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SCREW FEEDER FLOW PROFILE OF AGRO-FOOD BULK SOLIDS. LABORATORY STAND REVIEW

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Abstract: *Handling of bulk solids in agriculture and food industry often involves the use of screw feeders. These are suitable for a wide variety of bulk solids materials with various physical-mechanical characteristics. In the food industry it is important to control material flow and the behaviour of the screw feeder affects characteristics of the feeding hopper. Another key parameter is amount of time that the material remains still in the bunker because the properties of the material are time dependent. The experimental stand presents the discharging profile of screw feeders with variable geometrical design.*

Key words: *screw feeders, discharging profile, mass flow, bulk solids.*

1. Introduction

Screw feeders were used in industry in various fields and applications as they are efficient transport systems for the bulk materials and is widely used in all fields of industry.

Dosing screws are commonly used to extract bulk solids from feeding hoppers and storage bunkers. The material flow from the hopper to the screw feeder influences the flow characteristics, storage periods, segregation, attrition and torque requirements of the screw.

Motion regimes of the bulk solids in various sections of the bunker are a simple qualitative analysis that enables predictions to be made based on material and screw parameters.

Advantages of the horizontal screw feeders are: reduced dust pollution, protection outside contamination, flexibility, reliability, simple construction, easy to clean and good control of the materials flow [1].

The disadvantage of screw feeders is the poor mechanical transport efficiency. Another problem when using screw feeders comes from accidental objects that can damage the screw flight by tapering in the screw clearance and the chamber [5].

The flow profile of this type of screw (Fig. 1) is given by the fact that it will fill with bulk material only the first one or two pitches, and this is the active area of the feeding hopper. The rest of the feeder length will be passive and results in material stagnating above, forming a region of stagnant flow [1].

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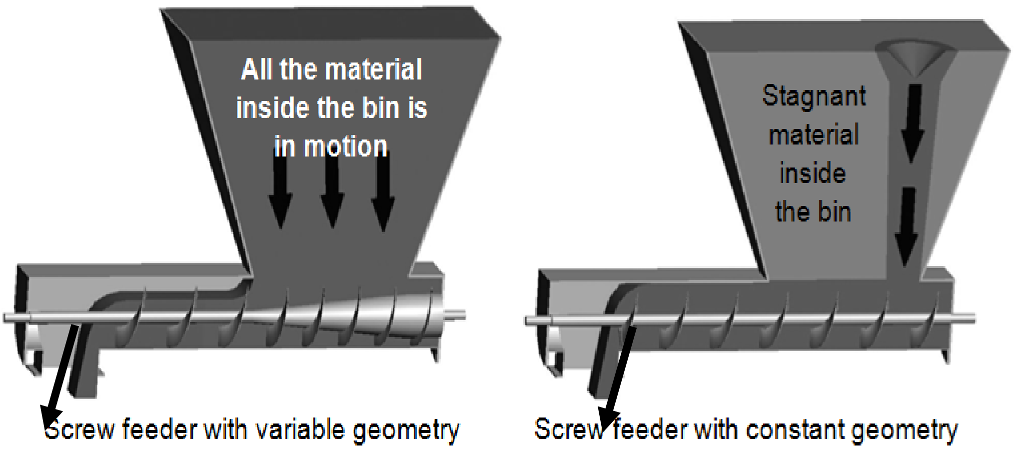

Fig. 1. *Schematic presentation of material extraction with screw feeder with constant geometry right and variable geometry left [4]*

2. Flow Pattern of the Dosing Screw Feeders

The debit flow of the screw feeder $\dot{m}$ is influenced by the filling with material of the screw pitch, coefficient ε, the real density ρ_r of the material in the hopper outlet, the axial transport speed of the screw v_{ax} and the transversal transport section A_{fw} of the material found in the chamber of the screw feeder [6]:

$$\dot{m} = \varepsilon \cdot \rho_r \cdot v_{ax} \cdot A_{fw} \tag{1}$$

Therefore, for the full flight screws the transversal transport section can be calculated using the following relation [7]:

$$A_{sc} = \frac{\pi}{4} \cdot \left(D^2 - d^2\right) - \frac{b}{2s} \cdot \left(D - d\right) \cdot \sqrt{\frac{\pi^2}{4}\left(D - d\right)^2 + s^2} \tag{2}$$

Considering that the transport volume of the screw if filled completely (filling coefficient ε =1), then the extracted material will act as a unitary solid, moving in a helicoidal – axial transport direction.

Using this hypothesis it can be calculated the axial velocity v_{ax} (considering that the actual diameter of the transport section is the diameter of the screw D, in the case of materials with a big granulation, D is equal with the screw chamber diameter D_0), the periphery speed v_u, the transport angle ω and screw flight inclination angle β_1 according with the diameter D. The following relation expresses the axial velocity:

$$v_{ax} = v_u \cdot \frac{\tan\omega \cdot \tan\beta_1}{\tan\omega + \tan\beta_1}; \tag{3}$$

where:

$\beta_1 = \arctan(s / \pi \cdot D)$;

$v_u = \pi \cdot D \cdot n_s$;

n_s is the screw rotation speed and s is the screw flight's pitch [6].

The transport angle ω can be determined with a good approximation based on the equations of stresses and moments equilibrium that act on the axial direction, the angle ω will be calculated through a relation that will neglect the effects given by the internal frictions from material and will consider as the friction factor the surface of the screw flight μ_{ws} [6]:

$$\omega = \arctan\left(\frac{1-\mu_{ws}\tan\beta^*}{\tan\beta^* + \mu_{ws}}\right) \qquad (4)$$

The greater the friction coefficient μ_{ws} (and so the friction angle Φ_{ws} is greater), the smaller will be the transport angle ω and the number of rotations of the material in the dosing screw chamber will be bigger.

The risk of backflow increases with the inclination and with an inclination of 15°, there is already a reduction in conveying efficiency.

The portion of screw feeder that runs under the stagnant material region is under larger shear stresses. More torque power is needed to rotate and greater impact will be acted upon the bulk material, leading to changes in the physical properties of the bulk.

3. Designing of Mass Flow Screws Feeders

From the quality point of view this solution does not provide constant material properties, since the residence time period of the material in the stagnant region requires a longer time to be extracted. Bigger consolidation forces due to the movement of the screw feeder and of the bulk pressure induce more changes in the physical properties.

The construction parameters are constant pitch in the feed section and larger constant pitch in the conveying section. Usually the pitch of the screw feeder is designed to be about two thirds of the diameter value in the feed section, and equal with the diameter in the conveying section. Larger values are consider to lead to poor transport efficiency [1].

Screw Feeders with variable pitch (Fig. 4) provide increasing extraction capacity by starting with a short pitch of the screw flights and progressively increase the pitch to the maximum capacity. For short distances they can achieve a continuous bulk flow. The capacity of each increment depends on the transfer capacity of each screw flight pitch.

The larger the pitch, the better the extraction of the bulk solids. Minimum pitch used must be no less than one-half the screw diameter and the maximum pitch should be about the screw flight diameter.

Screw feeders with tapered diameter (Fig. 4) are another solution to provide a mass flow in the extraction of bulk materials. By starting with a small diameter and increasing it to a maximum value the conveying capacity increases along the tapered length. The pitch of the screw flight is constant and only the flight diameter increases.

This solution has the disadvantage that bulk materials tend to arch above the narrow section of the screw flight diameter and therefore practically it does not convey material. It is very difficult to manufacture and therefore it is also very expensive.

Screw feeders with tapered shaft (Fig. 4) develop the mass flow extraction from the feeding bin by assuring a progressive extraction along the axis since the screw diameter starts from a maximum value in the section of the first screw flights and gradually decreases until it reaches the minimum value which is equal with the maximum output of the screw [2].

This solution for obtaining a mass flow of the extracted material from the bin is very likely to fail because of the fabrication tolerances. Bulk materials tend to arch above the narrow section of the screw shaft diameter and therefore will develop stagnant flow regions. Dead regions in the flow of material will have as consequences the uneven residue periods and unwanted deterioration of the flow properties in the material.

It is expected that the flow profile of the mass flow dosing screw systems for bulk solids, to behave as mass flow so that all the material above the screw will be in motion.

4. Classic Experimental Stand used in Flow Profile Determination

The problem of material extraction by mass flow screw feeders has been experimentally researched by L. Baets [1].

The experimental stand proposed by L. Baets (Fig. 2), consisted of a glass-sided hopper with vertical walls mounted above and outlet that allowed the use of interchangeable screws [1]. The screw chamber was made of transparent plastic in order to observe the material extraction process. The hopper was divided by polished stainless steel grid, fitted vertically above the screw. This hopper grid formed a central division above the screw and isolated each division into a number of equispaced divisions [1].

Various screws of differing geometric characteristics were fitted so that each exposed section of the screw feeder was of identical dimensions. The profile of extracted material from each division was determined and so predicted capacity for each feeding screw was established [1].

This experimental stand offered some valuable information on the way the screw feeder extracted material from the hopper outlet. The disadvantage was that it hindered the real flow of the material and affected the bulk solid density above the screw feeder.

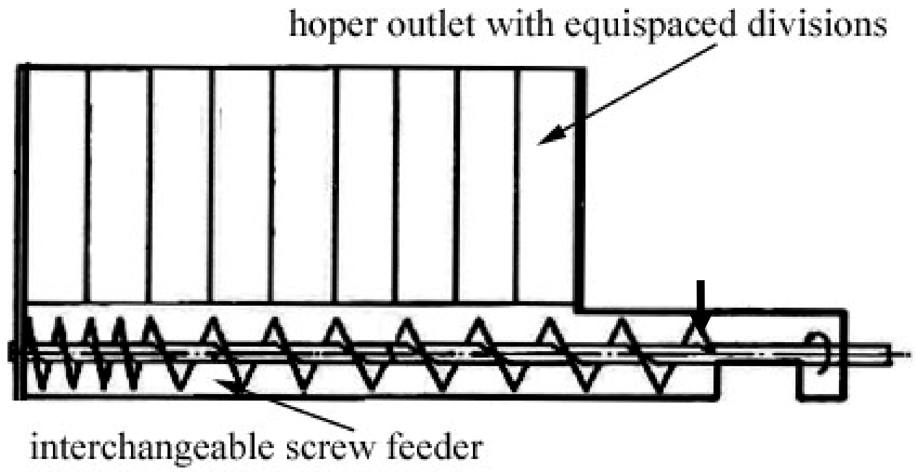

Fig. 2. *Schematic representation of the experimental stand developed for studying of the flow profile of screw feeders* [1]

5. Experimental Stand Developed

The experimental stand proposed by this paper (Fig. 3) analyses the flow profile of the screw feeders by monitoring the free surface of the material found in the feeding hopper.

The laboratory stand offers the possibility of using 4 types of screw feeders that can be easily interchanged.

The flow profile stand is powered by a three-phase electric motor with 1,5kW power that can adjust the rotational speed by using a belt transmission.

A chain transmission drives connects the electric motor to the screw feeder shaft. The electric motor is powered through a variable frequency drive that can provide variable speed control of the electric motor.

The stand offers the possibility of using 4 types of screw feeders that can be easily interchanged. The presentation of the stand is made in Fig. 3.

The screw chamber is made out of a steel tube with an inner diameter of 140 mm and a length of 830 mm. The inlet and outlet areas of the bulk solid are of rectangular section in order to study the most commonly used situation in industry.

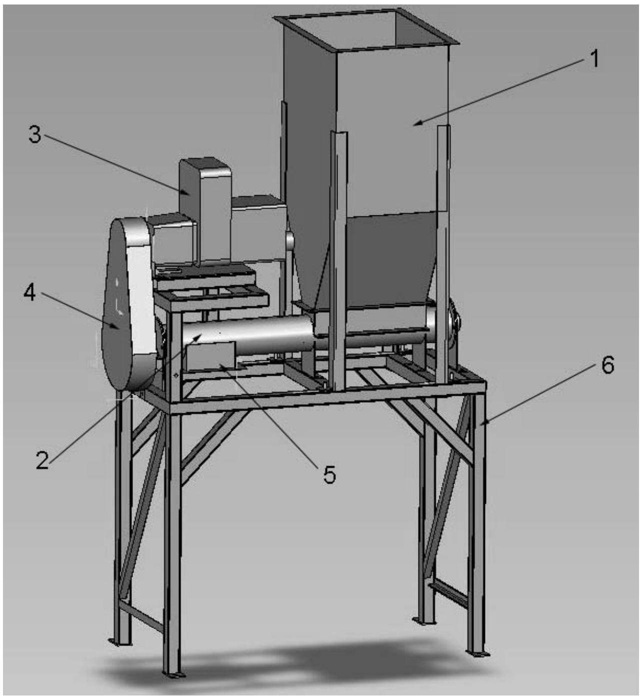

Fig. 3. *3D CAD modelling of the experimental stand used for the determination of the extraction flow profile of screw feeders. 1 – hopper; 2 – screw feeder chamber; 3 – power unit; 4 – chain transmission; 5 – screw feeder outlet; 6 – support frame*

At both ends of the feeding chamber there are easily changeable ball bearing flanges that allow for a quick access for changing the screw feeders.

The feeding bin is made out of steel sheets coated with a wear resistant paint. The capacity of the bin is of 0.2 m^3 and has a rectangular cross section.

The shape of the bin was chosen to prevent the formation of arching of the material above the screw feeders. The bin has no agitating devices.

The feeding screws used in experiments have the following characteristics (Fig. 4):

- constant pitch and diameter: screw flight diameter 125 mm, screw flight step 100 mm, screw flight shaft 40 mm, screw flight thickness 1,5 mm.
- variable pitch: screw flight diameter 125 mm, screw flight shaft 40 mm, with four progressive screw flight steps in the extraction area and a constant 100 mm step in the transport area of the screw, screw flight thickness of 1,5 mm;
- tapered diameter: the screw flight diameter starts at 45 mm and reaches 125 mm on the extraction area, screw flight step 100 mm, screw flight shaft 40

mm, screw flight thickness 1,5mm;

- tapered shaft: screw flight diameter 125mm, screw flight shaft gradually decreases from 120 mm to 40 mm in the extraction area, screw flight step 100 mm, screw flight thickness of 1,5 mm.

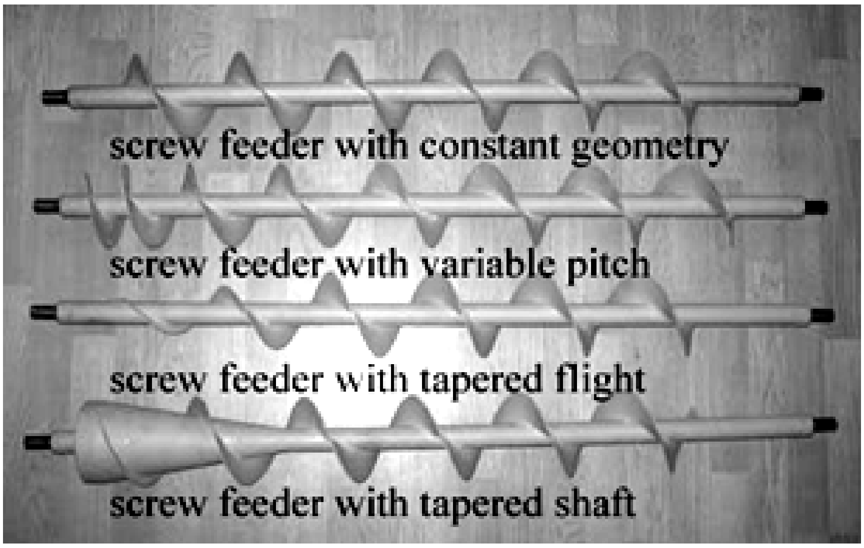

Fig. 4. *Interchangeable screw feeders with different extraction geometries*

The surface of the bulk solid from the feeding bin is monitored according with the characteristics of each screw feeder used [3].

The material surface is determined by a matrix of 9 level sensors placed on sensor plate which determines the swept volumes of material from the feeding bin (Fig. 5).

The sensor plate is mounted on the top of the feeding bunker.

Graphic representation of the measurements provided the surface shape generated at each time interval depending on screw geometry and rotational speed. This method provides a comprehensive insight upon the way the screw geometry affects the flow of the extracted bulk material.

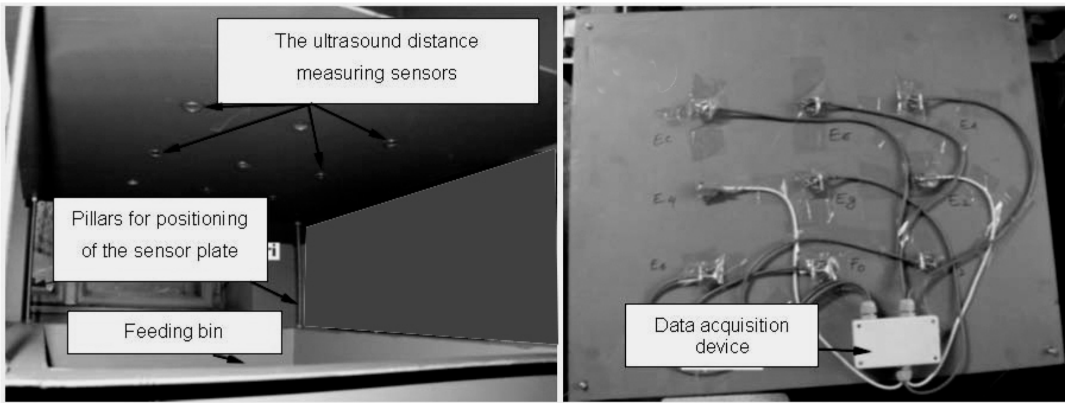

Fig. 5. S*ensor plate used to monitor the material level*

The material extraction behaviour from the feeding hopper can be analysed for each screw feeder type. A matrix of values for the 9 level points of the free surface inside the bin is plotted as a material surface at each time interval established.

The screw feeder with constant geometry reveals a extraction pattern in the area of the first screw flights. The material stagnates for the rest of the screw feeder and flow is active only in the right side of the hopper.

Uniform extraction of the material in the feeding hopper is studied by using screw feeders with variable geometry.

6. Conclusions

The graphic results provide important data for the flow behaviour of the different materials and their flow stagnation times according with the type of the mass flow screw feeder used. The material flow is strongly influenced by the material characteristics to flow freely.

It is expected that materials with cohesive properties to form bridging above the screw feeder, expected manly above the first part of the variable geometry were the extraction capacity is minimum.

Since the density is sensitive to states of stress during flowing, the precision of the output flow is dependent on the uniform characteristics of the bulk solids in the hopper outlet above the screw feeder.

Due to the bigger extraction capacity of the last pitches of the screw with variable geometry and because of the way materials tend to fill more efficiently larger extraction volumes the variable geometry of the screw feeders must not be proportional with distance but rather to take in account the minimum efficient extraction volume.

Since some materials fill with difficulty smaller volumes of the first screw flights it is best to design the variable geometry according with the particle distribution of the bulk solid.

The experimental stand presented, can provide important data aspects regarding the residence periods of the bulk material inside the feeding bin. The experiments can also identify the locations of insufficient material flow that are more suitable for agitation devices to be installed.

Agitation of the bulk material and proper extraction screw feeder can provide uniform quality of the food products during extraction.

By installing proper agitation device, a constant state of fluidization in the material is achieved and so constant bulk density can be obtained, assuring in this way the uniform characteristics needed for a constant extraction flow.

In order to guarantee the mass flow from the bin, the width of the hopper may be only a little larger than the diameter of the screw feeder. In particular, for conical screws the chamber should be accordingly designed.

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