Journal of Food Engineering 195 (2017) 235–246

Contents lists available at ScienceDirect

Journal of Food Engineering

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

Screening efficiency and rolling effects of a rotating screen drum used to process wet soft agglomerates

B. Bellocq [a], T. Ruiz [a], G. Delaplace [b], A. Duri [a], B. Cuq [a, *]

[a] UMR 1208 IATE, Montpellier SupAgro, Université de Montpellier, INRA, CIRAD 2 Place Viala, 34000, Montpellier, France
[b] INRA, U.R. 638 Processus aux Interfaces et Hygiène des Matériaux, F-59651, Villeneuve d'Ascq, France

ARTICLE INFO

Article history:
Received 18 July 2016
Received in revised form
23 September 2016
Accepted 24 September 2016
Available online 1 October 2016

Keywords:
Rotating screen drum
Durum wheat couscous
Circularity
Agglomeration mechanisms
Dimensional analysis

ABSTRACT

The rotating screen drums are largely used in most powder handling and processing industries. They are commonly used for size separation of granular materials. Objectives of the present work are to better understand both roles, screening efficiency and shaping effects and to investigate and model which process parameters are relevant when using an inclined rotating screen drum for processing wet couscous agglomerates. Durum wheat semolina was used as raw material to produce the wet agglomerates. The pilot rotating screen drum equipment was composed of two sieves to separate three fractions: fine, medium, and large agglomerates. The shaping effects of the rotating screen drum were evaluated from the measurements of the physico-chemical characteristics (size distribution, water content, compactness, and circularity) on wet soft agglomerates. To describe the screening efficiency parameters of a rotary screen drum, a specific method was developed by using a matrix analysis of the different measured weights of the collected products. The impacts of rotating screen drum parameters (angle of inclination, rotating speed, and product flow rate) on the sieving efficiency and on the shaping effects were investigated. The present results demonstrate high apparent screening efficiency of the rotating screen drum when used with wet agglomerates of durum wheat, ranging between 89 and 96% depending on the process conditions Finally, using dimensional analysis, two correlations were proposed on the circularity and the apparent screening efficiency whatever the operating conditions used (drum speed, angle of inclination and feed rate).

1. Introduction

The rotating drums are equipments largely encountered in process lines (both in continuous and batch modes) for handling and processing power and wet media. Indeed simple cylinders rotating about their central axis can be used in a horizontal position as batch drums, or as continuous drums when inclined at a few degrees to generate granular flows. The rotating drums are very versatile by realizing a large diversity of unit operations (e.g. solid-solid separation, mixing, drying, heating, chemical reactions, spraying, coating, granulation, screening, shape classification, etc.) in a large number of fields of application (*e.g.* environmental, chemical, mineral, metallurgical, food, pharmaceutical and civil engineering sectors, etc.). Different regimes for granular flow in rotating drums can occur (slipping, slumping, rolling, cascading, cataracting, and centrifuging modes) as a function of the process conditions, the regime type impacting on the process efficiency (Ding et al., 2001; Gray, 2001; Mellmann, 2001; Spurling et al., 2001; Ding et al., 2002; Scott et al., 2009; Liu and Specht, 2010; Liu et al., 2013; Komossa et al., 2014).

Among the applications, the rotating screen drums are commonly used for size separation of granular materials. The rotating screen drums are relatively simple, low expensive, requiring little operating and maintenance costs compared to other separation systems. It consisted of a cylindrical perforated drum that rotated to perform size separation. Perforations or holes in the cylinder allow smaller materials to drop out during the rotation process. The fine particles are then first separated, at the beginning of the screening process. Due to the inclination of the drum, the remaining particles travel onward to the subsequent screening rings to be separated. Over-sized materials pass through the rotating screen drum. The flow of particles through the orifices on the rotating drum occurs due to the combination of the mobility of grains (like falling in avalanches, ballistic trajectory …) caused by

* Corresponding author.
E-mail address: cuq@supagro.inra.fr (B. Cuq).

http://dx.doi.org/10.1016/j.jfoodeng.2016.09.023

the rotation regime of the drum and jamming in the vicinity of the orifices. The rotating screen drum can be managed by controlling the product flow, the driving speed and inclination angle of rotation axis (Prasanna Kumar, 2005; Chen et al., 2010; Kopral et al., 2011). The screening efficiency was inversely proportional with the product flow rate and the drum rotational speed. An increase of the angle of inclination of the drum improves the screening efficiency, until a critical angle that generates too high horizontal motion velocity of the particles on the drum screen. The rotating screen drum can also classify particles of different shapes with different residence times of particles in the drum due to the particle shape (Furuuchi et al., 1993; Hartmann et al., 2006).

Attempts to predict performance of rotating screen drums still remain unsatisfactory due to a lack of understanding of the screening mechanisms when applied to continuous screening. Prasanna Kumar (2005) studied the effect of the various screen drum, grain and operating parameters on the flow rate of grains and developed empirical equations for the flow rate by dimensional analysis. The spacing between orifices, the diameter of orifice, the percent fill of drum and rotational speed of the drum significantly affect the screening flow rate. Comprehensive effect of granular flow under various operational parameters and screening methods are not yet been thoroughly understood, more particularly if the granular materials are characterized by heterogeneous size distribution (Liu, 2009; Chen et al., 2010). Some works have developed modelling by the dimensional analysis approach and proposed integrated models considering the equipment characteristics and the process conditions (Bongo Njeng, 2016; Prasanna Kumar, 2005).

The granular flow inside rotating drums may generate undesirable breakage or erosion of the granular material. These mechanisms were observed inside a rotary drum, due to impacts and wear with the drum walls and shear deformation within the granular material (Grant and Kalman, 2001; Ahmadian et al., 2011). The breakage trends of the grains were found to increase with rotational speed. Inside a rotary drum, granular material may experience impacts and wear with the drum walls and shear deformation within the powder bed. Knowledge of the powder dynamics remains essential to understand how particulate material breaks inside a drum.

In the food domain, the rotating drum screens are used for the manufacturing of the classical couscous grains. The couscous grains are made with durum wheat semolina, by the succession of four unit operations: wet agglomeration, rolling-sieving, steam cooking, and drying (Abecassis et al., 2012; Ruiz et al., 2014). At the end of the wet agglomeration stage, the soft wet agglomerates made of durum wheat semolina and water are continuously introduced inside an inclined rotating screen drum, constituted by successive screens of increasing meshes. This equipment is known to play two roles in the process of couscous grains. First the screening role, by separating the wet agglomerates according to their size, in order to only select those in the expected range of diameters (between 1 and 2 mm). It also contributes to the couscous grain structure, by modifying the shape and the density of the wet agglomerates due to the mechanical stresses that are promoted by granular flow inside the rotating drum. It is the rolling effects. The grains of couscous rolled in the rotary drum are more spherical and less porous, than those that are sieved on traditional horizontal vibrating sieves (Hébrard, 2002; Abecassis et al., 2012). However, no scientific works have described the secondary agglomeration mechanisms that could occur on soft plastic grains during their flow inside a rotating drum. It should be noticed that on the current industrial lines, the rotating drum screens still generate large flow rates of under- and over-sized grains, after the wet agglomeration stage. These flows rates can represent more than 2.5 times the flow rate of target product. No study on the rolling stage during the process of the couscous grain has been yet conducted.

The objective of the present work is to develop an approach to better understand the two roles (screening efficiency and shaping effects) of the inclined rotating screen drum when used with the soft wet couscous agglomerates. Durum wheat semolina was used as raw materials to produce the wet agglomerates. The pilot rotating screen drum equipment was composed of two sieves to separate three fractions: fine, medium, and large agglomerates. The shaping effects of the rotating screen drum were evaluated from the measurements of the physico-chemical characteristics (size distribution, water content, compactness, and circularity) of the wet agglomerates, before and after processing by the rotating drum. The impacts of rotating screen drum parameters (angle of inclination, rotating speed, and product flow rate) on the sieving efficiency and on the shaping effects were investigated. A dimensional analysis approach is proposed to establish some relationships between the characteristics of the agglomerates and the process parameters. Experimental results give the very first tendency of this correlation.

2. Materials and methods

2.1. Raw materials

Durum wheat semolina of industrial quality (Panzani group, France) was used as raw material for the agglomeration experiments. Semolina was stored in hermetic containers at 4 °C until experiments were carried out (less than 6 months). Semolina was first characterized using standardized methods. The water content of semolina (16.0 ± 0.5 g water/100 g dry semolina) was determined according to the approved method 44-15A (AACC, 2000), by weighing after oven drying (RB 360, WC Heraeus GmbH, Hanau, Germany) at 105 °C for 24 h. The characteristics values ($d_{10} = 66 \pm 1$ μm; $d_{50} = 283 \pm 1$ μm; $d_{90} = 542 \pm 4$ μm) of particle diameter of semolina ($d_{50} = 283 \pm 1$ μm) were measured by a laser granulometer (Coulter TMLS 230, Malvern, England) at room temperature. The diameter span ((d_{90}-d_{10})/d_{50}) was 1.67. The semolina true density (1.478 ± 0.005 g cm^{-3}) was measured by azote pycnometry. The total nitrogen content (TN) of semolina was determined by the Kjeldahl method, and the crude protein content (12.3 g protein/100 g dry matter) was calculated according to TN - 5.7 based on the AFNOR method V 03-050 (AFNOR, 1970).

2.2. Agglomeration process

The wet agglomeration process was conducted by using a horizontal low shear mixer. A sample of 5.0 kg of semolina was first introduced in the mixing tank (48.5 cm length, 20.0 cm width, and 19.0 cm height). The two horizontal shaft axes were positioned at 6.1 cm from the bottom of the tank, with 12 metal rotating paddle blades (47.5 cm length and 14.0 cm gap between 2 blades). The sample of semolina was mixed for 2 min at constant mixer arm speed (80 rpm) to equilibrate the temperature at 25 °C (±2 °C). Water was directly poured over the semolina under mixing at almost constant flow rate (8 g s^{-1}) during 2 min. Water addition was conducted to reach a final water content of 42.5 g water/100 g dry matter. After the water addition step, the mixture was stirred for 18 min to homogenize and agglomerate. The wet agglomerates were then collected using a plastic bowl and directly introduced in the rotating drum equipment.