academicJournals

Vol. 9(1), pp. 1-5, July 2017
DOI: 10.5897/JETR2016.0592
Article Number: 6E3C31465457
ISSN 2006-9790

http://www.academicjournals.org/JETR

Journal of Engineering and Technology Research

Full Length Research

Theoretical modeling of strain in the single screw feeder of cassava flash dryer

Noutegomo Boris[1*], Djeumako Bonaventure[2] and Ndjouenkeu Robert[3]

[1]Laboratory of Mechanical and Production Engineering, University of Douala, Douala, Cameroun.
[2]Department of Mechanical Engineering, ENSAI, University of Ngaoundéré, Ngaoundéré, Cameroun.
[3]Department of Health and Applied Nutrition, ENSAI, University of Ngaoundéré, Ngaoundéré Cameroun.

Received 1 April, 2016; Accepted 7 September, 2016

The aim of this study is to model screw feeder unit to handle granulated wet cassava to the flash dryer column. The knowledge of the flow behavior, physical and mechanical properties, rheology of the product and the geometrical characteristics of feeders unit were essential to evaluate the best conditions of handling granulated cassava based on the theory of virtual works. The effect of granular media strain on the rotational speed which is limited to 2 rps corresponding to the elastic limit of 30% was studied. With the same strain limit, maximum screw length of 1300 mm and the maximum residence time of 100 s in the bin were identified as the best area used to design the screw feeder unit and conduct the process operation. The modeling of the strain was based on the theory of virtual works or energies.

Key words: Modeling, virtual works, strain, screw feeder, cassava.

INTRODUCTION

The screw feeder is one of the most useful feeding devices which not only has good metering characteristics, but also uses relatively simple components and can be designed to feed many kinds of bulk solids, reliably in a variety of applications. Those materials can be chemical, agricultural, pharmaceutical and mineral. The rheology of the granular media is very important when designing devices in order to avoid blockage, flooding, air lock and others which are the main problems. Rheology is the study of the behavior of material when subjected to stress or strength. Metcalf (1965) considered the mechanics of a screw feeder, concentrating on the rate of delivery and the torque required to feed different types of coal using mining drill rods as screws. The model chosen was that of a rigid plug of material moving in a helix at an angle to the screw axis. A detailed experimental investigation was conducted by Burkhardt (1967). The tests included the effect on the performance of a screw feeder, of the pitch, the radial clearance between the screw flight and trough, the hopper exposure and the head of the bulk solid contained in a hopper. Rautenbach and Schumacher (1987) carried out scale-up experiments with two geometrically similar screws. By dimensional analysis, the relevant set of dimensional numbers was derived for

---

*Corresponding author. E-mail: borisnoutegomo@yahoo.fr.

the calculation of power consumption and capacity. More recently, Roberts and Manjunath (1994) analyzed the mechanics of screw feeder performance in relation to the bulk solid draw-down characteristics in the feed hopper. In their study, the force exerted on the screw flights is assumed to be uniformly distributed along the whole feed length and three empirical pressure ratios are used in the determination of the required torque. Problems like metering, unsteady flow rates, bridging, channeling, arching, product inhomogeneity, segregation, high startup torques, equipment wear and variable residence time have been reported by many researchers (Cleary, 2007; Owen and Cleary, 2010; Bortolamasi and Fottner, 2001). In addition, the design and optimization of screw feeder performance is not well understood and has been based on semi-empirical approach, numerical or experimental techniques using dynamic similarities (Bortolamasi and Fottner, 2001). Earlier researchers have investigated the effect of various screw (auger) parameters including choke length (the distance beyond which the screw projects beyond the casing at the lower end of the intake) and pitch-diameter ratio (Ghosh, 1967). Augers with large diameters attain maximum output at lower speeds as compared to those with small diameters. They also reported that for maximum throughput during conveying, longer chokes are necessary. The subject of modelling screw conveying of granular materials with the Discrete Element Method (DEM) Cundall and Strack (1979) is fairly recent.

The model we are going to elaborate will help the constructors of screw feeders unit to take decisions when designing devices in order to ameliorate energy consumption, efficiency of the equipment and the best quality product.

MATERIALS AND METHODS

Feeder loads

McLean and Arnold (1979) proposed the simplified approach to evaluate the feeder loads for mass flow bins Q which is uniformly distributed over the hopper outlet by the following relation:

$$\boldsymbol{\sigma_0} = \frac{Q}{LB} \tag{1}$$

B, opening width of hopper outlet (m); *L,* length of feed section (m); Q, feeder loads (N); σ_0, resulting stress (N/m^2).

When a moving bulk solid reaches steady state, there is equilibrium between the driving force and the resisting force. Assuming that the axial stress and the radial stress are functions of *x* only as showed in Figure 1, we have the transverse section of a screw pitch (Figure 2). Stress σ_w is the normal wall pressure acting perpendicularly to the wall of the trough and the core shaft. σ_x, axial compression stress (N/m^2); τ_w, shear stress on confining surface (N/m^2); R_t, radius of the trough (m); R_c, radius of the core shaft (m).

The ratio $\lambda_s = \frac{\sigma_w}{\sigma_x}$ is known as the stress ratio of the bulk material sliding on the confining surfaces (trough and core shaft surfaces) (Figure 3). A general expression can be obtained by:

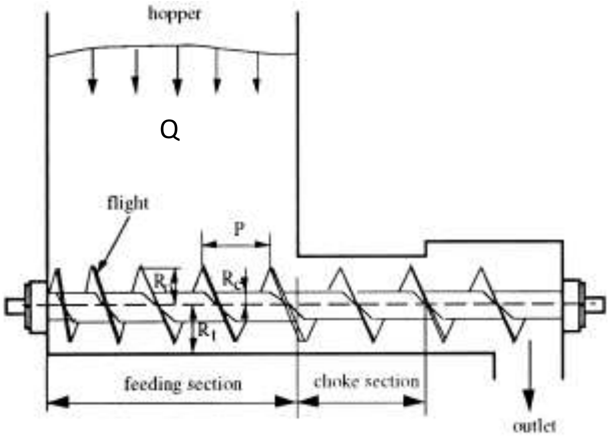

Figure 1. Typical form of a hopper fitted with a screw feeder (McLean and Arnold, 1979).

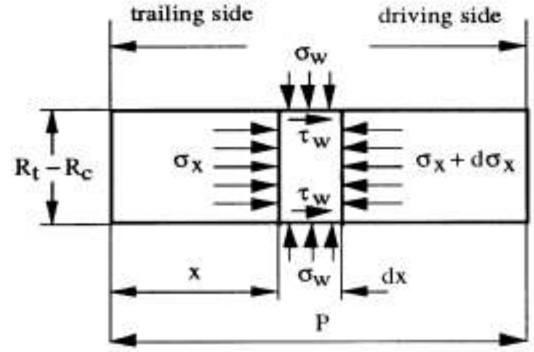

Figure 2. Stress on an element at the lower region of the screw.

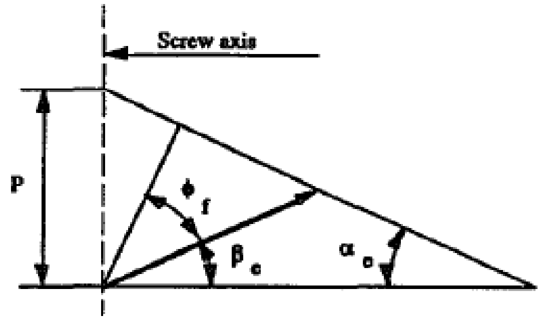

Figure 3. Direction of material element motion.

$$\boldsymbol{\lambda_s} = \frac{\sigma_w}{\sigma_x} = \frac{1}{1+2\mu_d^2+2[(1+\mu_d^2)(\mu_d^2-\mu_w^2)]^{1/2}} \tag{2}$$

μ_w is the friction coefficient between the bulk solid and the confining surface.

$$\boldsymbol{\mu_w} = \frac{\tau_w}{\sigma_w} \tag{3}$$

Table 1. The characteristics of granulated cassava (CIGR Handbook of Agricultural Engineering Volume IV) (1999).

Parameter	Symbol	Values
Bulk density	ρ_b (Kg/m^3)	760
Young modulos	E (N/m^2)	2370000
Poisson's ratio	v	0.38
Friction coefficient between the bulk solid and a confining surface	μ_w	0.364
Friction coefficient of the bulk solid	μ_d	0.80

μ_d is the friction coefficient between the bulk solid and the confining surface.

$$\mu_d = \tan\delta \quad (4)$$

Where δ is the effective angle of internal friction of the bulk solid. Average wall stress was defined by Yu and Arnold (1997) as:

$$\sigma_{wm} = \sigma_0 \frac{R_t - R_c}{2\mu_w}\left[\exp\left(\frac{2\mu_w\lambda_s P}{R_t - R_c}\right) - 1\right] \quad (5)$$

The theory of the uniform flow pattern is

$$M = \rho_g\left(R_t^2 - R_c^2\right) P\, n\, \eta_v \quad (6)$$

M, mass of product per revolution (kg); ρ_g, density of bulk solid (kg/m^3); η_v volumetric efficiency; P screw pinch (m); n, number of screw revolutions.

The volumetric efficiency has been proposed by Yu and Arnold (1996) as:

$$\eta_v = \frac{\tan\beta_c}{\tan\beta_c + \tan\alpha_c} \quad (7)$$

Where $\beta_c = \tan^{-1}\left[\frac{\pi(D+d) - 2\mu_w P}{2P + \pi\mu_w (D+d)}\right]$

$\alpha_c = 90° - \phi_w - \beta_c$; α_c = flight helix angle at core shaft (deg), β_c = friction angle between particles bulk (deg), ϕ_w = wall friction angle between bulk solid and confining surface (deg),

Theory of virtual works

The modeling is based on the theory of virtual works or energies which is related by:

$$\int_D f_1 \delta U_1 dv + \int_S F_1 \delta U_1 ds = \int_D \sigma_{ij} \delta \mathcal{E}_{ij} dv \quad (8)$$

σ_{ij}, Tensor of constraints; $\mathcal{E}_{ij}$, tensor of deformations; F_1, Force of surface (N/m^2); f_1, force of volume (N/m^3); U_1, displacement (m).
It is assumed that there is no internal variation of energy in the medium, then $\int_D f_1 \delta U_1 dv = 0$ and (8) becomes:

$$\int_S F_1 \delta U_1 ds = \int_D \sigma_{ij} \delta \mathcal{E}_{ij} dv \quad (9)$$

Assumptions

1. We work in a plan deformation on the revolution problem,
2. The medium is homogeneous and isotropy, then (9) becomes:

$$F\,US = \sigma_{ij} \delta \mathcal{E}_{ij} V \quad (10)$$

$$F = \sigma_{ij} \delta \mathcal{E}_{ij} \quad (11)$$

The matric form of (11) is:

$$\begin{bmatrix} 0 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & F_{zz} \end{bmatrix} = \frac{E(1-v)}{(1+v)(1-2v)} \begin{bmatrix} \mathcal{E}^2 & \frac{\mathcal{E}^2}{1-v} & \frac{\mathcal{E}^2}{1-v} \\ \frac{\mathcal{E}^2}{1-v} & \mathcal{E}^2 & \frac{\mathcal{E}^2}{1-v} \\ \frac{\mathcal{E}^2}{1-v} & \frac{\mathcal{E}^2}{1-v} & \mathcal{E}^2 \end{bmatrix} \quad (12)$$

$$F_{zz} = \frac{E(1-v)}{(1+v)(1-2v)} \mathcal{E}^2 = \sigma_{wm}.S \quad (13)$$

Where E is Young Modulus, v is Poisson's ratio;

Equation (5) in (13):

$$\frac{\pi Mg}{LB}\left(R_t^2 - R_c^2\right) \frac{R_t - R_c}{2\mu_w\lambda_s P}\left[\exp\left(\frac{2\mu_w\lambda_s P}{R_t - R_c}\right) - 1\right] = \frac{E(1-v)\ \mathcal{E}^2}{(1+v)(1-2v)} \quad (14)$$

Equation (6) in (14):

$$\frac{\pi g \rho_b\, P n \eta_v}{LB}\left(R_t^2 - R_c^2\right)^2 \frac{R_t - R_c}{2\mu_w\lambda_s P}\left[\exp\left(\frac{2\mu_w\lambda_s P}{R_t - R_c}\right) - 1\right] = \frac{E(1-v)\ \mathcal{E}^2}{(1+v)(1-2v)} \quad (15)$$

$B = 2R_t$ and $L = xP$; x = pitch number after n revolution $= N.t$,

Equation (15) becomes:

$$\frac{\pi g \rho_b\, N \eta_v}{2R_t x\, L}\left(R_t^2 - R_c^2\right)^2 \frac{(R_t - R_c)}{2\mu_w\lambda_s P}\left[\exp\left(\frac{2\mu_w\lambda_s P}{R_t - R_c}\right) - 1\right] t = \frac{E(1-v)\ \mathcal{E}^2}{(1+v)(1-2v)} \quad (16)$$

Where, N is rotational speed and t the residence time.

Equation 7 must also be introduced in 16 which is the final theoretical model. The characteristics of granulated necessary for the simulation of the equation are shown in Table 1.

RESULTS AND DISCUSSION

Figures 4, 5 and 6 present the same evolution of the strain. Each curve in the figures has two parts.

1. The first part is linear and corresponds to the elastic strain. When N = 0 rps, the screw is stopped corresponding to the strain of 0%. As N (rotational speed) increases up to 2 tr/s, the strain increases also rapidly until elastic limit of 30%. For the same elastic limit, the maximum screw length is 1300 mm according to Figure 5 and the residence time of product in the hopper is 100 s according to Figure 6.

In those elastic parts, the product flows normally and keeps well his best quality. In those conditions, the flow operation can avoid blockage, flooding, air lock and the

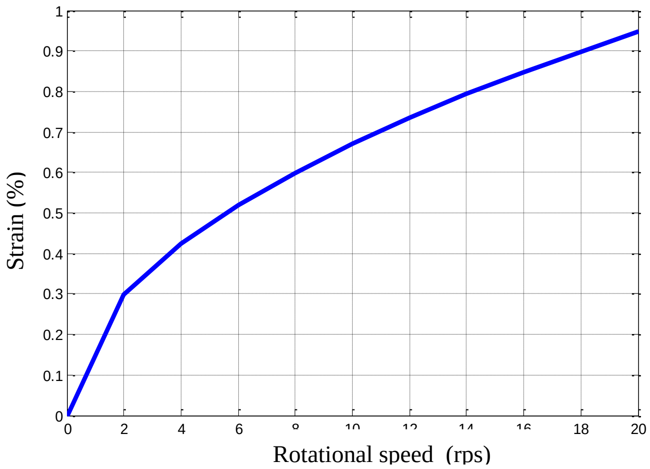

Figure 4. Influence of the screw rotational speed on the strain.

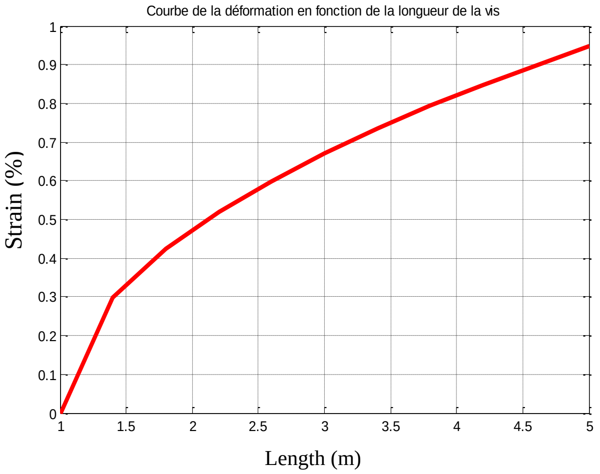

Figure 5. Influence of the screw length on the strain.

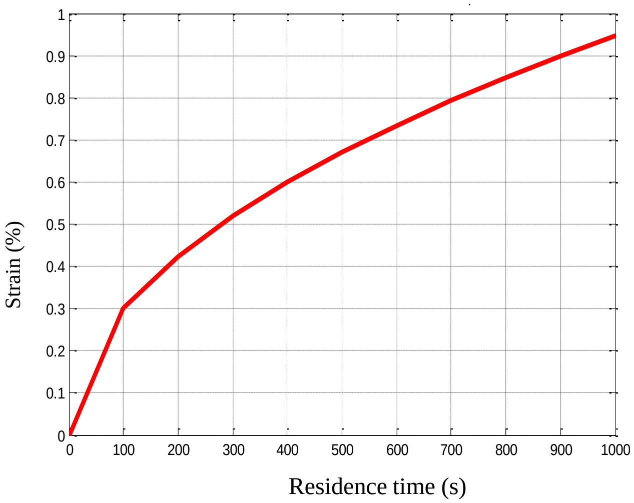

Figure 6. Influence of the residence time on the strain.

equipment is efficient and effectiveness.

2. The second part is nonlinear corresponding to the plastic strain. In those parts, the deformations increase very slowly with the increase of rotational speed, screw length and residential time in the hopper. It can be concluded that the product is well damaged and affect the flow and the quality. These are the characteristics of poor equipment designed because if the hopper is bigger than the normal, if the length of screw is too long and if the rotational speed is high, then the constrains of the equipment will have time to damage the granulated cassava, transforming it solid nature to liquid. The liquid state of cassava cannot allow the flow in the equipment. The cassava must pass with less time in the screw feeder and must be conducted with low rotational speed in order to keep the quality of the product for the next processing and to enhance the output of the equipment.

Conclusion

The physical properties and structure of the granular matters are often accompanied by modifications of the product which affects the flow directly. The formation of the pasty structure and the interruption of flow in the screw feeder influence the course of drying, the quality of the ended product and reduces the output of the equipment. The choice of operation when designing equipment must be done in the elastic zone to preserve the quality of the product and to allow a better operation of the equipment.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

REFERENCES

Bortolamasi M, Fottner J (2001). Design and sizing of screw feeders. In: Proc. Partec 2001. Int. Congr. Particle Technol. 69:27-29.

Burkhardt GJ (1967). Effect of pitch, radial clearance, hopper exposure and head on performance of screw feeders. Trans. ASAE. 10:685-690.

Cleary PW (2007). DEM modelling of particulate flow in a screw feeder Model description. Progr. Comput. Fluid Dyn. Int. J. 7:128–138.

Cundall PA, Strack ODL (1979). A discrete numerical model for granular assemblies. G´eotechnique 29(1):47-65.

Ghosh BN (1967). Conveyance of wet parchment coffee beans by an auger. J. Agric. Eng. Res. 12(4):274-280.

McLean AG, Arnold PC (1979). A simplified approach for the evaluation of feeder loads for mass flow bins. Powder Bulk Solids Technol. 3(3):25-28.

Metcalf JR (1962). The mechanics of the screw feeder, Proc. Inst. Mech. Eng. 180(6):131-146.

Owen PJ, Cleary PW (2010). Screw conveyor performance: comparison of discrete element modelling with laboratory experiments. Progr. Comput. Fluid Dyn. Int. J. 10(5):327-333.

Rautenbach R, Schumacher W (1987). Theoretical and experimental analysis of screw feeders. Bulk Solids Handling 7(5):675-680.

Roberts AW, Manjunath KS (1994). Volumetric and torque characteristics of screw feeders, Proc. Powder and Bulk Solids Conf., Chicago, IL, USA. pp. 189-208.

The International Commission of Agricultural Engineering (1999). (CIGR Handbook) of Agricultural Engineering Volume IV Agro-Processing Engineering Michigan State University, USA. http://www.cigr.org/documents/CIGRHandbookVol4.pdf

Yu Y, Arnold PC (1996). Influence of screw feeders on bin flow patterns. Pow. Technol. 88:81-87.

Yu Y, Arnold PC (1997). Theoretical modeling of torque requirements for single screw feeders. Pow. Technol. 93:151-162.