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Application of image analysis to determine design loading in flighted rotary dryers

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ABSTRACT

The amount of solids contained within the flights and in the airborne phase of a flighted rotary dryer is critical to the analysis of performance and the optimal design of these units. In this paper, image analysis techniques are utilised to estimate the amount of material within the flights of a rotating drum and to determine the optimum loading condition. Multiple photographs of the cross-sectional area of both flight borne and airborne solids within the dryer at different loading conditions are processed. The image analysis process involved contrast enhancement, filtering and thresholding using a combination of tools within both ImageJ and MATLAB. The verification of the process used to estimate the cross-sectional area of material in the flights is described. Alternative methods for estimating design loading are described and their suitability is discussed. The design load was estimated using conventional design criterion based on the saturation of material at the first unloading flight, saturation of the entire upper half of the drum and saturation of the airborne solids.

1. Introduction

Rotary dryers are commonly used in the food and mineral processing industries for drying granular or particulate solids due to their simplicity, low cost and versatility compared to other dryers. The rotary dryer consists of a cylindrical shell slightly inclined towards the outlet and fitted internally with an array of flights. These flight configurations vary from spirals to straight flights and assist in cascading solids toward the dryer outlet. Wet feed enters one end of the dryer, dry material discharges at the other. The degree of flight loading is determined by the operating conditions, physical properties of the material and the geometrical configuration of the dryer including the flights [1,2].

In the rotary dryer, there are three potential degrees of loading namely underloaded, design loaded and overloaded. Typical definition of design loading in the literature focuses on the location of the first instance of solids cascading off the flights [3,16]. It has been suggested that a dryer is operating in an under loaded condition when the flights are not full to their capacity. Under this condition, the first point of discharge occurs late in rotation as shown in Fig. 1a for a clockwise rotating drum. Depending on rotational speed, the material in an under loaded dryer may travel faster obtaining retention time below the required drying time. Furthermore, the airborne solids are less than their potential loading. A design loaded dryer is one in which the flights are at their maximum capacity and the first discharge occurs precisely at the 9'o clock position. It is widely assumed that there is a maximum amount of solids in the airborne phase at this loading state. For ease of discussion, a flight located with its tip at the 9'o clock position is referred to as the First Unloading Flight (FUF) as indicated in Fig. 1b. The design load condition represents the point of operation when it is assumed there is a maximum interaction between the airborne solids and the drying gas. In this loading state, there is a saturation of the airborne phase and it is assumed that increase in loading do not increase airborne solids. A dryer is classified as overloaded when there are more solids than required to fill the flights (see Fig. 1c). In this situation, there is a discharge before the FUF and the excess material rolls in the base of the dryer. The kilning material bypasses the potential interaction with the gas that the cascading solids encounter. As a result, the operation of a dryer at underloaded or overloaded conditions results into poor efficiency and the optimal economics of the dryer will not be achieved. Consequently, the design load of a dryer is an important parameter that should be determined for both design and modelling.

In order to validate design loading states in flighted rotary dryers, there is a need to carry out experiments at different solids loading. Previous studies have described the determination of flight hold up using photographs of the cross-sectional area of a rotating drum [3,4]. This technique has also been used to determine angle of repose as a function of the angular position of the flights and has demonstrated that accurate analysis of the photographs is vital to the proper estimation of the design load. However, previous studies have not given a detailed description of photographic analysis involved or have focused on single flight [4,5].

Image analysis and image processing has been used widely in the biological science literature and many of the techniques used to filter and process images have arisen from these fields. Similarities between particles and cells and the ability to capture real time images have led to explosion of its applications in particle engineering system such as

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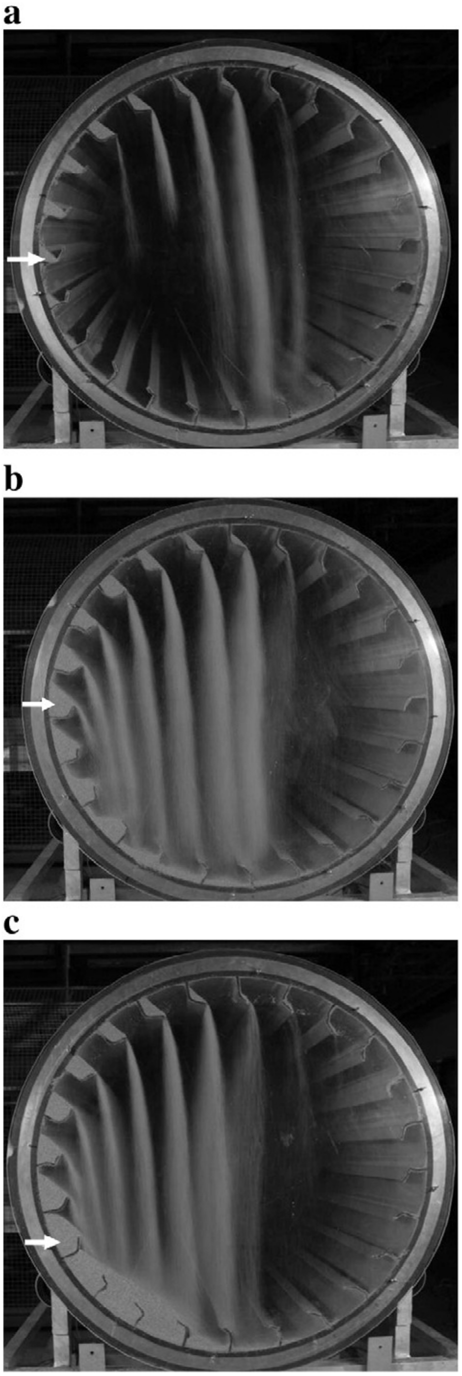

Fig. 1. a: Under load dryer (Arrow shows there is no discharge at 9'o clock position). b: Intermediate loading assumed close to design load (NB: The flights underneath the FUF are not overflowing) (Arrow shows there is discharge at precisely the 9'o clock position). c: Overloaded dryer load (NB: The flights underneath the FUF are full to the point of overflowing) (Arrow shows there is discharge before 9'o clock position).

fluidized beds. In the last decade, there has been a substantial increase in the amount of publications in image analysis of particles/solids behaviour. A ISI web knowledge search (Engineering) using terms image analysis and particles shows an increase from 57 articles in 2001 to 143 articles in 2010. Examples of studies demonstrating the use of image analysis to resolve critical engineering problems include Heffels et al. [6], Obadiat et al. [7] and Boerefijn and Ghadiri [8]. Dagot et al. [9] used image analysis to confirm the assumption that there is decrease in the quantity or quality of filamentous bacteria in Sequencing Batch Rector (SBR) .The study concluded that image analysis can be used to control and monitor the SBR in real time. Poletto et al. [10] used image analysis to establish a linear correlation between voidage pixel intensity within a fluidized bed and. Boerefijn and Ghadiri (1998) developed an image analysis technique to characterize particle flow behaviour for fluidized bed jets. In another study, image analysis was used to describe particle curtain behavior in a solar particle receiver [11]. Their study showed variation in the solid volume fraction and the falling particle velocity at different heights within the curtain. It can be concluded that image analysis is a powerful tool for solving different engineering challenges in particle technology.

Image analysis is the process of extracting important information from images; mainly from digital images by means of digital image processing techniques. An image can be defined as a two-dimensional function, $f(x, y)$, where x and y are plane coordinates and the magnitude of f at any pair of coordinates(x,y) is called the pixel intensity of the image at that location. There are four basic types of images namely binary, grayscale, true colour or red–green–blue (RGB) and indexed. In binary images, the pixels are either black or white and they are represented 0 and 1 for black and white respectively. The grayscale image consists of shades of gray and the pixels range from 0(black) to 255(white). This type of image is predominantly used in image analysis for engineering applications due to its distinctive and easily analysed colour variation. For the true colour image, each pixel has a colour which is described by the amount of red, green, and blue in it. Each of these components can have range of values from 0 to 255 giving a total of $255^3 = 16{,}777{,}216$ different possible colours in the image and every pixel in the image corresponds to three values, complicating analysis. An indexed image has each pixel with a value that does not give its colour but an index to the colour in an associated colour map. The knowledge of the types of images facilitates appropriate choice of image analysis technique to be implemented.

Different image analysis techniques are available in engineering applications and they are mostly implemented using image processing software. These techniques can be sub-categorised into the following algorithms: image enhancement, image restoration and image segmentation. Image enhancement can be regarded as the pre-processing of an image and involves the sharpening of the image, highlighting the edges, improving image contrast or brightness. The next step in the algorithm is the image restoration and it entails repairing the damage done to an image by a known cause. Examples of image restoration are removal of optical distortions or periodic interference. The image segmentation involves isolating certain regions of interest within the image or subdividing the image into component parts. This process can include estimating the area within the region of interest or finding and counting particular shapes in the image. Fig. 2 shows a typical algorithm structure used in image processing.

In this paper, the authors focus on the detailed techniques involved in analyzing the photographs to determine design loading in flighted rotary dryers. The validation process of the selected image analysis technique is discussed. The different regions of interest within the drum which are used as criteria to estimate the design load are examined.

2. Experimental set-up

A series of experiments were carried out on a horizontal pilot scale rotary dryer in order to investigate the effect of dryer loadings on saturation of both the flight and the airborne phase. The dryer is rotated in a clockwise direction. The geometrical configuration of the dryer is described in Table 1 and the flight geometry is shown in Fig. 3. Fig. 3 illustrates a typical 2-staged flight defined by the flight base length (s_1), flight tip length (s_2), the angle between the flight base and