Powder Technology 333 (2018) 347–352

Contents lists available at ScienceDirect

Powder Technology

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

Unloading characteristics of flights in a flighted rotary drum operated at optimum loading

Mohamed A. Karali [a,*], Eckehard Specht [b], Fabian Herz [b,c], Jochen Mellmann [d], Hassanein A. Refaey [e]

[a] Department of Mechanical Engineering, Faculty of Engineering and Technology, Future University in Egypt, 90 St., New Cairo, Egypt
[b] Institute of Fluid Dynamics and Thermodynamics, Otto von Guericke University Magdeburg, Universitätsplatz 2, 39106 Magdeburg, Germany
[c] Department of Applied Biosciences and Process Engineering, Anhalt University of Applied Sciences, BernburgerStrasse 55, 06366 Koethen,Germany
[d] Leibniz Institute for Agricultural Engineering and Bioeconomy (ATB), Department of Postharvest Technology, Max-Eyth-Allee 100, 14469 Potsdam, Germany
[e] Department of Mechanical Engineering, Faculty of Engineering at Shoubra, Benha University, 11629 Cairo, Egypt

ARTICLE INFO

Article history:
Received 19 September 2017
Received in revised form 21 January 2018
Accepted 19 April 2018
Available online 21 April 2018

Keywords:
Granular solid
Rotary drums
Optimum loading
Flights
Unloading characteristics
Image analysis

ABSTRACT

In this contribution, experimental analysis is introduced to determine the unloading characteristics of granular solid from flights. In a flighted rotary drum operated at optimum-loading. The studied unloading characteristics are: kinetic angle of repose of solid reside inside a flight, individual flight holdup, final discharge angle, cascading rate, and height and time of falling curtains. These characteristics are determined as a continuous function of the flight angular position. The tested drum is 0.5 m diameter and 0.15 m length, the rpm changes from 1 to 5, two number of flights 12 and 18, and two flight length ratios 0.375 and 0.75 are researched. Results revealed that: flights holdup is mainly influenced by flight length ratio among other studied parameters. Maximum height of falling curtains can be achieved when operating rotary drums at optimum-loading, since the bottom solid bed is no longer exists compared to over-loaded drums.

1. Introduction

Many vital products in our daily life including a variety of building materials, chemicals, pharmaceuticals and food are granular, such as: sand, sugar, corn, wheat, salt, peanuts, flour, cereal, cement, limestone, fertilizers, wood chips, and pills. The most common used devices for the processing materials with free flowing or cohesive nature are rotary drums.

A rotary drum consists of a long cylinder tilted to the horizontal and have the possibility to rotate around its axis. The solid granular is fed into the upper end of the drum by various methods including inclined chutes, overhung screw conveyors and slurry pipes. The charge then travels down along the drum by axial and circumferential movements, due to the drum's inclination and rotation. During the travelling of the solid it interacts with a processing gas along the drum specially in the gas-borne area for a certain process. In either counter or co-current flow directions. Until the processed solid discharged from the lower end of the drum [1].

In many applications, rotary drum's interior wall is equipped with baffles known as lifters or flights. Which lifts the granular material from the bottom bed then cascade and showers it through the gas-borne area developing a series of curtains [2–6]. Many flight profiles were developed to meet industrial requirements for a specific product. Blade or radial flight profile is used for sticky materials, rectangular profile are mostly used for free flowing bulk materials [7,8].

The loading of a flighted rotary drum is the total amount of solid material carried by the drum. Which can be calculated as the sum of three amounts; solid carried by the flights (flights holdup), solid found in the gas-borne area, and solid in the bottom bed if exists [9,10]. Three types of drum loading states can be categorized: under-loading, design-loading (optimum-loading), and over-loading which are characterized based on the holdup and the discharge angle of the first unloading flight (FUF) [10–15]. Detailed information of these loadings are found in [16]: the design loading means the FUF starts to unload the material very close to the 9 o'clock position (Fig. 1-a), while the unloading starts earlier before the 9 o'clock position in the overloaded drum and lately than the 9'oclock position in the case of under loaded drum.

Many investigations from literature emphases the fact that, the best performance of a flighted rotary drum occurs when the drum operates at optimum-loading conditions [17,18]. Therefore, a lot of experimental and theoretical work has been done to assess the optimum loading of a flighted rotary drum [16,19]. The determination criterion of the optimum-loading was based on reaching saturation of the FUF by the solid material at the 9 o'clock position. While the experimental work was depending on record videos in front of the drum and by means of different image analysis methods, the area of the material reside in

* Corresponding author at: Department of Mechanical Engineering, Faculty of Engineering and Technology, Future University in Egypt, 90 St, New Cairo, Egypt
E-mail address: mkarali@fue.edu.eg. (M.A. Karali).

https://doi.org/10.1016/j.powtec.2018.04.052
0032-5910/

Nomenclature

d_p	particle diameter (m)
D	drum diameter (m)
f	filling degree (%)
Fr	Froude number, $Fr = \omega^2 R/g$ (−)
FUF	first unloading flight
g	gravitational acceleration (m/s^2)
h	curtains height of fall (m)
H	holdup (m^3/m or cm^2)
L	drum length (m)
l_1	flight radial length (m)
l_2	flight tangential length (m)
N	rotational speed (rpm)
n_F	total number of flights
r_H	effective radial distance (m)
R	drum radius (m)

Greek letters

α	flight tangential angle(°)
γ	kinetic angle of repose of solid reside inside flight (°)
δ	flight tip angle(°)
Θ_A	solid dynamic angle of repose (°)
ρ_b	solid bulk density (consolidated) (kg/m^3)
ω	drum angular velocity (rad/s)

Subscripts

b	solid bulk
d	design or optimum loading
F	flight
L	final discharge angle
p	particle

flights can be obtained and consequently the volume and mass can be calculated.

In our previous work [20], a comparison between different image analysis methods were conducted; manual and automated. The manual method is depending on using traditional manual tools of image analysis. In the automated method the use of a mix between manual tools and Matlab image analysis tool box is applied. In principle, the comparison conducted to choose the best method to save time needed for image analysis in presence of large number of images to be analyzed. The paper concluded that, the automated method is strongly nominated to replace the manual one in favor of saving time needed for image analysis. However, special modifications and precautions have to be adapted on the camera and light positions.

Our latest published work [21] extended the experiments with testing different camera and light positions to facilitate the automated method used for the image analysis. The paper proposed that camera position should focused at the drum center point, and light source position should be adapted to minimize the shadows of the solid in the drum. That way, measuring distances and angles will be more reliable. Also, the transformation of the RGB images to black and white before fed to Matlab will be much easier than the tradition technique of automated method.

Unloading characteristics from flights in a flighted rotary drum, such as: kinetic angle of repose of solid reside inside a flight, individual flight holdup, final discharge angle, cascading rate, and height and time of falling curtains, are of importance to be studied. As they determines the amount of solid will present in the gas-borne area and disperse nature. Which influences the overall performance of the drum [15,18].

Sunkara et al., 2013 [18] developed a mathematical model for a flighted rotating drum that determines the holdup and the cascading rate of the particles discharging from the flight surface. And performed experiments with adrum of 500 mm in diameter and 150 mm in length, which is furnished with 12 flights around the inner shell of the drum. The model predictions depicted that the carrying capacity of the flight increases with increasing the flight length ratio, but the discharge rate decreases during the initial discharge. Bulk movement of the material has been observed into the gas-borne phase of the drum during the final discharge at higher flight length ratios. The validation of the model was carried out with different profiles of the flight by varying the tangential length. It is proved from the experiments that increase in flight length ratio increases the material distribution over the drum cross section. The experimental results were observed to be in good agreement with the model predictions. It worth noting that Sunkara

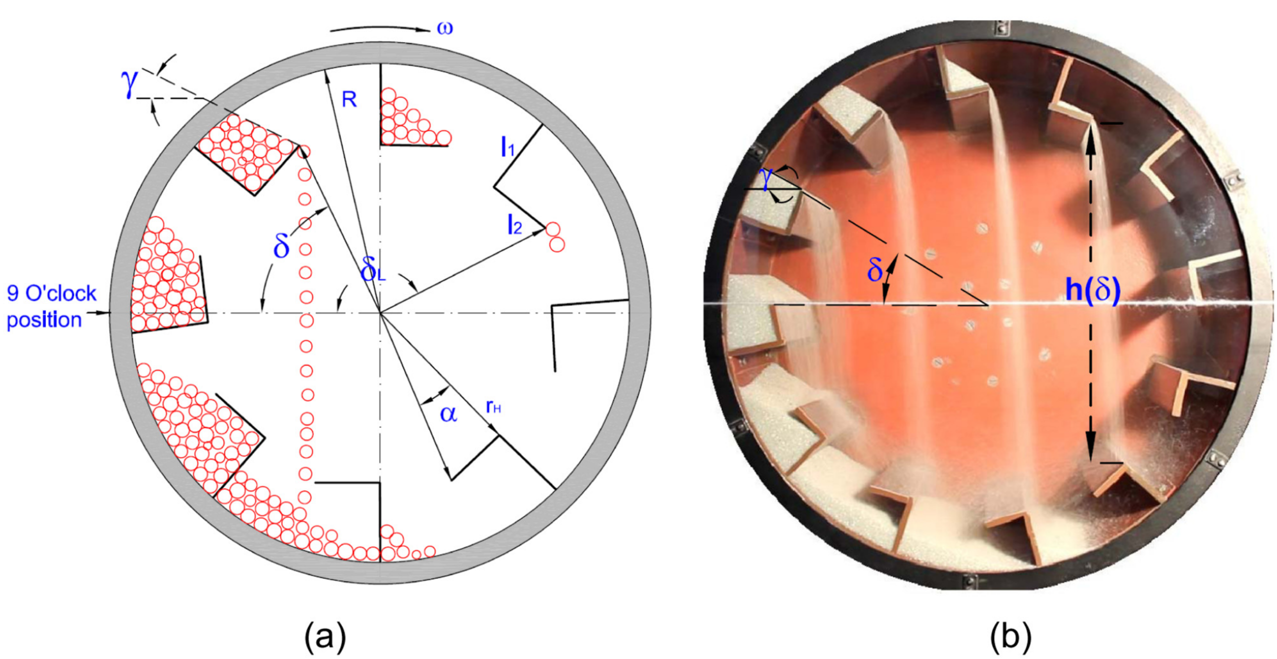

Fig. 1. Geometrical parameters of flighted rotary drum (a) schematic diagram (b) photo from experiments.