REVIEW ON GENERATION OF MONODISPERSE SPRAYS FOR MANUFACTURING MICRON-SIZE UNIFORM PARTICLES USING A SPRAY DRYING TECHNIQUE

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Recent advances in spraying and atomization technologies exercised in various fields have shown that a spray with narrower drop-size distribution, or even a monodisperse spray, may be advantageous in many ways. Monodisperse droplets with controlled trajectory, highly spherical shape and micron sizes were reported to be generated by several droplet generators. Majority of the existing droplet generators, however, deal with very low feed flow-rates. In this work, a few commonly used monodisperse droplet generators are presented in order to assess a possibility of producing monodisperse sprays of high volumes and using them in commercial spray drying operations. This review paper is also aiming to discuss working principles, advantages and limitations of commonly used droplet generators in other fields.

1. Introduction

Atomization is the most important processing step during spray drying. The size, size-distribution, trajectory and velocity of droplets, overall product quality, energy requirement to form a spray, chamber design, drying efficiency and powder collection efficiency are all dependent on the performance of the atomizers [1]. The fully established spray with minimum droplet-size distribution is targeted before mixing of droplets with the hot gas in order to make particles of narrow size distribution. Pressure, rotary-wheel/disc, two-fluid nozzles and sonic-type atomizers, which produce polydisperse sprays of various patterns, are currently being used in commercial spray drying operations. With existing technologies, it is very difficult to control the interaction of droplets in the drying chamber in order to avoid wall deposition and unwanted agglomeration during a spray drying step. In recent days, the trend in the market is to produce micron-size particles of uniform characteristics which may be further processed to yield agglomerates if necessary. Micron-size individual particles with a spherical shape are key ingredients in preparing many of the valuable products including functional food products, pharmaceuticals, nutraceuticals, catalysts and coating powders.

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Recently, Patel and Chen [2,3] reported a smart drying technique to produce uniform spherical particles using a single stream drying approach. They developed a laboratory-scale ink-jet spray dryer, which employed single ink-jet device as an atomizer. The ink-jet device produced single stream of monodisperse droplets, which were dried using hot air in a cylindrical-glass drying chamber. This approach seemed very attractive because it offers good control over the droplet trajectory, size-distribution and collisions. This lab-curiosity of Patel and Chen [2,3] may be further extended to manufacture 'smart' particles at such a production rate that can be commercialized for various applications such as development and testing of new products and drying of heat-sensitive materials. In order to elevate the production rate of the ink-jet spray dryer, we suggest producing monodisperse 'sprays', which consist of multiple monodisperse streams of uniform-sized droplets.

Today monodisperse stream or sprays are widely being used in diverse applications such as chemical deposition, microcapsules production, polymer-based electronics manufacturing, DNA arraying, pesticide spraying, surface coating, aerosol production, controlled-release of drugs and many more [4-7]. Piezoelectricity-driven, thermally-driven and mechanical vibrations-driven droplet generators are dominating the market today to produce monodisperse droplets. Piezoelectricity-driven droplet generators with single or multiple orifices are proved to be flexible for a range of applications. However, use of such generators is restricted to operations where very small liquid flow rates are sufficient. Industrial applications of these droplet generators require handling of high liquid flow rates. In this paper, commonly used droplet generators and their working principles, advantages and limitations are briefly reviewed in order to explore the possibility of generating high volume monodisperse sprays for using in spray drying operations.

2. Monodisperse droplets generators

Monodisperse droplet generators are classified here in following three groups based on the type of nozzles used and their mechanical layouts in order to understand their functionalities and to assess the possibility whether these techniques can be incorporated in spray drying operations.

2.1. *Ink-jet droplet generators*

Ink-jet devices are the most common droplet generators, which produce uniform, spherical, micron-sized droplets to accomplish various tasks. Major types are thermal energy-driven and vibration-driven devices. These devices contain a thin capillary with a small orifice at one end and the liquid reservoir at another end. Thermal ink-jet devices contain a thermal resistor, which usually forms a vapour bubble near the nozzle orifice [8]. Formation and subsequent collapse of the bubble lead to formation of single droplet. These devices are however not suitable for handling heat-sensitive materials [6].

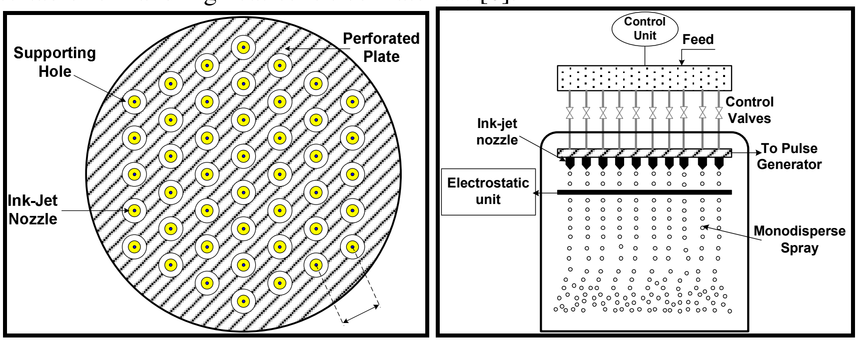

Figure 1: Multiple nozzles droplet generators to produce monodisperse sprays

Another type of droplet generators are operated using electro-mechanical vibrations, which are generally produced by piezoelectric, ultrasonic or electrostatic oscillator. In piezo-based droplet generators, the liquid is supplied to the thin capillary, which is bonded using an annular piezoelectric transducer. The droplets are only produced when a voltage pulse is supplied to the piezo-transducer, which pushes liquid out of the small orifice. The droplet frequency is mainly controlled by the piezo-transducer, and this way of droplet generation is called a drop-on-demand mode [9]. In contrast, when the liquid is pressurized to the thin capillary and a series of waveforms is applied to the piezoelectric element, a continuous stream of droplets is generated from a laminar liquid jet. This continuous mode of droplet formation follows the Reyleigh jet disintegration theory [4,6,9]. If pulse characteristics (i.e. shape, amplitude, width, rise time, fall time and frequency), fluid properties and system pressures are constant over the entire period of jetting, ink-jet droplet generators produce spherical and uniform-sized droplets [5].

The droplet size can be varied for the fixed size orifice by adjusting feed and pulse characteristics. Ink-jet droplet generators can eject droplets of the size ranging from 20 to 200 μm at a rate of 2,000 to 100,000 droplets per second [6,9]. MicroFab Technologies, Inc. (USA) has developed a wide range of ink-jet droplet generators to meet specific requirements. These droplet generators are applicable where very small yet accurate flow rates are required. The flow rates can be elevated by grouping of several nozzles into a common assembly, thus generating multiple nozzle systems. A common example of a multiple devices droplet generator is the ink-jet cartridge found in office ink-jet printers [9]. Another possible design is to place a large number of ink-jet nozzles into an atomizing plate, schematically shown in Fig.1. Such multiple nozzles droplet generators produce cylindrical monodisperse sprays. To achieve a liquid flow-rate of 15 litres/hour with devices operated at a drop frequency of 10,000 and size of 200 µm, 100 devices have to be grouped in the atomizing plate. The distance between two adjacent nozzles plays a key role for controlling droplet-droplet interactions. Designing and operating such droplet generators are very complex due to the requirement of individual feed supply and same feed and operating conditions to each device.

2.2. *Multiple orifices atomizing plate*

The atomizing plates are relatively simple structures and typically made of non-corrosive metals. Single or multiple orifices can be precisely drilled on the plate (thickness varies from 20 to 200 µm) using laser techniques. The droplets are produced by Rayleigh breakup of laminar liquid jets, which are controlled by a piezoelectric oscillator that applies disturbances with well-defined frequencies. Multiple orifices permit many monodisperse droplet streams to be generated simultaneously (one stream per orifice) which may form conical, cylindrical or other kind of monodisperse sprays. A typical multiple-orifice atomizing plate with a 62 orifices is shown in Fig.2. High flow rates up to a 13.8 liter/hour were achieved using an orifice diameter of 63 µm with such a plate [5].

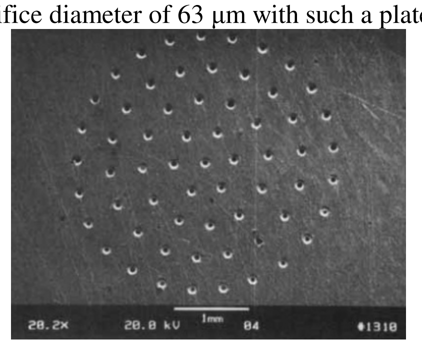

Figure 2: Photograph of a 62 orifices atomizing plate for generating monodisperse sprays [5]

The geometrical configuration of the orifices in the plate is crucial for the successful ejection. A minimum distance between two adjacent orifices must be higher than three times the orifice diameter in order to avoid droplet interactions with each other [5]. Once the monodisperse spray is formed in the chamber, the droplets-aerodynamic interaction eventually leads to collisions between the droplets, even of different jets, and disturbs the monodisperse size distribution [10]. This effect may be reduced by inclining the orifices to the normal direction of the plate and by keeping high accuracy during drilling of orifices of equal diameters [5,10]. These droplet generators are rapidly being popular for many industrial, production and research applications.

2.3. *Microfluidic droplet generators*

Microfluidics devices are an emerging technology for producing highly controlled and monodisperse droplets, or more specifically micro-emulsions. A most common geometry for contacting two immiscible feed streams is a T-junction configuration. The microfluidic chip, shown in Fig.3, is prepared by etching microchannels on a polymer plate and sealing channels using thermal techniques. The liquid stream can be replaced by a gas stream if bubbles (hollow droplets) are of interest [11]. The break-up of the dispersed phase could be geometry-based, perpendicular flow-induced or the crossflowing rupture, depending on the microchannels layouts and feed flow-rates.

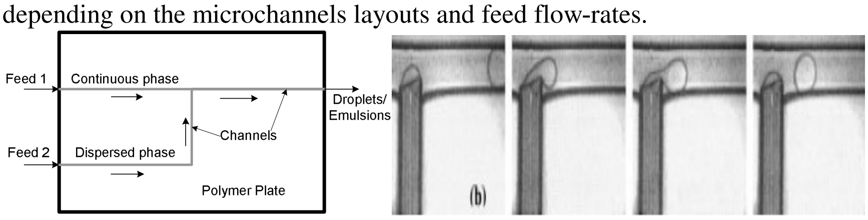

Figure 3: Microfluidic (T-junction chip) monodisperse droplets generator [12]

The drop size is mainly affected by viscosity, interfacial tension, flow-rates of both phases and wetting effects [12]. The formed droplets were observed to be highly spherical, and the polydispersity index was noticed to be lower than 2% for most of the experimental work [11,12]. Relatively larger droplets, size ranging from 50 to 500 μm, can be generated. A major limitation of microfluidic devices is the very low feed handling capacity, usually in the order of a few milliliters per hour. The research work is under progress for elevating the liquid flowrate with these types of microfluidic droplet generators.

3. Summary

In this review paper, we have presented several monodisperse droplet generators, which may be used as atomizers for production of uniform particles [2,3]. The ability of these generators to produce ‘sprays’ of controlled, reproducible, uniform and micron-sized droplets can lead to development of ‘innovative’ spray dryers, which may minimize several potential problems such as fouling and unwanted agglomeration. Monodisperse droplet generators as atomizers, if incorporated to the drying chamber, stable and spherical particles or micro-capsules of diverse morphology and microstructure may be generated. Since the drying period for droplets with diameter in the order of tens of micron is relatively short, only small volume drying chambers are sufficient. Monodisperse droplets generators such as multiple-orifice atomizing plate and multiple ink-jet nozzles plate have high potentials to find place in small-scale spray drying operations. However, specific dryer geometries have to be designed and optimized that allows controlled dispersion of hot gas and monodisperse sprays in the chamber. Detailed work is under progress within the Biotechnology and Food Engineering Group, Monash University, Australia on production of uniform particles by generating monodisperse sprays.

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