A Review on Screw Conveyors for Bulk Materials in Various Applications

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Abstract

Screw conveyors are widely operated for handling bulk materials in many industries. This literature review will illustrate the recent research works which relate with mineral, agriculture, biomass, and chemical sections. The mechanism of the screw conveyor seems like simple but the physics of particle handling in many fields have some different behaviors that need to be understood clearly. Hence, this comprehensive review has been revealed the theoretical flow rate formulas for the U-shape screw and enclosed the screw conveyors. Moreover, this paper gathers recent literature reviews of various applications for illustrating various results of each section that can use to be a guide for future research works.

Keywords :Screw conveyor, Bulk materials, Handling, U-shape screw conveyor, enclosed screw conveyor

1. Introduction

Materials handling equipment is a part of many industries that have to be employed to convey raw materials or finish goods. Screw feeder and conveyor are one of the most suitable choices for conveying process because they not only can control the mass flow, which provides the clean solution to the environment while the handling process is running, but also, gain a high quality of conveying with the low cost, including the maintenance requirement [1]. Usually screw feeders and conveyors are employed to handle the bulk materials for controlling the mass flow rate in many fields, such as the transportation process in agriculture, mining, chemical, plastic industries, and so forth. The fundamentals of the screw feeders and conveyors are indicated by Metcalf [2] and Carleton, Miles, and Valentin [3]. The main components of the standard screw conveyor are consisted of a screw flights, shafts, hoppers, and screw's casing, which elevate the bulk materials, and feed the part. They can be classified into two main types, U-shape and enclosed shape as shown in **Fig.1** and **Fig.2** respectively [4]. The U-shape conveyor always runs merely low speed drive around 30 to 70 rpm depending on screw shaft diameters, according to CEMA standard [5]. The advantage of this screw type is a good handling system for the cohesive and heavy bulk materials. Meanwhile, the enclosed conveyor can operate at a high-speed drives around 200 to 2000 rpm that can convey and compact a variety of light materials. However, it cannot deliver cohesive and heavy weight of bulk materials [4]. As the recent researches, the enclosed screw conveyor has vary auger's sizes between 75 to 400 mm in diameter and screw's length between 1 m to more than 30 m [6].

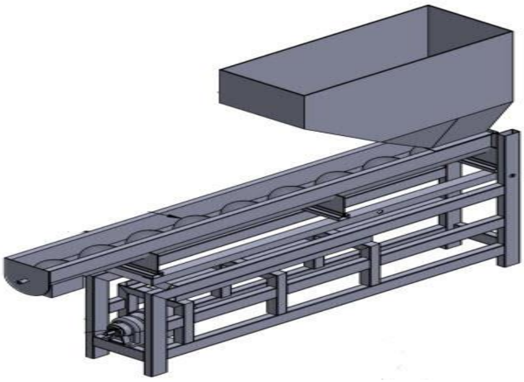

Figure 1 Screw conveyor as U-shape casing

Figure 2 A Screw conveyor as enclosed casing

For the screw feeder, there are some different details from screw conveyor as shown in **Fig.3**. The screw feeder is usually used to control the flow rate of the granular materials. The hopper is a part that supports to feed materials into screw conveyor. The size of the hopper opening ranges is between one to three times of the screw pitch [4]. The main advantage of screw feeder is the stability to control the flow rate of bulk materials during conveying. The rotational velocity of screw feeder should maintain as low in order to gain the uniform flow rate and reduce the overload effects from the centrifugal of screw power.

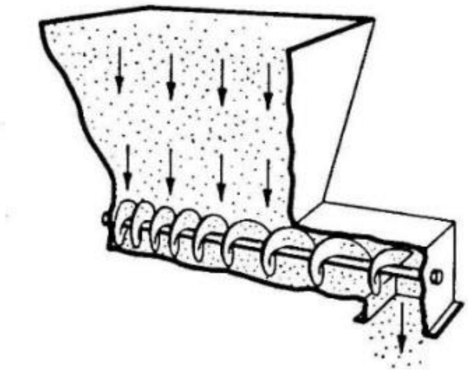

Figure 3 Example structure of screw feeder

As surface explained about the types of screw conveyor, many researchers had attempted to solve material handling problems through the screw feeder and the conveyor. Some experiment researches had been investigated in various characteristic problems such as focusing on cohesion and non-cohesion during handling process [3],[7–10]. Some researchers studied methodology of the mass flow rate measurement [11–12], and some concentrated on the mixing result of the bulk materials [13–14]. These experimental results provided a good improvement to optimize the machine parameter and design. Moreover, some researches seek for suitable power, torque requirement for materials handling [15–17] and the theoretical models of the particle motions during transportation [2],[18–20]. In addition, Zareiforoush et al. [1] tried to conclude from many researches on screw conveyor performance. They explained about theoretical models for bulk materials handling, however, the scope of the reviewed literature are concentrated on the agriculture material fields and also derived the volumetric flow rate for the merely enclosed screw conveyer. Another technique that has recently been applied to solve the bulk materials handling is the discrete element method (DEM) which is one of the numerical methodology. Cundall and Strack [21] introduced DEM in bulk materials handling fields to illustrate the particle flow behavior, the particle interaction, and particle reaction forces of bulk materials under many situation constraints. DEM methodology was used to simulate and compare the relationship of particle between theoretical and experimental results, especially the mass flow rate, average particle speed, and so on. The outputs of DEM provide closely results comparing with the experiments. For instance, some researchers investigated granular handling for the horizontal screw conveyor [22–24], bulk materials handling in inclined screw conveyor [25], vertical screw conveyors [26], and screw conveyer with mixers [27]. Moreover, DEM seems to obtain the detailed data, related with the flow pattern, flow rate, power requirement, particle speed and other factors of granular particles via simulation before making empirical tests. Thus, it will reduce experimental time for researches.

According to the previous published literature reviews, the screw feeder and conveyors need to be deeply studied for a better understanding in optimization and design of screws because they are currently utilized in a wide range of activities and conditions. Therefore, this review paper gathers and illustrates the theoretical flow rate capacities for the design of U-shape and enclosed screw conveyors. In addition, the review contents related with the screw conveyor would be separated into the different areas of agriculture, mining biomass, and chemical groups which have their own specific constraints

2. Theoretical Formula of Screw Conveyor

The theory of transportation of bulk materials in screw conveyor and feeder has been continually researched [16–17],[20],[28]. The main factors and effects of screw theory are screw dimension, shaft dimension, clearance between housing and screw, flow rate, efficiency of material handling, torque requirement, and power consumption. Thus, the main content of this paper would be mentioned about two types (U-shape casing of screw conveyor and enclosed casing screw conveyor) of screw design calculation. Thus, the flow rate capacities in each type of the screws can derive as the following.

2.1 U-Shape Screw Conveyor

The key objective of U-shape screw conveyor as shown in **Fig.4** is material handling capacity that depends on conveyor size and speed. In order to specify the speed and size of screw conveyor, it firstly needs to know the details of material properties for the transportation.

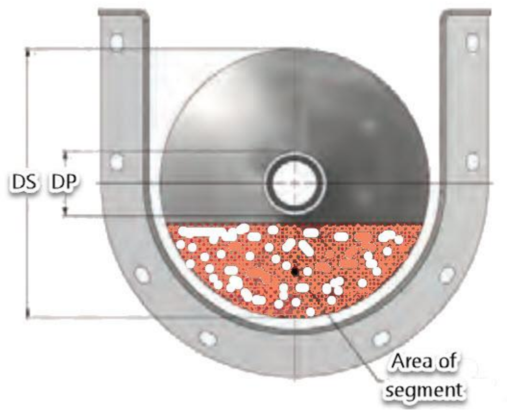

Figure 4 structure of U-shape casing of screw conveyor

Conveyor Equipment Manufacturers Association standard [5] provided various material properties and material code to be a guideline for selecting the suitable screw conveyor properties and checked the limitation of the lump size before selecting the screw dimension. The formula of flow rate calculation can be derived from Equation. (1) as follows [5]:

$$\frac{C}{RPM} = \frac{0.7854 \times (D_S^2 - D_P^2) \times P \times K \times 60}{1728} \qquad (1)$$

Where:

C is the flow rate (ft^3 / hr)

RPM is revolutions of screw per minute

D_s is a diameter of screw (in) that can gain from fig.4

D_p is a diameter of pipe (in) that can gain from fig.4

P is pitch of screw (in)

K is percent through loading that can search from CEMA guide book [5]

Note: This formula assumes that the flow rate in ft^3 / hr per 1 RPM

This formula is established without concerning flight thickness, flight tolerance dimension, and pitch tolerance. Therefore, the pitch of the screw, the type of the flight, and the operation of mixing paddles within the flight pitches are concerned as CF_1 , CF_2, and CF_3 respectively that can select from as a table 2-4 in ref [5].

The equivalent flow rate can be provided as Eq. (2):

$$Equivalent\ flow\ rate = (\text{Required flow rate}) \times (CF_1) \times (CF_2) \times (CF_3) \quad (2)$$

Another factor that has to be concerned for the screw conveyor design is a conveying speed that can be calculated according to CEMA standard for regular helical screw flight with standard pitch as Eq. (3). [5]

$$N = \frac{\text{Required Capacity},(\frac{ft^3}{hr})}{\frac{ft^3}{hr}\ at\ 1\ RPM} \quad (3)$$

Where:

N = Conveyor Speed, RPM of screw, and this equation is used for only recommended speed according to CEMA standard [5].

2.2 Enclosed Screw Conveyor

For enclosed screw conveyor as shown in Fig.2, the theoretical flow rate capacity can be expressed according to the research of Srivastava et al. [29] as Eq. (4) below:

$$Q_t = \frac{\pi}{4}(D_{sf}^2 - D_{ss}^2)l_p n \quad (4)$$

Where:

Q_t = theoretical volumetric capacity, m^3/s

D_{sf} = screw diameter, m

D_{ss} = shaft diameter, m

l_p = pitch length, m

n = screw rotational speed, rev/s

According to Eq. (4), it is theoretical flow rate capacity. Actually, the flow rate capacity of screw conveyor should be considerably below the theoretical capacity because during conveying, there are many effects that make loss on the volumetric efficiency. Thus, the volumetric efficiency can be derived as Eq. (5) below.

$$\eta_v = \frac{Q_a}{Q_t} \quad (5)$$

Where:

η_v = volumetric efficiency

Q_a = actual volumetric capacity, m^3/ s

Whereas Q_a can be approximately calculated by developing predicted equation from experimental data that illustrated the good performance of screw conveyors for transporting wheat, oats, and shelled corn as shown in Eq. (6)

$$\begin{aligned} \frac{Q_a}{\frac{\pi}{4}(D_{sf}^2 - D_{ss}^2)l_p n} &= (4.33 \times 10^{-4})a * b * c \\ a &= \left(2\pi n\sqrt{\frac{l_p}{g}}\right)^{-0.44} \\ b &= \left(\frac{l_i}{l_p}\right)^{0.31} \\ c &= (f_1(\theta))^{1.35}{\mu_1}^{-4.59}{\mu_2}^{-3.72} \end{aligned} \quad (6)$$

where, $f_1(\theta) = 1 + cos^2\theta$; θ is handling angle as measured from the horizontal, degree; $414 > \mu_1 > 0.374; 0.554 > \mu_2 > 0.466$; g is an acceleration of gravity, m/s^2 ; l_i is exposed screw intake length m.

3. Research Group in Mining Experiments

For the research of mining clusters, there are many aspects that many researchers were concerned. For example, Yu and Arnold [16] studied the theoretical torque requirements of screw feeders for handling cement and semolina by investigating both feeding and choke sections.

The outcome of this research provided the theoretical model of torque requirement that was improved by principles of powder mechanics and concentrating a transferred element within pitch of screw. The theoretical model indicated almost the same as experimental data and all geometry parameters of screw feeder. Moreover, it presented the relationships between the torque characteristics and another result from this research, which was the starting torque value near to the operating torque value. Therefore, this outcome will be usable for designing flow load of screw feeder. Shimizu and Cundall [30] deeply concentrated on the numerical analysis of bulk materials handling, especially simulation and particles through the screw conveyors by using discrete element method (DEM). These results provided both horizontal and vertical screw conveyor analysis. For horizontal screw test, the critical angle should be considered smaller than the predicted angle model from the static force equilibrium. The overall power should be estimated over the derived model at 15% and also the number of particle was increased, which resulted to the power enhancement. The clearance between screw and casing is a remarkable concern during transportation. For vertical screw test, DEM simulation provided a realistic behavior because not only the particle makes faster speed, but the screw speed is also increased and vice versa. Moreover, the transfer angle and the upward particle speed are almost the same between DEM and theoretical model from the static force equilibrium. Waje et al. [31] studied Residence Time Distribution (RTD) of screw conveyor dryer (SCD) for sand. The experimental results showed that screw speed increased then the degree of particle homogenies would also increase, whereas the mean residence time would be decreased. On the other hand, the feed rate of sand was high with low screw speeds then the capable material mixing would decline. Gaivoronskii and Postoronko [32],[33] investigated ceramic green mixes via screw conveyor. The results concerned about the optimal productivity of a screw conveyor vacuum press that considered the productivity losses due to geometric factors such as the gap among the screw blades and casing, the lift angle of handling line of screw conveyor, the number of the entries screw blade, and the plasticity of the molded paste. Mondal and Ghosh [34] indicated a relationship between filling factor and flood-feeding of short length screw conveyor during handling dry coarse sand. The results presented that the high value of filling rate would reflect flood-feeding situation during short screw conveyor operation. Moreover, the filling factor of short length screw should be two times of long length screw conveyor. It means that the effective filling rate of long length screw should be lower than the short length screw conveyor. Li et al. [35] established experimental research about the behavior of particle flow especially the trajectory angle of particle motion that affected to mass flow rate during transferring sand. The result illustrated that there was the increase of the inclination angle and screw velocity, in contrast to, the decrease of the outlet mass flow capacities. Thus, this research can be concluded that various inclination angle and pitch-diameter ratio are the main effects to the outlet mass flow capacities. Pezo et al. [36] applied DEM to analyze particle movement and premixing bulk materials (natural zeolite and sand) of five types of screw conveyor and three different lengths of horizontal screw conveyor. The advantage of this research is the predicted model of mixing bulk materials based on ANOVA confirmation and the usage of the artificial neural network to develop the model. Sun et al. [37] studied the coal particle handling through the screw conveyor and drum conveying performance by comparing DEM experimental tests with empirical tests. The result showed that the screw blade axial tilt angle affected the screw conveying performance and the best flow rate of screw conveyor. The axial tilt angle of screw blade should be 15°

that will gain 5% higher than the screw blade without axial tilt angle. Yang et al. [38] researched the axial velocity of coal particles for vertical screw conveyor via DEM method. The research outcome provided the axial velocity model of the coal particle via DEM simulation test and confirmed the model via empirical test.

4. Research Group in the Agriculture Experiments

In agriculture screw conveying research, many researches had been attempted to solve the screw design and enhance more efficiency of the screw conveyor. For instance, Moser et al. [39] applied the sensor transmitter for flow rate measurement of wheat particles during screw conveyor operation. The results showed the good performance for the reliable measurement of mass and volume capacity. Zareiforoush et al. [6] studied paddy handling in inclined screw conveyor. There were the investigations of the paddy's moisture content, screw velocity, and conveying inclined angles. The result indicated that paddy's moisture content at 14%, screw velocity at 100 rpm, and an inclination angle at 10° could provide the flow rate capacity with the reduction of broken grains, husked grains, and husked-cracked grain respectively. Mariajayaprakash and Senthilvelan [40] concerned with process parameter optimization of screw conveyor in sugar mill industries. The results provided the root cause of the screw conveyor failure on the fuel-feeding system that occurred from fuel type, fuel moisture, drum speed, and air flow. Dixit et al. [41] studied the effect of con germ's loading percentage, castor bean, and sugar on horizontal screw conveyor. The experimental data showed the incremental percentage of loading materials on screw conveyor. Then the maximum recommended screw speed and flow rate capacity would also be increased, whereas screw diameter should be dramatically decreased. Among three agriculture material tests, sugar may require higher horsepower than others for handling. Olanrewaju et al. [42] studied parameter design of screw conveyor for granular materials (miaze ,sorghum,and gari) at 13% moisture content. The results show that the elevated location of screw conveyor can provide 99.95% and recommended inclined angle should be at 0°,30°, and 45° especially gari handling. Hevko et al. [43] investigated about a flexible screw conveyor for bulk agricultural materials especially peas and wheat. This research provided a condition guideline for flexible screw operation by suitable screw speed at 650 to 670 rpm and the screw speed for minor damage of bulk materials during transportation, which should be the range of 550 to 650 rpm. Ozbek [44] tried to seek the volumetric and energy consumption efficiency in agriculture screw conveyor, especially barley particles. This result employed the fuzzy logic methodology to optimize screw speed, screw pitch, and loading angle. The outcome provided the suitable screw speed, screw pitch, and loading angle at 450 rpm, 100 mm, and 15° respectively for the best volumetric efficiency. In addition, the optimal energy consumption should use screw speed at 550 rpm, 100 mm screw pitch, and 22.5° loading angle.

5. Research Group in the Biomass Experiments

For the biomass researches in screw conveyor, the solution guidelines for the material handling section have been interested recently to improve all constraints and aim for the better performance. Miao et al. [45] studied biomass materials (miscanthus and switchgrass) in a commercial screw conveyor by concentrating on the flow performance, the angle of material's repose, the energy efficiency, the volumetric efficiency, and so on. The results showed that the energy efficiency and mass flow rate of miscanthus and switchgrass presented lower than the corn conveying, while the volumetric flow rate and volumetric efficiency of biomass materials (miscanthus and switchgrass) had value near to corn conveying. The angle's response of miscanthus and switchgrass depended on particle size and moisture content. Another result from this research was a non-relationship of the angle's response and the specific energy consumption to transfer miscanthus and switchgrass. Nachenius et al. [46] researched the residence time distribution of biomass particles for the screw conveyor reactor. This work illustrated the mathematical predicted model of the mean residence time of biomass materials such as pine chips, rice, and sand. It provided a good performance, which not only could apply to similar materials, but also applications. Rackl and Gunthner [10] tested the effect of different grades of wood chips on screw feeder. In this research, three different wood chip grades and two blends of wood chips were concerned to investigate mass flow and torque requirement. The conclusion of this work, wood chip was difficult to transfer with screw conveyors, especially the large dimension of wood chip and the particle size of wood chip were a main factor for the driving torque. Another main result from this work was the wood chip mixing that could solve the excessive driving torque of screw feeder by mixing 70% of hard-to-feed wood chip grade and 30% of a high-fine grade including bark and needle content. Chamberlin et al. [47] researched the residence time distribution of wood chip feedstock in screw conveyor reactor. There were four methods to derive residence time distribution of handling (the estimated ideal residence time, the positive step, the pulse input of tracer, and the negative step). The result showed that the pulse input of tracer illustrated a long trailing tail that could not be investigated. Also there was a conclusion that the average residence times were short, and then the flow rate capacities would be higher. Lian et al. [48] concentrated DEM simulation for mixing coal and cylindroid biomass particles in a screw feeder. The results provided the biomass feeding ratio, feeding rate, and screw speed. It could be concluded that a higher biomass feeding ratio would result to the stabilization of the real time mass flow rate and biomass blending rate. On the other hand, an excessive feeding rate might be a reason of some cylindroid biomass flow obstacle.

6. Research Group in the Chemical Experiments

Another cluster that screw conveyor, which played an important role is the chemical section. For instance, Fu et al. [49] studied the design of screw conveyor in rubber manufacturing. The details of this research provided theoretical equation for designing screw conveyor in rubber process fields. This described step by step for producing screw conveyor in rubber process operations and illustrated the main parameters for the design, such as humidity of bulk materials, characteristics of materials, purification of materials and so forth. Deng-cheng et al. [50] concentrated on the processing interaction of Ashalt mixture on screw conveyor. There was demonstration of the relationship between a paving segregation of asphalt and a parameter design of screw conveyor. The result then showed that screw blade diameter, pitch, and position of mixing in the screw distribution related to the performance of paving asphalt, the reduction of a tangential force, and the increment of an axial force during handling via screw conveyor. That would provide the satisfied efficiency of mixing asphalt. Pezo et al. [51] researched the mixing mechanism of screw conveyor through DEM methodology and used the painting spherical granules that made from zeolite for being material tests. In this research, there was a usage of helix or helical strips to be added on the normal screw types, in order to concentrate homogeneity of screw mixture. DEM was employed to study fifteen screw conveyor and five different geometries. The results indicated that the straight-line blade could blend bulk material better than the others at any screw length. Sun et al. [52] used DEM simulation to investigate non-spherical particles that made from polymethyl methacrylate (PMMA) for handling in screw conveyor. The conclusion of this research provided that the axial, filling level and angular velocity would be decreased, when shape index of particle was increased. Meanwhile the shape index of particles has been increased, the contact force, the power consumption, the wear of conveyor, and the pressure during screw conveying would be continually increased. Moorthi and Megaraj [53] tried to design and develop the single screw conveying machine for transforming waste plastic to oil. This research applied screw conveyor to be a part of pyrolysis process. The result showed that the integrated screw conveyor in pyrolysis process could transfer oil more efficiency than the pyrolysis process without integrated screw conveyor.

7. Discussion and Conclusions

This review paper attempts to indicate the important concerns in various industries of screw feeders and conveyors. As mentioned in the literature researches, mineral, agriculture, biomass, and chemical applications have some different constrains of elevating and mixing purposes for the bulk materials. Many researchers investigated by varying screw pitch, screw dimension, screw velocity, angle of elevation, angle of repose, clearance between screw and casing, and so on . Most of them attempted to optimize the mass flow rate, the volumetric rate, the power consumption, and the torque requirements, while each group could provide the different results depending on its objective because screw conveyor depended on many factors, especially bulk material properties, which each material had the different properties Therefore, screw conveyors of each industry group should be selected to suit their own theoretical models for the best design and operation. These will provide reliable results of screw performance. Therefore this review paper can provide some concluded guidelines for each industry group as:

The mining group

- The screw conveyor in mining industries should concern about the torque requirements because of feeding and choke process sections.
- The critical angle screw design should be considered smaller than the predicted angle model from the static force equilibrium for reducing power requirement.
- The clearance between screw and casing is a remarkable concern during mining transportation.
- If the feed rate of the coarse particle was high, then the capable material mixing would be decline.
- The relationship between filling factor and flood-feeding of short length screw conveyor during handling dry coarse particle is important whereby the filling factor should be two times of long length screw conveyor.

The agriculture group

- Agriculture particle handling in inclined screw conveyor, the particle's moisture content, screw velocity, and conveying inclined angles have an effect for particle quality such as broken grains, husked grains, and husked-cracked grain, respectively.
- The experimental agriculture particles showed the incremental percentage of loading materials on screw conveyor caused by the increasing screw speed and flow rate capacity and the decreasing screw diameter.
- The flexible screw conveyor for agriculture handling should be applied the screw speed as the range of 550 rpm to 650 rpm.

The biomass group

- The angle's response of biomass particles was depended on particle size and moisture content while the angle's response and the specific energy consumption were independent from each other.

- The conclusion of this biomass researches, biomass chip was difficult to transfer with screw conveyors, especially the large dimension of the particle size that required a higher driving torque.
- If there is the necessity of mixing biomass chips and the driving torque requirement, this should use excessive 70% of the screw feeder.

The chemical experiments

- The chemical particle handling should have the concern about moisture content of bulk materials, characteristics of materials, and purification of materials.
- The screw blade diameter, pitch, and position of mixing in the screw distribution related to the performance of paving asphalt.
- For chemical particle blading, the research results indicated that the straight line blade could blend bulk material better than the others at any screw length.
- The non-spherical particles of chemical materials for handling in screw conveyor and shape index of particle will affect to the contact force, the power consumption, the wear of conveyor, and the pressure during screw conveying.

Moreover, many researches employed DEM configuration to solve the model of bulk material flow in screw feeders and conveyors by considering on the factors of inter particle forces, residence time distribution, particle shape and size, in order to prove the model and their results before the empirical experiments. By this way, it will provide the best performance of cost saving and time reduction for the research operation.

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