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Twin screw granulation: Understanding the mechanism of granule formation along the barrel length

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ABSTRACT

The objective of this study was to develop a detailed understanding of the roles and effects of the screw elements in the granule formation along the length of barrel in the twin screw granulator (TSG) by incremental addition of the elements in the screw configuration. The number of kneading and conveying elements in the screw configuration, liquid to solid ratios (L/S) and screw speeds were varied while studying their effects on the mechanism of granule formation and the granule attributes (size, shape and structure). In order to study the granule formation mechanism, the length of TSG barrel was divided into 10 Parts. This was done to mimic and understand the actual granulation process that occurs in the individual Parts (sections) when total barrel length (cumulative length of all 10 Parts) comprising both conveying and kneading zones in the screw configuration is used. Part-1 consisted two long pitch conveying elements (LPCE) followed by four short pitch conveying elements (SPCE). Part-2 consisted of two kneading elements (KE) placed at the end of the granulator after 4SPCE. Similarly, Part-3 to Part-7 subsequently consisted 4, 6, 8, 10 and 12KE. In Part-8, 2SPCE were placed next to 12KE which is named as 12KE + 2SPCE. Same thing was repeated for Part-9 with 4SPCE and Part-10 with 6SPCE. In a separate experiment, last 4SPCE in Part-10 were replaced by 2LPCE to study the effect of increase in the screw channel width on the granule size and structure.

It was found that the granules became bigger in size, elongated and denser with increasing number of KE (Part-2 to Part-7) due to increase in shear and compaction forces acting on them. The influence is more evident at higher L/S. However, the presence of SPCE in addition to the KE (Part-8 to Part-10) reduced the size and elongation of granules due to the shearing and cutting action of SPCE. The granule formation and growth in the TSG was found to be the function of the type and number of elements in the screw configuration and the L/S. Presence of 2LPCE at the end of the screw configuration resulted in an increase in the granule size and structural voids due to the coalescence or re-agglomeration of granules.

1. Introduction

Granulation involves different dominant rate processes or mechanisms such as nucleation, coalescence, consolidation (growth) and breakage (Iveson et al., 2001b; Liu et al., 2009). Twin screw wet granulation is a continuous process where different mechanisms exist at each region or compartment along the length of the screw or barrel (Dhenge et al., 2012a). Twin

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screw wet granulation involves different process variables (powder feed rate, screw speed, length of screw, screw configuration, etc.) and formulation variables (primary particle size, type of powder, viscosity of granulation liquid, amount of binder, etc.). Some of the previous research works in the area were focused on parametric studies evaluating the influence of above-mentioned process and formulation variables on the granules properties such as size, shape, strength, flowability, etc. (Isaac et al., 2003; Keleb et al., 2004; Djuric and Kleinebudde, 2008; Van Melkebeke et al., 2008; Dhenge et al., 2010, 2012b; Vercruysse et al., 2012; El Hagrasy et al., 2013; Yu et al., 2014; Fonteyne et al., 2015; Saleh et al., 2015; Sayin et al., 2015). For instance, Keleb et al. (2004) and Djuric and Kleinebudde, 2008 found that the increasing amount of liquid (liquid to solid ratio (L/S)) results in an increase in the granule size. This was confirmed and understood from the various papers and reports published recently. Djuric et al. (2009), Dhenge et al. (2010), Dhenge et al. (2011) and Dhenge et al. (2012a) studied that higher L/S results in large number of bigger granules and reduction in the amount of fines. Furthermore, Djuric et al. (2009) and Dhenge et al. (2010) also studied the effect of varying screw speeds on the granule size using water as a granulation liquid. They found that granule size do not change significantly with screw speeds. Dhenge et al. (2010) argued that increasing screw speed restricts the granule growth by breaking the bigger agglomerate at high shear forces; hence, change in granules was not noticeable. Vercruysse et al. (2013) also studied the influence of screw speed on the granule size in terms of amount of fines, yield and agglomerates. They found that with increasing screw speed, the amount of fines, yield and agglomerates do not change significantly. These studies helped establishing the twin screw granulation as a method of choice for the wet granulation. Moreover, Dhenge et al. (2012a, 2011), Liu et al. (2015), Kumar et al. (2014), Li et al. (2014) and Vercruysse et al. (2015) studied the granule formation in the twin screw granulator (TSG). Their studies were focused on studying the effect of blocks of kneading and conveying elements in the screw configuration on the granule properties. These studies provided pioneering understanding of the granule formation in the TSG. However, the specific roles and effects of screw elements in the blocks along the barrel length have received limited attention. Therefore, in this study, an attempt has been made to further the current understanding of the granule progression in the TSG. The specific roles of kneading and conveying elements in the screw configuration on the granule growth along the length of the barrel have been investigated in detail to improve the mechanistic understanding of the granulation in the TSG.

2. Materials and methods

2.1. Materials

2.1.1. *Powder and granulation liquid*

α-Lactose monohydrate (Pharmatose 200 M, DMV-Fonterra Excipient GmbH and co., Goch, Germany, median size-42 μm) was used as powder. Distilled water was used as a granulation liquid (liquid binder) and 1 g of red dye (Erythrosine B; Acid red 51, Sigma Aldrich) was added to it.

2.1.2. *Granulation equipment*

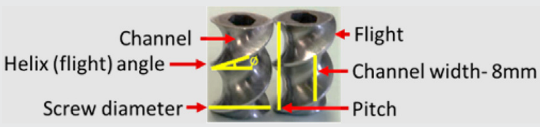
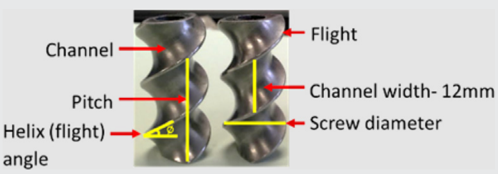
Co-rotating twin screw granulator (TSG) (Euro lab 16 TSG, Prism, Thermo Fisher Scientific, Karlsruhe, Germany) was used for the granulation trials. The TSG is derived from twin screw extruder. The die of the twin screw extruder is removed to make open-end TSG. It has 400 mm long barrel (*L*) and 16 mm bore diameter (*D*) (so, *L*/*D*—25/1). The TSG consists of a gravimetric, loss-in-weight twin screw powder feeder (K-PH-CL-24-KT20, K-Tron Soder, Niederlenz, Switzerland) with a maximum feeding capacity of 25 kg/h, a pair of co-rotating screws enclosed in metallic barrel to convey, wet and mix the powder, a peristaltic pump (101U, Watson Marlow, Cornwall, UK) to inject the liquid binder into the granulator.

2.2. Methods

2.2.1. *Preparation of granules*

Lactose powder was granulated using red-dyed distilled water in the TSG. The granules (60 g in each experiment) were collected after 1 min when the system reached the equilibrium. This was based on the K-Tron feeder stabilisation time (~30 s at powder feed rate of 2 kg/h). The granulation was carried out towards the end section of the granulator using different screw configurations. The different screw elements used to obtain the various screw configurations for the experiments are mentioned with their respective abbreviations in Table 1. The length of long pitch conveying elements (LPCE) (32 mm) is twice that of the short pitch conveying elements (SPCE)

Table 1 – Screw elements used in the experiments.

Screw element	Screw element code	Ratio of length to diameter	Screw element description
Short pitch conveying element	SPCE	L = D	
Long pitch conveying element	LPCE	L = 2D	
Kneading element with staggering angle of 60°	KE	L = D/4