Particuology xxx (2015) xxx–xxx

Contents lists available at ScienceDirect

Particuology

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

Invited review

On the spray drying of uniform functional microparticles

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ARTICLE INFO

Article history:
Received 21 April 2015
Accepted 23 April 2015

Keywords:
Microfluidic spray drying
Uniform microparticles
Encapsulation
Controlled release

ABSTRACT

Spray drying is a typical method to produce particles in dry powder forms at industrial scale. Most spray-dried products often show a wide range of particle properties even within the same batch. At Monash University, we utilise a microfluidic spray drying approach to generate uniform microparticles with tightly controlled characteristics and sizes in a scalable, almost waste-free process. The technique is useful to correlate the effects of formulation and spray drying conditions on the properties of spray-dried particles, and can be used to test new formulations for targeted applications such as encapsulation and release of active ingredients. The synthesis route can be applied to other self-assembling systems, including mesoporous, crystalline, and hierarchically structured microparticles. As spray drying is commonly used in commercial scales, the understanding of how functional particles are formed in relation to formulations and process conditions could assist in developing a cost effective, energy and material-efficient route to produce powders with better properties and ease of handling for more advanced applications such as selective adsorption and bio-separation.

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Introduction

Spray drying is an elegant one-step route for the production of powder particles in a large scale, transforming a liquid feed into dry particles by atomising the feed into a hot, dry medium (Masters, 1972). The process is composed of three stages, namely (1) the atomisation of a liquid feed into a spray; (2) the mixing of fine droplets in the spray with a heated gas stream to evaporate the solvent; and (3) the separation and collection of dried powder from the gas stream. Conventional atomisers generally produce a spray that contains droplets of different sizes and trajectories (Patel & Chen, 2007). These droplets then experience various drying profiles within the same environment. As a result, a typical feature of most spray-dried products is the significant variation in properties such as particle size, morphology, and microstructure,

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Abbreviations: DOD, droplet-on demand; EHDG, electro-hydrodynamic droplet generator; MDG, monodisperse droplet generator; MFAN, microfluidic aerosol nozzle; MFJSD, micro-fluidic-jet spray dryer; MHDG, mechano-hydrodynamic droplet generator; THDG, thermo-hydrodynamic droplet generator.

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http://dx.doi.org/10.1016/j.partic.2015.04.001

Please cite this article in press as: Liu, W., et al. On the spray drying of uniform functional microparticles. *Particuology* (2015), http://dx.doi.org/10.1016/j.partic.2015.04.001

which could affect downstream processing and the final product properties (Chen & Patel, 2008). For example, in therapeutic applications, polydisperse particles could induce different drug loadings and distributions between individual particles, and thus variations in release behaviour of active ingredients (Tran, Benoît, & Venier-Julienne, 2011).

A microfluidic jet spray drying technique to produce uniform microparticles has been developed at Monash University (Wu, 2010). This unique spray drying technique enables the production of homogeneous microparticles with a wide variety of applications including for controlled release, encapsulation, and selective adsorption. The well-defined drying conditions allow systematic studies to correlate the formulation of precursors and drying conditions with the physicochemical and functionalities of particles. The knowledge is useful to design microparticles with specific properties for encapsulation and controlled release.

Spray drying

The formation of a spray by atomisation is crucial to allow an optimum liquid evaporation condition that affects the properties of final products (Parikh, 2005). A force application is required to atomise the liquid feed. The commercially available atomisation systems are classified according to the type of energy used to generate the spray: pressure nozzles, centrifugal atomiser, kinetic energy nozzle, and sonic energy atomiser (Filková, Huang, & Mujumdar, 2006). Ideally, the spray droplets should have a relatively narrow size distribution to avoid a wide variation of drying rates (Parikh, 2005). The droplet size ranges generated by different types of atomisers are shown in Fig. 1. The size of droplet can be altered by changing the atomisation energy, with smaller droplets formed with larger atomisation energy (Parikh, 2005). With the same amount of energy, a feed with lower surface tension or viscosity tends to form smaller droplets (Parikh, 2005).

Once the liquid feed is atomised, the spray is dispersed and introduced into the drying chamber to come in contact with the heated gas and induce evaporation from the surface of the droplets. The layout of the atomiser and the inlet of heated gas stream can be varied depending on the configuration of the drying chamber (Broadhead, Edmond Rouan, & Rhodes, 1992). The co-current dryer is where the liquid spray and drying air pass through the dryer in the same direction, while counter current is referred to when the spray and drying air enter from the opposite direction. The co-current spray dryer is suitable for heat-sensitive products as the solvent evaporation is rapid with very short residence time of droplet/particles, so that the temperature of dried particles does not rise much over the wet bulb temperature, and the inherent properties of materials do not change significantly (Broadhead et al., 1992; Okuyama, Abdullah, Lenggoro, & Iskandar, 2006). The counter-current spray dryer has efficient heat utilisation and is suitable for non-heat sensitive products. There is also a mixed flow strategy where the spray-air contact is intermediate between co-current and counter-current, and is usually used in smaller dryers. The entire particle formation process in spray drying can be completed in the matter of seconds without the need of further separation or purification. The compositions of precursor can be varied within corporation of any components that can be dispersed in a solution (Rama Rao et al., 2002).

Generation of uniform microparticles via spray drying

The polydispersity of microparticles obtained from conventional spray drying is due to the broad size range of droplets and random droplet trajectories generated by conventional atomisers. Thus, a way to improve the uniformity of spray dried microparticles is to adopt atomisers capable of forming droplets with narrow size distributions and predictable trajectories (Wu, 2010). One such device is the monodisperse droplet generators (MDGs) originally developed to improve the resolution for inkjet printers (Le, 1998),

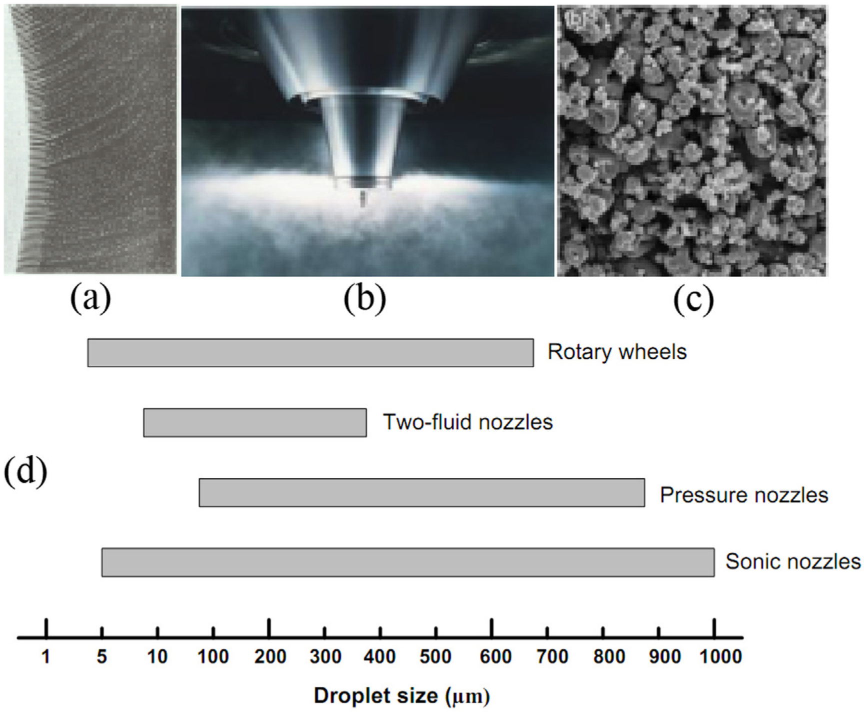

Fig. 1. (a) Droplet generation and (b) spray pattern from a rotary wheel atomiser; (c) spray dried particles; (d) droplet size ranges from different atomisers (Filková et al., 2006).

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