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Modeling the discharge characteristics of rectangular flights in a flighted rotary drum

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ABSTRACT

Rotary drums equipped with longitudinal flights are essentially used to dry granular material to handle high throughputs. The design of the flights is the crucial task that influences the distribution of the material over the dryer cross section. A mathematical model for the flighted rotating drum that determines the holdup and the cascading rate of the particles discharging from the flight surface is developed. Experiments were performed with a drum 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 airborne 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.

1. Introduction

Rotary dryers are one of the most commonly used devices to dry granular or particulate material providing large throughputs. They are often used in mineral, food and metallurgical industries to remove the moisture from the granular material and raise its temperature. It is especially used for drying nickel ore which is being directly collected from the mining, and then sent as a feed to the kiln for the reduction of the nickel. These dryers are long cylinders rotated axially and slightly inclined red ($0–5^0$) to the horizontal [1,2]. The granular material to be treated is fed at the upstream side of the kiln and collected at the downstream end. Most of the rotary drums are equipped with longitudinal fins/flights attached to the wall of the drum to shower the solids across the free gas zone [3–6]. In direct contact dryers hot gas is passed through the drum which provides enough heat to vaporize the moisture from the showering solid particles. The performance of the drums greatly depends on the gas–solid contact, which is controlled by the flight design. Rectangular and angular flights are used for free flowing granular materials in general. However, in practice different shapes of the flights are employed along the dryer length due to the varying characteristics of the material [7].

The rotary dryers can be termed either under-loaded, design-loaded or over-loaded based on the holdup of a flight [1,8]. If the flight holds the material smaller than its capacity it is termed as under-loaded. If the flight occupies the material at the bottom of the drum to the maximum extent is said to be the design-loaded, and if the flight surface is completely submerged by the material presented at the bottom of the drum then it is said to be overloaded. In principle, under-loaded drum behavior gives lower efficiency than the design-loaded. The efficiency of the dryer depends on the uniformity of the material distribution over the dryer cross section. For a proper design, the full width of the dryer becomes a shower of material. The key parameters having influence on the material distribution include: diameter of the drum (D), geometrical parameters of the flight (l_1 and l_2), the total number of flights (n_F), filling degree of the drum (f_D), rotational speed (n), particle diameter (d_p), and material properties such as the dynamic angle of repose (Θ_A). Influence of all these parameters increases the complexity of the problem, which motivates to develop a model by considering all these variables.

Various geometrical models were developed to demonstrate the discharge characteristics of a flight [9–11]. The holdup of a single flight as a continuous function of the tip angle was formulated to demonstrate the particle distribution velocities through the drum [11]. It was successfully extended to compute the holdup of the angular and extended circular flights [5]. Sherritt et al. [6] proposed a mathematical model based on the length of the material surface on the flight to predict the residence time of the material in the drum by dividing the particle motion into two phases: airborne phase and dense phase. The total holdup of the material at any cross section becomes the sum of the holdup of each phase [6]. The authors depicted that the airborne phase occupies approximately 10% of the total holdup of the drum, where as in the under loaded drums most of the material is in the non discharging flights. However, the proposed model shows poor performance towards under-loaded drums operated with Equal Angular Distribution (EAD [12]) flights and for overloaded drums when the number of flights is less than 12. This can be attributed due to the oversimplification of the geometry of the drum while calculating the holdup of the flight.

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Differential approach technique had been followed to predict the particle transport in the flighted rotary drums. An outline was also proposed for the optimization problem to achieve the maximum drying efficiency, which is again an open challenge for further investigation [13]. A normalized model was developed by linearizing the flight holdup as a function of angular position to depict the discharge characteristics of particles [14].

These studies had shown that the researchers concentrated primarily on the design of the angular flights with two segments alone. Kelly [12] proposed a method in order to get the optimal and equal distribution of the particles along the horizontal drum diameter for an idealized flight profile named as Equal Horizontal Distribution (EHD) flights. Equal quantity of the material was considered to be discharged between any two discrete locations. However, this flight design was not practical to implement in the industry due to its complex design for sticky and wet materials. The design of the flights with three segments was the study of [15]. A generalized model was developed to find the holdup and flux of solids, which can also be implemented to two segmented angular flights.

Recently Vanpuyvelde [16] described a GFRLift model to predict the holdup profile of the complex geometries. The area occupied by the material in the lifters had been predicted based on the geometrical analysis by approximating the influence of arc of the cylindrical drum as linear. He observed that an inclined flight holds higher amount of material when compared to the one perpendicular to the drum wall. The radial lifters attain higher solid flux when compared to any other flights that were presented in his study. Lee and Sheehan [17] also developed a geometrical model to determine the holdup and unloading profile of two segmented flights. They pointed that the model was sensitive to the mean angle of repose and it should be measured accurately in order to eliminate the experimental errors. The experiments were performed to find the mass flow rate of the solids discharging from the flight using four 50 kg button load cells.

Even though the geometrical models from various authors are existing, limited knowledge is available in the literature to predict the influence of the flight length ratio on the flight holdup and cascading rate. No experimental validation of different flight length ratios had been performed till date for the rectangular flights. In the current study, a model has been developed to predict the dense phase of the material in the flight without any geometrical red simplifications, which later can be used to predict the material responsible for the heat and mass transfer that occurs in the airborne phase of the drum. A criterion for the theoretical number of flights is also proposed based on the studies of Baker [5].

2. Theoretical model

2.1. Dimensionless parameters

In order to increase the drum from the laboratory scale to the industrial scale, the dimensionless approach has been followed for the modeling. The dimensionless parameters used in the study for the rotary drum with rectangular flights are described as follows.

Radial length of the flight (l_1) and tangential length (l_2) are the typical dimensions of the flight cross-section as shown in Fig. 1. The effective dimensionless radial distance (r_H) of the flight is given by

$$\frac{r_H}{R} = 1 - \frac{l_1}{R} , \tag{1}$$

where R is the radius of the drum. The characteristic angle made by the tangential length of the flight (l_2) to the effective radius of the flight (r_H) is

$$\tan\ \alpha = \frac{l_2}{r_H} . \tag{2}$$

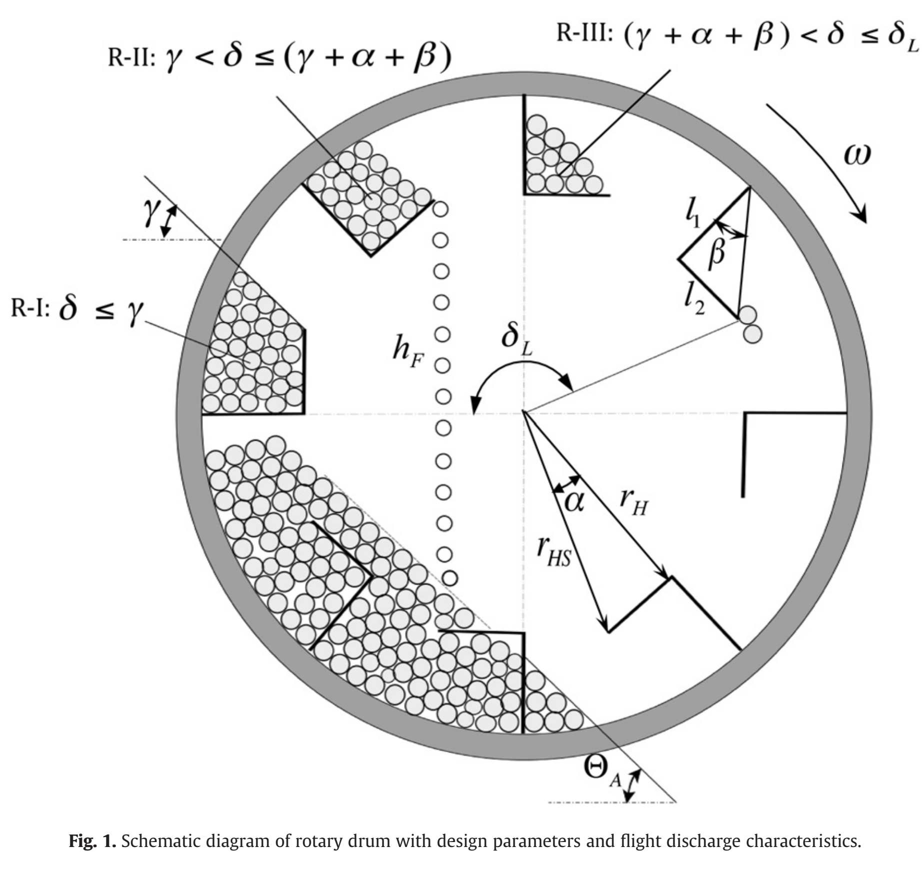

Fig. 1. Schematic diagram of rotary drum with design parameters and flight discharge characteristics.