Development and Performance Evaluation of a Domestic Granular Screw Conveyor

Olanrewaju, T. O.¹, Olawepo-Olayiwole, O. S.², Wahab, A. A.² and Fagge, A. A.¹

¹NAERLS, Ahmadu Bello University, Zaria, Kaduna State, Nigeria.
²Institute of Technology, Kwara State Polytechnic, Ilorin, Kwara State, Nigeria.

Available online: December 31, 2014

To cite this article:
Development and Performance Evaluation of a Domestic Granular Screw Conveyor

Olanrewaju, T. O.¹, Olawepo-Olayiwole, O. S.², Wahab, A. A.² and Fagge, A. A.¹

¹NAERLS, Ahmadu Bello University, Zaria. Kaduna State. Nigeria.

(Received: 27 November 2014 / Accepted: 19 December 2014 / Published: 31 December 2014)

Abstract

In this study, a domestic granular screw conveyor was developed to eradicate the labour intensiveness involved in transporting grain into silo, bin or trailer to save time. The machine was fabricated using locally available materials; hence, the ease of maintenance and repair is ensured to the local/peasant users. This machine can be driven by electric motor where there is electricity or with an IC Engine where electricity is not available. The result obtained from the tests carried out on the conveyor indicated a 99.95% efficiency showing that the conveyor is effective to transport granular materials through an elevated location. The average output capacities at varying angles of inclinations were 407.1, 282.4 and 263.1 kg/hr. for 0°, 30° and 45° respectively.

Keywords: Screw conveyor, Period of conveyance, Output capacity and Angle of inclination

For corresponding author:
E-mail: info@esxpublishers.com
Subject: 1114-0236
© 2014 Exxon Publishers. All rights reserved
Introduction
Grain handling equipment is available for any situation under which grain must be transported from one location to another. The four types most commonly used for commercial and farm applications are belt, bucket, pneumatic and screw conveyors. Conveyors play an important role in the handling of agricultural materials. The high productive capacity of modern farms has created a real need for handling agricultural products in a rapid and efficient manner. The pitchfork and shovel are being replaced by power conveying equipment. Proper selection of power conveying equipment will make it possible to integrate component parts into a smooth, efficient and functional materials handling system. There are several methods used to convey agricultural materials. The selection of conveying method depends upon the nature of application and on the type of material being conveyed. The agricultural materials may be granular, powder, fibrous, or any combination of these.

A screw conveyor consists of a circular or U – shaped tube which a helix rotates. Grain is pushed along the bottom of the tube by the helix; thus the tube does not fill completely. Screw conveyors are widely used for transporting and/or elevating particulates at controlled and steady rates. They are used in many bulk materials applications ranging from agriculture i.e. conveying grain from storage bins and transport vehicles, mixing grain in storage, and moving grain in a bin to a central unloading point, chemicals, pigments, and food processing. They are very effective conveying devices for free flowing or relatively free flowing bulk solids, giving good throughput control and providing environmentally clean solutions to process handling problems because of their simple structure, high efficiency, low cost and maintenance requirement. They are not practical for high capacity or long transport distances due to high power requirements. Screw conveyors vary in size from 75 to 400 mm in diameter and from less than 1 m to more than 30 m in length (Hemad, Mohammad and Mohammad, 2010; Owen and Cleary, 2009; Labiak and Hines, 1999).

The physical characteristics of the material to be handled must be known before the appropriate conveying system can be selected. In particular, the following properties are relevant for agricultural products: moisture content, average weight per unit volume, angle of repose, and particle size. Grain flow rate, distance, incline available space, environment, and economics influence conveyor design and operating parameters. Miller, (1985) reported investigation by an Agricultural establishment making comparison between trailer to discharge and employing six able bodied men using containers requiring to unload an average capacity of 2.68 m³ grains. The six able bodied men using containers was reported to have spent a period of about 20 to 30 minutes off-loading while the trailer takes just about a minute to discharge the same quantity of the grain. Besides the high cost of labour that may be involved, the manual method is cumbersome and offloading may be hindered where labour is scarce or too expensive to employ. It was also assumed that the estimated time will be increased as those men are consistently engaged in continuous or intermittent offloading. According to Aremu (1988), Oliver Evans (An inventor of screw conveyor) was given general attention to the material handling. He made a research and find out that about 30% of labour in food manufacturing is expended on food material handling. He therefore went into food material handling. In the study of Henderson (1974), material flow requisite determines possible conveyors usages. This gives rise to another development of various devices of conveying equipment with this classification: Pneumatic conveyor, Chain conveyor, Screw conveyor, Bucket elevator, Gravity conveyor, Auger conveyor, Belt conveyor, Powered roller conveyor, Non-powered roller conveyor.

A screw conveyor with the housing diameter of 15.5 cm, screw diameter of 13 cm and screw shaft diameter 3.5 cm having the length of 150 cm was constructed by Hemad, Mohammad, and Mohammad (2010) for conducting an experiment. Their results revealed that the specific power requirement of the conveyor increased significantly with increasing the screw diametric clearance and screw rotational speed. The net power requirement of the conveyor increased significantly with increasing the screw rotational speed; whilst the value found to be decreased with increasing the screw clearance. As the rotational speed of the screw conveyor increased, the actual volumetric capacity increased up to a maximum value and further increases in speed caused a decrease in capacity. The volumetric efficiency of the screw conveyor decreased significantly with increasing the screw diametric clearance and screw rotational speed. Ahmad, et al., (2014) designed and develop a conveyor belt lift with tractor P.T.O. as prime mover. During operation, the conveyor belt acts normal to the longitudinal tractor axis, while the tractor P.T.O. transfers power to the gearbox of the conveyor system. The conveyor system angle of inclination i.e. gradient can be adjusted through a hydraulic cylinder actuated by the hydraulic output of the tractor. The linear velocity of the conveyor is adjusted through a pulley carrying wedge-shaped belts. The conveyor belt is 5 hp which can also be actuated through mechanical/electrical motors with lower horse powers.

Therefore, due to the disadvantages associated with loading of a trailer or silo manually, an auger type for grains could be introduced for loading a trailer or into the silo. The machine could be mobile or mounted type on the trailer or silo, but considering the economic aspect of the two, it will be advantageous to design a simple and medium size which could be stationed at the site of the material deposited and can also be used for subsequent loading, hence, an Auger loader development for grains is this work which was aimed at conveying grains in a slanted form (at an angle of inclination) into a silo or trailer. The fabrication of this machine enhances the rate of conveying agricultural materials compare to manual method. More so, it improves the hygienic condition of conveying agricultural material and also helps to reduce the cost of operation by reducing drudgery encountered in the agricultural sector.
Materials and Methods

The design parameters considered while developing this machine were based on cost, material availability, physical and mechanical properties of both the machine and crops to be conveyed. However, in order to choose suitable materials in fabricating the machine, factors like rigidity, heat resistance, durability of the material used, wear resistance, corrosion resistance, strength and vibration stability, cost of repair and maintenance, portability of the machine etc were taken into consideration. More so, availability of the material and economic factor are also factors that were not compromised so as to make the machine available to small scale farmers. The motorized screw auger conveyor consists of a Worm Auger, Cylindrical Housing, Standing Frame, Hopper, Pulley, Power Source Clamp and V-belt for power transmission as shown in Figure 1. The discharge point is at the upper end of the system where the materials conveyed are discharged. Due to economic consideration, the machine was designed to load a trailer/silo with average size of 2.68 m³ within 15 minutes with the help of an operator. The granular materials to be conveyed are fed into the hopper at the lower end (when at an inclined position), the materials are then moved through the driven transmission via an electric motor positioned at the feeding end by the rotational effect of the auger and discharge the materials at the upper end through the outlet port. An adequate clearance between the auger blade and the Housing (Barrel) was considered in the design to avoid clogging and breakage of grain kernels. A V-belt and pulley is preferred for the transmission components to ensure appropriate operational speed of conveyance. For effective operation, the materials to be conveyed should be at safe moisture level to prevent clogging which could hinder the performance of the transmission unit and the electric motor.

Essential design calculations are made in order to determine and select the appropriate strength and size of the component parts of the prototype of the machine. This is done with the aid of the results and established formula in the design analysis. The design of the shaft is based on the correct determination of its diameter in order to ensure satisfactory strength and rigidity when the shaft is transmitting power when operating and under loading condition. The shaft used could be designed in a way to resist any shear forces which may be subjected due to Torsional or bending stress.

Bending Control

The bending stress “σb” of the shaft was calculated using the expression below for Hollow shaft

$$\sigma_b = \frac{32BMd_0}{\pi(d_0^4 - d_i^4)}$$

Where:

- σb = bending stress, BM = bending moment, d0 = outside shaft diameter,
- di = inside shaft diameter, π = 3.142 constant, 32 = constant

Source: Khurmi and Gupta (2005)

Torsional Control

$$\frac{TxL}{GxT}$$

Angle of twist =

Where:

- T = Torque or torsional moment, L = Length of the shaft, G = Modulus of rigidity of the shaft,
- J = Polar moment of inertia of the cross section area about the axis of rotation.

$$Torsional\; Moment (T) = \frac{2TxJ}{D}$$

But J Hollow Shaft =

$$\pi(d_0^4 - d_i^4)$$

$$T = \frac{\pi d_0^4 (d_0^4 - d_i^4)}{32 \pi x D}$$

Source: Khurmi and Gupta (2005)

Where:

- J = maximum shear stress (chosen to 53 x 10⁶ according to ASME code), π = 3.142, D = Diameter of the shaft,
- d0 = Outside diameter of the shaft, di = Inside diameter of the shaft
Driving power of the motor “P”

\[ P = Q \times g \times L \times K_i \pm H \times k \text{w} \]

Source: Lobotka et al., (1997)

Where:
Q = Capacity of the auger (kg/s), \( K_i \) = Coefficient of friction for grains,
Chopped hags (ki = 2.2 – 2.7), K = Overloading coefficient (k = 1.05 – 1.2),
Lv = Length of the conveyor = 2.44m, H = Perpendicular height = 1.840m,
g = Acceleration due to gravity = 9.81 (m/s\(^2\))

Driving Force of the Conveyor

For a conveyor to function, the angular moment must be directly proportionally to the angular force which has to be greater than the required driving force, hence,

\[ \text{Actual angular force } F_w = \frac{2M_w}{d_i \tan(a + B)} \]

Where:
\( M_w \) = Angular Moment, \( D_i \) = Diameter of Screw where the Bulk of the materials moves (m),
Q = Pitch Angle, \( R = 23^\circ \), B = Frictional Angle for the whole Screw
Source: Labotka et al., (1997)

Angular Momentum for the Shaft is calculated using the expression

\[ M_w = \frac{q_m}{2 \pi n} (Nm) \]

Where:
\( q_m \) = weight of the materials to be transported (kg/m) and is given as
\[ q_m = \frac{Q_s}{V} \]

\( N \) = number of Screw Rotation and is taking according to the Conveyor materials for dense (Coarse) Material and ranges between 0.8 – 1.5,
\( V \) = Velocity of the Auger (m/s) and is given as
\[ V = S \times \pi \]

Where:
\( S = \) Pitch of the Auger = 0.031

Magnitude of the driving Force “\( F_v \)” is determined using the formula

\[ F_v = q_m \left( L_v \pm H \right) F \cdot g (N) \]

Where:
\( L_v \) = Length of the Conveyor, \( H \) = Vertical height, \( F \) = Coefficient of friction, \( g \) = acceleration due to gravity

Cylindrical Housing

\[ \text{Volume of Cylinder} \left( V \right) = \pi r^2 h \]

Where:
r = radius of the cylinder
h = height of the cylinder

Performance Test and Results

The conveyor was tested at no-load, known weight of the granular materials i.e. maize, sorghum and garri were then introduced into the auger through the hopper while the machine was running; the average quantity discharged at the outlet were collected and the time taken to discharge them recorded and presented in the tables below

The efficiency \((\xi)\) of the system can be obtained by the expression

\[ (\xi) = \frac{\text{Total Weight of grain collected}}{\text{Total Weight of grain feed into the Hopper}} \]

Efficiency \((\xi) = 100 - 0.05/10 \)
\[ = 99.95\% \]
Results and Discussion
During the running of the conveyor, minimal damages were experienced with maize due to the clearance between the Auger and the Housing Barrel which seems smaller to accommodate the major diameter of the maize grain. However, grains of smaller diameter like Sorghum, and Garri were accommodated. It was observed that when the conveyor was at horizontal position (i.e. 0°, 180°, 360°), the discharge was higher for each grains. A reduction in the discharge was discovered as the angle of inclination increases, hence, the time taken to discharge increases simultaneously as reflected in Figure 2. From tables 1, 2 and 3, it was observed that the average discharge rate at 45° is about 0.070kg/sec. This implies that to transport 10kg of Maize grains, 133sec will be required. Also, the average rate of discharge at 30° angle of inclination was about 0.080kg/sec. implying that to transport 10kg of maize grains, 127seconds is required. For average discharge rate at 0°, 180°, 360° is about 0.12kg/sec. indicating that to transport 10kg of maize grains, 84seconds is required. The relatively shorter time required by the conveyor to transport grain at horizontal position is due to easiness of conveyance at horizontal level than at an elevated position i.e. gravitational force is responsible for such. Some computations were done to obtain the Average capacity (kg), Average period of conveyance (Sec) and Average output capacity (kg/hr) and then tabulated to develop a relationship (Table 3). From Table 6, relationships between the Angles of inclination, the Output capacities (OC) and the Periods of discharge (P) are developed as shown in Figures 2 and 3.

Result in Table 4 is used to develop the relationships between the Average output capacities (kg/hr), Angles of inclination and Periods of conveyance (Sec). The relationship is as presented in Figures 1 and 2. It could be observed that as the Angle of Inclination increases, the Output capacity reduces while the period of conveyance increases as shown in the figures. This can be accounted for in the hypothesis that it requires minimum effort to move products in a horizontal manner than in elevated levels. Since the efficiency of this system is 99.95%, it implies that if the machine is operated continuously with large quantity of grains, the percentage damaged will diminish and hence a higher efficiency will be attained. Same applies to the percentage broken and in this case the grain auger conveyor may be of tremendous usage to the feed millers.

Conclusion and Recommendations
The auger conveyor was primarily developed and fabricated to eradicate drudgery involved in the indigenous method of handling grains especially into silos, bin, cribs, trailers and feed mills. The result obtained from the performance evaluation carried out shows that the conveyor is effective to transport granular materials through an elevated location due to its efficiency of 99.95%. The Average output capacities were 407.1, 282.4 and 263.1kg/hr. for 0°, 30° and 45° respectively. Hence, with appropriate design consideration and adequate material selection to specification, the difficulties in manual loading of grains into storages, bin, silos, and processing points shall be overcome and an eventual prevention of wastage and damages will be achieved. This will also minimize the high cost of labour incurred in manual loadings.

References
## Tables

### Table 1: Grain Output at Angle of Elevation of 45°

<table>
<thead>
<tr>
<th>Replication</th>
<th>Input (kg)</th>
<th>Grain Output (kg)</th>
<th>Time taken to Discharge (sec)</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>1.00</td>
<td>0.99</td>
<td>22</td>
</tr>
<tr>
<td>II</td>
<td>1.50</td>
<td>1.45</td>
<td>25</td>
</tr>
<tr>
<td>III</td>
<td>2.00</td>
<td>2.00</td>
<td>25</td>
</tr>
<tr>
<td>IV</td>
<td>2.50</td>
<td>2.50</td>
<td>28</td>
</tr>
<tr>
<td>V</td>
<td>3.00</td>
<td>3.00</td>
<td>32</td>
</tr>
</tbody>
</table>

Average Output Capacity (kg/hr.) = 263.05 kg/hr.

### Table 2: Grain output at angle of elevation of 30°

<table>
<thead>
<tr>
<th>Replication</th>
<th>Input (kg)</th>
<th>Grain Output (kg)</th>
<th>Time taken to Discharge (sec)</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>1.00</td>
<td>1.00</td>
<td>20</td>
</tr>
<tr>
<td>II</td>
<td>1.50</td>
<td>1.50</td>
<td>21</td>
</tr>
<tr>
<td>III</td>
<td>2.00</td>
<td>2.00</td>
<td>24</td>
</tr>
<tr>
<td>IV</td>
<td>2.50</td>
<td>2.50</td>
<td>29</td>
</tr>
<tr>
<td>V</td>
<td>3.00</td>
<td>3.00</td>
<td>33</td>
</tr>
</tbody>
</table>

Average Output Capacity OC (kg/hr.) = 263.05kg/hr.

### Table 3: Grain Output angle of elevation of 0°

<table>
<thead>
<tr>
<th>Replication</th>
<th>Input (kg)</th>
<th>Grain Output (kg)</th>
<th>Time taken to Discharge (sec)</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>1.00</td>
<td>0.99</td>
<td>12</td>
</tr>
<tr>
<td>II</td>
<td>1.50</td>
<td>1.49</td>
<td>14</td>
</tr>
<tr>
<td>III</td>
<td>2.00</td>
<td>1.99</td>
<td>16</td>
</tr>
<tr>
<td>IV</td>
<td>2.50</td>
<td>2.49</td>
<td>18</td>
</tr>
<tr>
<td>V</td>
<td>3.00</td>
<td>2.99</td>
<td>24</td>
</tr>
</tbody>
</table>

Average Output Capacity (kg/hr.) = 263.05kg/hr. (Horizontal Position)

### Table 4: Average output capacity, angle of inclination and period of discharge for Maize

<table>
<thead>
<tr>
<th>Angle of Inclination (°)</th>
<th>Output capacity (kg/hr.)</th>
<th>Average Time taken to Discharge (sec)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>407.046</td>
<td>17.6</td>
</tr>
<tr>
<td>15</td>
<td>313.04</td>
<td>20.6</td>
</tr>
<tr>
<td>30</td>
<td>282.353</td>
<td>25.5</td>
</tr>
<tr>
<td>45</td>
<td>263.05</td>
<td>26.6</td>
</tr>
<tr>
<td>60</td>
<td>216.33</td>
<td>31.25</td>
</tr>
</tbody>
</table>

### Table 5: Average output capacity, angle of inclination and period of discharge for Sorghum

<table>
<thead>
<tr>
<th>Angle of Inclination (°)</th>
<th>Output capacity (kg/hr.)</th>
<th>Average Time taken to Discharge (sec)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>450.2</td>
<td>16.6</td>
</tr>
<tr>
<td>15</td>
<td>400.1</td>
<td>19.6</td>
</tr>
<tr>
<td>30</td>
<td>350.5</td>
<td>24.4</td>
</tr>
<tr>
<td>45</td>
<td>263.0</td>
<td>25.6</td>
</tr>
<tr>
<td>60</td>
<td>240.15</td>
<td>29.25</td>
</tr>
</tbody>
</table>
Table 6: Average output capacity, angle of inclination and period of discharge for Gari

<table>
<thead>
<tr>
<th>Angle of Inclination (°)</th>
<th>Output capacity (kg/hr.)</th>
<th>Average Time taken to Discharge (sec)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>460</td>
<td>15.6</td>
</tr>
<tr>
<td>15</td>
<td>410.2</td>
<td>17.6</td>
</tr>
<tr>
<td>30</td>
<td>365.3</td>
<td>21.4</td>
</tr>
<tr>
<td>45</td>
<td>310</td>
<td>22.6</td>
</tr>
<tr>
<td>60</td>
<td>300</td>
<td>24.5</td>
</tr>
</tbody>
</table>

Figures

Figure 1: Isometric view of the screw conveyor

Legend

13  Worm Auger
12  Support
11  Adjuster
10  Discharge Unit
9   Belt
8   Motor Pulley
7   Auger Pulley
6   Frame
5   Electric Motor
4   Electric Motor Mountain
3   Main Shaft
2   Cylindrical Housing (Barrel)
1   Hopper
**Figure 2:** Relationship between Angle of inclination and Output capacity

![Graph showing the relationship between Angle of inclination and Output capacity for Ga, Sorghu, and Maiz.](image)

**Figure 3:** Relationship between Angle of inclination and period of discharge

![Graph showing the relationship between Angle of inclination and period of discharge for Maize, Sorghu, and Gar.](image)

**Figure 4:** Relationship between Angle of inclination and period of discharge

![Graph showing the relationship between Angle of inclination and period of discharge for Maize, Sorghu, and Gar.](image)

Fig 3: Relationship between Angle of Inclination and Period of Discharge
Figure 5: Fabricated domestic granular screw conveyor