Advanced Powder Technology 26 (2015) 1391–1399

Contents lists available at ScienceDirect

Advanced Powder Technology

journal homepage: www.elsevier.com/locate/apt

Original Research Paper

Modified screw conveyor-mixers – Discrete element modeling approach

Lato Pezo [a], Aca Jovanović [a], Milada Pezo [b,*], Radmilo Čolović [c], Biljana Lončar [d]

[a] Institute of General and Physical Chemistry, University of Belgrade, Studentski Trg 12-16, 11000 Belgrade, Serbia
[b] Laboratory for Thermal Engineering and Energy, Institute of Nuclear Sciences "Vinča", University of Belgrade, P.O. Box 522, 11001 Belgrade, Serbia
[c] Institute of Food Technology Novi Sad, University of Novi Sad, Bulevar Cara Lazara 1, 21000 Novi Sad, Serbia
[d] Faculty of Technology, University of Novi Sad, Bulevar Cara Lazara 1, 21000 Novi Sad, Serbia

ARTICLE INFO

Article history:
Received 9 January 2015
Received in revised form 20 July 2015
Accepted 21 July 2015
Available online 29 July 2015

Keywords:
DEM
Modified screw conveyor
Premixing
Mixing quality

ABSTRACT

Screw conveyors are widely used in the food industry, building construction and mining companies, chemical, agricultural and processing industries, mostly for elevating and/or transporting bulk materials over short to medium distances. Despite their apparent simplicity, the improvement of the transport parameters is a very demanding task and designers usually have to rely on data obtained from empirical investigations.

In this paper, fifteen horizontal single-pitch screw conveyors with modified geometry and the different lengths were investigated for premixing action, during the transport of materials. All investigations were performed experimentally and numerically, by using Discrete Element Method (DEM).

The influences of screw length, observed geometry variations and different types of screw design, on the performances of the screw conveyor-mixer during material transport were explored. The auxiliary mixing action (used to improve the mixing process) was achieved during the transport of the material. The geometry of the screw conveyor is changed by adding three complementary helices oriented in the same or the opposite direction from screw blades. The particles of the material being transported tumble down from the top of the helix to the next free surface, and that segment of helix was used for additional mixing action. According to experiments and DEM analysis, the particle path length is increased, with the observed modification of screw conveyor, and the improved geometry could be determined for increasing the quality of mixing.

1. Introduction

Screw conveyors are widely used for transporting and/or elevating particulates at controlled and steady rates. They are used in different branches of industry, such as mining industry, agriculture, building construction, chemicals, process and food industry.

Screw conveyors are also known as worm conveyors, and they are used for materials that are free flowing. The modern conveyor consists of a helical screw rotating in a U-shaped trough or enclosed pipe. They can be used horizontal or at an incline to lift materials. Screw conveyors are not efficient as belt conveyors. The reason for low efficient is friction between the solids and the flights of the screw. But, they are cheaper and easier to maintain. They are used to convey solids over short distances, and when some elevation is required [1].

Despite their apparent simplicity, optimization of the transport parameters is a very demanding task and designers usually have to rely on data obtained from empirical investigations. Operating conditions such as: the rotational speed of the screw, the inclination of the screw conveyor and its volumetric fill level exert strong influence on screw conveyor performances.

There are different constructions of screw conveyors, with the same or variable pitch. The shape of the screw blades is also variable. The proper design of screw conveyor is crucial for transport. If design is not adequate for transport materials, certain problems can occur: surging and unsteady flow rates, inaccurate metering and dosing, inhomogeneity of the product, deformation or melting of the granules, product degradation, excessive power draw, high start-up torques, high equipment wear and variable residence time and segregation, increasing energy consumption, increasing cost of the final product, lower the quality of the final product.

Specific shapes of particles and differences in weights have great impact on segregation of the powder materials. But, the length of screw transporter is also very important parameter for

* Corresponding author.
E-mail address: milada@vinca.rs (M. Pezo).

http://dx.doi.org/10.1016/j.apt.2015.07.016
0921-8831/

Nomenclature

d	diameter, m
d_i	distance particle from edges of helix, m
E	Young's modulus, Pa
F	force, N
F_c	contact forces, N
F_s	shear force, N
g	acceleration due to gravity, m/s^2
I	moment of inertia, kg m^2
k_i	stiffness constants, N m^{-1}
m_i	mass of particle, kg
n	unit vector in the normal direction of two contact spheres, dimensionless
p	pressure, Pa
R	radius vector (from particle center to a contact point), m
r	cylindrical coordinate, m
t	time, s
v	velocity of particle, m/s

Greek

α	value of overlap, m
δ	vector of the particle–particle or particle–wall overlap, m
ε	porosity, dimensionless
ρ	density, kg/m^3
μ	friction coefficient
θ	angle from x axis to xy plane
τ	fluid viscous stress tensor, N/m^3
ω	rotational velocities of particle, rad/s

Indexes

c	contact
i	particle i
n	normal
p	particle
s	shear
w	wall

designers. Manufactures have problems with increasing the length of screw transporter, particularly due to deformation of long screw shaft, in which case additional support(s) are required between the initial and final bearings case.

A summary of current design methods and problems experienced for screw conveyors can be found in [2]. The description of the theoretical behavior of screw conveyors can be found in numerous articles [3,4].

Numerical models based on DEM (Discrete Element Method) showed to be reliable and useful in catching particle interactions and predicting mixing process for investigation of solids mixing. The soft-sphere method originally developed by Cundall and Strack [5] was the first granular dynamics simulation technique published in the open literature.

DEM is a numerical technique used to predict the behavior of collision dominated particle flows. Each particle in the flow is tracked and all collisions between particles and boundaries are modeled. The particles are allowed to overlap and the extent of overlap is used in conjunction with a contact force law to give instantaneous forces from knowledge of the current positions, orientations, velocities and spins of the particles, [5].

DEM of particulate flow in a screw conveyor was first reported in [6]. In this work, the performance of horizontal and vertical screw conveyors were examined and compared with the results of empirical equations. In article [7] the use of a periodic slice model was introduced to explore the performance of a long screw conveyor. Cleary, [8], used DEM to study draw down patterns from a hopper by a 45° inclined screw conveyor. This work was extended in [9] in order to examine the effect of particle shape on the draw down flow from the hopper and on the transport characteristics of the screw conveyor. In article [10], DEM study of the flow of cohesive particles in a screw feeder was done. The effects of the cohesive force between particles and the rotational speed of the screw were examined, as well as the effects of the screw length in the associated charging container and the container design. The aim of this investigation was to identify a method to overcome the blockage problem induced by inter particle cohesion. In article [11], solids inflow and solids conveying of single-screw extruders using the discrete element method were modeled. The DEM technique allows fundamental study of the local transport phenomena within the screw channel. Zhong and O'Callaghan [12] analyzed the effect of the shape of the feed opening on the performance of a horizontal screw conveyor. Fernandez et al. [13] examined the effect of screw design on hopper drawdown of spherical particles in a horizontal screw feeder. DEM is used to predict particle transport in a horizontal screw feeder system for a range of conventional screw designs including a variable screw pitch, variable screw flight outside diameters and variable core diameters. The influence of the screw choice on the particle mass flow rate, the evenness of particle drawdown from the hopper, power consumption, screw wear and wall friction variations are investigated. Cleary [14] used DEM with realistic shaped particles for particulate mixing in a plough share mixer. Using a much more realistic representation of the particle shape leads to better representation of the bed strength due to increased numbers of contacts with neighboring particles and the inability to fail. Moysey and Thompson [15] proposed a new approach to model the solids transport within an extruder, using the discrete element method for a non-isothermal, three-dimensional simulation of the solids conveying zone. To improve the application of DEM, the same authors evaluate the contact mechanics of a selection of commonly used polymers [15]. Moysey and Baird [16] used DEM for the size segregation of spherical nickel pellets in the surface flow of a packed bed.

For the devices where working fluid has the significant influence on the behavior of the granular particles, coupling CFD (Computational Fluid Dynamics) and DEM proved to be more reliable and more efficient technique for numerical the simulation and the mathematical modeling [17–22] than single DEM analysis.

Screw conveyors are also used for metering or measuring small amounts of trace materials such as granular materials or powders or pigments from storage tanks, [23–25]. Dosing feeders are often constructed by adding frequency converters for speed change and fine dosing to the desired value. The proper choice of the geometry of screw transporter is very important in this case. Significant increase of the homogeneity and reduction of the segregation of materials by particle size can be achieved by changing the screw geometry, with several additional elements welded on screw blade.

Screw transporters are frequently used to remove powder or grain material from silos or tanks, and transport it to the mixer. All individual components must be mixed thoroughly, in order to