135</td>
<td>87</td>
<td>40.00</td>
</tr>
<tr>
<td></td>
<td>1.5</td>
<td>4</td>
<td>128</td>
<td>90</td>
<td>42.19</td>
</tr>
<tr>
<td></td>
<td>1.5</td>
<td>5</td>
<td>120</td>
<td>92</td>
<td>45.00</td>
</tr>
<tr>
<td>2</td>
<td>2.0</td>
<td>3</td>
<td>161</td>
<td>89</td>
<td>44.72</td>
</tr>
<tr>
<td></td>
<td>2.0</td>
<td>4</td>
<td>152</td>
<td>91</td>
<td>47.37</td>
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<tr>
<td></td>
<td>2.0</td>
<td>5</td>
<td>140</td>
<td>93</td>
<td>51.43</td>
</tr>
<tr>
<td>3</td>
<td>2.5</td>
<td>3</td>
<td>188</td>
<td>89</td>
<td>47.87</td>
</tr>
<tr>
<td></td>
<td>2.5</td>
<td>4</td>
<td>174</td>
<td>90</td>
<td>51.72</td>
</tr>
<tr>
<td></td>
<td>2.5</td>
<td>5</td>
<td>165</td>
<td>92</td>
<td>54.55</td>
</tr>
</tbody>
</table>

From Table 2, the dehulling time decreases as the soaking time increases and increases as the quantity of soybean increases. The efficiency of the machine ranges from 87% to 93%, the highest efficiency was gotten when 2Kg of soybeans was soaked for five hours before dehulling. The machine capacity also increased as soaking time increases.

V. CONCLUSION

The motorized soybean dehulling machine was designed and fabricated. It was able to dehull the grains and separate the chaffs from the grains. Due to the non-complexity of the machine, it can be used by small scale farmers to enable efficient dehulling of soybean for further processing. It will also minimize time, energy and cost involved in traditional processing of soybeans. The efficiency of the machine ranges from 87% to 93% with the highest efficiency gotten when 2Kg of soybeans was soaked for five hours. It was therefore recommended that the users of this machine should soak for five hours before dehulling.
REFERENCES


