Improving Productivity in Soya-Bean Processing Through the Design and Fabrication of Double Action Decoating and Separation Machine

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Abstract

The disadvantages arising from wet process of decoating soya-bean seeds before being processed into varied food products has necessitated the search for better alternative. Wet decoating requires soaking in water for several hours or in some cases over night before attrition is applied to shed the coats. Large amount of water is required for washing the soya-bean severally especially for industrial scale processing. When the coats are isolated, the soya-beans are then dried in ambient sunlight or a dryer before further processing as case may be. This process adversely affects the food quality of the products as some chemical processes like rancidification and fermentation may have taken place. The wet process is also uneconomical, labour intensive and time consuming. Alternative method of decoating using a cracking machine was investigated. First 5kg of soya-beans seed dried under ambient sunlight to a moisture content of about 12 – 15 % were passed through a cracking machine at several impeller speeds ranging from 800 – 2000 rpm. The speed of 1400 rpm yielded a better decoating result of 70% decoating and 10 % undecoating. The soya-bean seeds were then toasted to a temperature of 60 – 70 °C in an oven and introduced into the cracking machine. The percentage decoating rose to 95% and 5% undercoating. The data so collected was employed in the design and fabrication of the double action soya-bean decoating and separation machine in order to solve the problems arising from wet decoating and separation and also to increase productivity and reduce cost and labour to the barest minimum.

Keywords: soya-bean, decoating, toasting, cracking, separation

INTRODUCTION

The Soybean or Soya bean (Glycine max, L) is a species of legume native to East Asia, widely grown for its edible bean which has numerous uses. Among the legumes it is classified as an oil-seed, is pre-eminent for its high protein content as well as its high oil content (Perkins, 1995). Soy varies in growth and habit with the height of plant varying from 20cm up to 2meters. The pods, stems and leaves are covered with fine brown or gray hairs. The fruit is a hairy pod that grows in clusters of 3-5; each pod is 3-8cm long and usually contains 2-4 seeds, 5-11mm in diameter. Soy beans occurs in various sizes and in many hull or seed coat colours including black, brown, blue, yellow, green and mottled. The hull of the mature bean is hard, water resistant and protects the cotyledon and hypocotyls (or “germ”) from damage (Blackman et al., 1992)

Cultivation is successful in climates with hot summers with optimum growing conditions in mean temperatures of 20 to 30 °C (68 to 86 °F). Temperatures below 20 °C and over 40 °C retard growth significantly. They grow in a wide range of soils with optimum growth in moist alluvial soils with a good organic content (EBO, 2008). Approximately 85% of the world’s soybean crop is processed into soybean meal and vegetable oil. In China, Japan and Korea, the bean products made from the bean are a popular part of the diet (soyatech.com, 2010). Soybean first arrived in Africa in Egypt in 1857 and was introduced as early as 1908 in Nigeria but its cultivation as a crop began in 1937 with the introduction of the Malayan variety (SIC, 2009). Industrial and domestic processing of the crop locally has given rise to numerous products utilized for both human and animal consumption. Some of these products include; Soya bean meal (a protein supplement in poultry, hog and cattle feed); Soya bean oil (refined to produce paints, varnishes, soap and sealant and in pharmaceuticals); in vegetarian cooking and others such as soy-milk, soy-akara, soymo-moi, dadawa and soy-ogi all local delicacies. Processing of soya beans to oil employs both the mechanical system of presses and expellers and the chemical system of solvent extraction. The solvent extraction is known to be more effective vis-a-viz the oil recovery rate (RMRDC, 2004).

Physical and engineering properties are important in many problems associated with the design of machines and the analysis of the behaviour of the product during agricultural process operations such as handling, planting, harvesting, threshing, cleaning, sorting and drying. The solutions to problems of these processes involve knowledge of the physical
and engineering properties (Irtwange, 2000). Various works have been carried out by researchers on physical and engineering properties of agricultural materials Some of these include. Baryeh, E. A. (2000) for Bambara groundnut; Olajide and Igbeke, (2003) for groundnut kernel; Amin et al., (2004) for lentil seed; Coskun et al., (2005) for sweet corn; Akaaimo D.I. and A.O. Raji (2006) for Prosopis Africana seed; Aviara et al., (2007) for guna seeds. For soybean, the physical properties such as length, width, arithmetic and geometric mean diameters, porosity, sphericity, true and bulk densities and angle of internal friction were investigated by Deshpande et al., (1993) and further by H. Kibar and T. Öztürk (2008) while Tavakoli et al., (2009) reported the moisture dependence of some engineering properties of soybean grains. In 2004, the Raw Materials Research and Development Council (RMRDC) in Nigeria carried out a survey on agricultural raw materials with emphasis on soya bean. Its cultivation, processing and various uses were reported with a list of available local process equipment given in its appendix. However from the foregoing it was observed that very little account was given on equipment that can de-coat and separate the soybean seeds. This work intends to provide information on this; to design, fabricate and evaluate the machine in order to improve the productivity of soybean processing in Nigeria.

**Description of the Designed Soya-Bean Decoating and Separation Machine**

The assembly drawing of the soya bean decoating and separation machine is shown in appendix. The machine is double acting. Dry decoating is carried out using this machine.

The machine consist of the following components:

- Feeding hopper
- Double inlet channel
- Double cracking chamber
- Double sweeping chamber
- Double cracking impeller
- Air blades
- Seed exit spout
- Coat exit spout
- Bearings
- Transmission shaft
- Bolts, nuts and washers
- Cover plates
- Drive pulley
- Driven pulley
- V-belts
- Electric motor
- Electric motor sitting
- Structural stand
- Bolting flanges
- Keys and key seats
- Adapter
- Lock pins

The cracking and sweeping chambers are integrated in one cylindrical casing. They are only demarcated by a short step. The cracking impeller with the air blades are housed by the cylindrical casing. The impellers are fixed on both ends of the transmission shaft with an adapter. The shaft is mounted on bearings, so that it rotates with the impellers freely. The impellers are positioned to rotate at the central axis of the cylindrical casings.

The driven pulley is keyed at the centre of the transmission shaft in between the bearings. The driven pulley is connected to the driver pulley on the electric motor with two v-belts. The electric motor is mounted on its sitting with bolts and nuts. The whole arrangement is carried on a rigid structure. The inlet hopper and inlet linings are integral. The exit end of the lining opens to the centre of rotation of the impeller. The cross-like impeller is made of hollow square pipes.

The cylindrical casing has exit channels for both decoated seed and chaff together. Both the decoated seed and coat move from exit channels into a separation column which is a little extensive above the machine to a height of about 2 meters. The column is inclined at an angle of about 35°. The column has decoated seed exit channel as well as coat (chaff) exit channel separately. In this column, separation of the decoated seed and chaff is achieved by density differential. The decoated seeds cannot climb the column because they are heavier. They therefore drop half way through the exit channel provided. The chaff which is lighter is carried in suspension by the large volume of air generated by the air blades and flow out through the chaff exit channel.

**Principle of Operation**

The machine operates on an impact principle and density differential. The dried toasted soya-beans are introduced into the machine through the receiving hopper. The soya-bean fall by gravity through the inlet channel into the centre of the cracking impellers. The rotating impeller accepts the soya-bean and imparts to them radial force. The soya-beans move in radial direction exiting the impeller tangentially and hit the anvil (casing). In this manner the coatings are split thereby releasing the inner seeds.

The volume of air generated by the air blades then sweeps both the cracked shells (coating) and the decoated seeds up to separation column. Both the decoated seeds and coats hit a restriction at the upper section of the column. The decoated seeds being heavier than the coats then drop and go out through the decoated seeds exit spout. The coats being lighter
are therefore carried away by the volume of air exiting through the chaff exit spout.

Advantages
- The machine is double acting and therefore productivity in decoating and separation is very high.
- Materials of construction of this machine are all locally available.
- The cost of construction of this machine is by far lower than cost of importation.
- The machine is simple in operation and requires only one operator.
- Power requirement is very low as the machine can be conveniently driven with a three or single phase electric motor of 3 H.p (2.25 kW).

OBJECTIVE
The objective of the design of the machine is to mechanize the process of decoating and separation of soya-bean coating from the decoated seed. It is also intended to achieve high productivity in decoating and separation.

Beneficiaries
The beneficiaries of the design and construction of this machine are
- Food processing industry
- Small, medium and large scale agro and allied processing industries
- Pharmaceutical industries
- Chemical manufacturing industries e.g. for manufacturing of paints, resin, vanish etc.

Mechanics of Operation of the Decoating Machine
The mechanics of operation of this machine is purely based on the dynamics of the machine components namely pulleys, belts, bearings, shaft, gravitational and rotational motion. Rotational motion of these components, gravitational motion of the soya-beans through the hopper and outlet channel are employed in order to achieve the desired decoating and separation.

Rotational Motion and Centrifugal Force (F_c)
The rotational motion from the shaft of the prime mover (electric motor shaft) is transmitted to the input shaft carrying the driven pulley and impellers. For any object of mass M moving in a circular motion, its acceleration is directed towards the centre of the body and its linear velocity is tangential to the radius of the object. The displacement which starts from point A, then to B and continues is in terms of θ. The angular velocity is designated ω. The acceleration (a) of the rotary body is given as
\[ a = \omega^2 r. \]  
(1)

Where \( r \) = radius of the object. The acceleration is centripetal. The radially inward, or centripetal force required to produce acceleration is given as
\[ F_c = Ma = M\omega^2 r = \frac{MV^2}{r} \]  
(2)

(John Hannah and Stephens R.C, 1984)

If a body rotates at the end of an arm, this force is provided by the tension on the arm, the reaction to this force acts at the centre of rotation and is centrifugal force. It represents the inertia of the body resisting the change in the direction of motion. A common concept of centrifugal force in engineering problems is to regard it as radially outward force which must be applied to a body to convert the dynamical condition to the equivalent static condition.

Rotational Torque (T)
The value of torque developed by a rotational body is given as the product of the force causing the motion multiplied by the radius of rotation (John Hannah and Stephens R.C, 1984)
\[ T = F_c \times r \]  
(3)

Work Done by a Torque
If a constant torque \( T \) moves through an angle \( \theta \)
\[ \text{Work done} = T \times \theta \]  
(4)

If the torque varies linearly from zero to a maximum value \( T \)
\[ \text{Work done} = \frac{1}{2} \times T \times \theta \]  
(5)

In general case where \( T = f(\theta) \)
\[ \text{Work done} = \int f(\theta) \text{d}\theta \]  
(6)

The power (P) developed by a torque \( T \) (N.M) moving at \( \omega \) rad/sec is
\[ P = To = 2\pi NT \]  
(watts)  
(8)

Where \( N \) is the speed in rev/min and
\[ \omega = \frac{2\pi N}{60} \]  
(9)

Pulley and belt drive

The velocity ratio between two pulleys transmitting torque or power is given as
\[ \frac{\omega_1}{\omega_2} = \frac{N_2}{N_1} = \frac{D_2}{D_1} \]
\[ \text{Load due to impeller and soya bean} \]

\[ \text{Centrifugal force from pulley} \]

\[ \text{Load due to impeller and soya bean} \]

\[ \text{Bearing 1} \]

\[ \text{Bearing 2} \]

\[ \text{Shaft Design} \]

\[ \text{Material used for shafting is stainless steel} \]

\[ \text{Bearing Selections} \]

\[ \text{Bearing selection is carried out using the following equations by Shigley and Mtscake (1961)} \]

\[ P_b = XVF_r + YF_a \]

\[ L_{10} = [C/P_b]^{1/3} \]

\[ \text{Where} \]

\[ P_b = \text{bearing load} \]

\[ F_r = \text{radial load} \]

\[ F_a = \text{axial load} \]

\[ X = \text{radial load factor} \]

\[ Y = \text{axial load factor} \]

\[ C = \text{basic load rating} \]

\[ V = \text{Inner ring rotation factor} \]

\[ L_{10} = \text{bearing life in million revolution} \]
Determination of Optimal Speed of Decoating

This experiment was carried out with 5kg of soya-bean, dried under ambient condition to about moisture content of 12 – 15%. A cracking machine with variable speed was used to determine the optimal speed needed for cracking of soya-bean seeds. The specific quantities of soya-bean were passed through the cracking machine under different rotating speeds of the impeller. The data generated is recorded below.

**Table 1: Effects of Speed Variation on De-coating of Soya-Bean**

<table>
<thead>
<tr>
<th>Rpm</th>
<th>% Decoated and whole</th>
<th>% Undecoated</th>
<th>% Decoated and broken</th>
</tr>
</thead>
<tbody>
<tr>
<td>2000</td>
<td>10</td>
<td>8</td>
<td>82</td>
</tr>
<tr>
<td>1800</td>
<td>20</td>
<td>14</td>
<td>66</td>
</tr>
<tr>
<td>1600</td>
<td>50</td>
<td>7</td>
<td>43</td>
</tr>
<tr>
<td>1400</td>
<td>70</td>
<td>10</td>
<td>20</td>
</tr>
<tr>
<td>1200</td>
<td>66</td>
<td>15</td>
<td>19</td>
</tr>
<tr>
<td>1000</td>
<td>40</td>
<td>45</td>
<td>15</td>
</tr>
<tr>
<td>800</td>
<td>20</td>
<td>70</td>
<td>10</td>
</tr>
</tbody>
</table>

(Source: Agulanna et al., 2007)

From the experimentation, speed of 1400 appeared to be optimal in the sense that it has up to 70% decoated whole seeds, 10% undecoated and 20% broken. The percentage breakage dropped drastically on this speed when the soya-bean seeds were toasted to a temperature of (60 - 70°C). The optimal speed of decoating obtained was employed in the design and fabrication of the double action decoating and separation machine.

The extensive testing of the double action decoating and separation machine fabricated was carried out. Three consecutive test were carried out with 5kg of toasted soya each time. The average values of the three test results carried out are recorded below.

**Table 2: Average Values of Percentage Decoating / Separation at Optimal Speed**

<table>
<thead>
<tr>
<th>Rpm</th>
<th>% Decoated and whole</th>
<th>% Decoated but broken</th>
<th>% Partly Decoated</th>
<th>% Undecoated</th>
<th>% Separation of coat from cotyledon</th>
</tr>
</thead>
<tbody>
<tr>
<td>1400</td>
<td>80</td>
<td>15</td>
<td>2</td>
<td>3</td>
<td>90</td>
</tr>
</tbody>
</table>

(Source: Agulanna et al., 2007)

Note: Refer to table-1 column 2, Decoated and whole means decoated seed that is unbroken.
DISCUSSION

The angular speed of the cracking machine affects the efficiency of decoating and separation of the coats from the cotyledon. Reference to the data collected and graph plotted from determination of optimal speed needed for cracking, high speed range from 1600 – 2000 rpm resulted in tremendous breakage of the soya-bean seeds. The breakage was up to 82%. Lower speeds below 1400 rpm resulted in high level of uncoated soya-bean seeds. The percentage undercoating was up to 70%.

The extensive test result carried out with the designed and fabricated machine on the toasted soya-bean seeds, resulted to a decoating efficiency of 95%, undercoating of 5% and separation efficiency of 90%.

CONCLUSION

Wet decoating of soya-bean is labour intensive, time consuming and uneconomical when compared with direct decoating of dried soya-bean. Toasting is applied to boost the efficiency of decoating and separation. From efficiency of decoating and separation achieved from extensive testing of the designed and fabricated double action decoating and separation machine, it is clear enough to conclude that the dry decoating is a better alternative to wet decoating.

APPENDIX

The assembly drawings of the designed and fabricated double action soya-bean decoating and separation machine are attached in the appendix. Attached also is a life photograph of the fabricated machine.
REFERENCES


