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Nano-spray drying applications in food industry

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Transforming a raw material into a suitable product for industrial use is a complex operation including drying processes. One of the most common drying processes is spray drying which produces powder with a defined particle size out of solutions, dispersions and emulsions. It is generally used for pharmaceuticals, food, biotechnology and other industrial materials synthesis. Spray drying has several advantages such as operational flexibility, applicability for heat-sensitive materials, as well as an affordable cost, but it has limitations in particle size, volume and the yield. Nowadays, nanotechnology, which refers to objects that are one-billionth of a meter in diameter, gained importance as a newest application trend in science. Accordingly, nano-spray drying technology was improved to create particles in nanometer range for efficient spray process for small quantities, narrow particle size distribution and highest yields of fine particles. In this review, new technological developments about nano-spray dryers and some of its applications in food industry will be discussed.

Key words: *Nano- spray dryer, microencapsulation, nanoencapsulation, food*

INTRODUCTION

Developing new technologies for obtaining standardized herb and food extracts is an important research topic nowadays and dried extract products have several advantages over conventional liquid forms. These advantages could be listed as low storage costs, providing more concentrated products and stable form of the active ingredients [1]. Several techniques can be applied for this purpose such as spray drying, freeze drying, spouted bed drying and fluidized bed drying. Spray-drying is a common technique used in the food industry since decades old. The first time idea was patented in 1872 by Samuel Percy where in 1920s, the industrial use had been launched with the production of milk powder and detergent [2].

Spray drying is commonly used in food, pharmaceutical, chemical and aroma industry [3-8]. Whole milk, skimmed milk and whey powders are the most popular products produced by spray drying processes. The other food products can be indicated as: instant coffee and tea, baby food, egg powder, cheese powder, ice cream mixes, fruit juices, flavoring agents, anthocyanins, enzymes, microorganisms, yeasts and pesticides [9-15].

Substantially, spray drying is a process where the liquid solution or suspension is dried to particles rapidly with atomization in a heated chamber (Figure 1). The powder obtained after this process has a flowing structure and a certain size distribution of spherical particles. Its quality depends on many factors interacted with each other like: physical and chemical properties of the raw material, feed rate and its concentration, atomizer rate and the temperature parameters of the drying medium. Among other drying processes, spray drying has relatively short drying time and it allows to dry heat-sensitive products [16]. Spray drying occurs in process steps like:

- pre-concentration of the liquid (generally for decreasing costs it is applied to low concentrated liquids),
- atomization (composing of liquid drops),
- drying in hot air/gas flow, formation of powder particles,
- separation of product from humid air/gas (cyclone stage) [17].

Removing water from the solution by spray drying is a common engineering application. In spray drying, liquid feed is atomized into hot gas flow, usually air and inert gases like nitrogen, and instantly dry. Feed liquid can be a solution, emulsion or a mixture suspension [3]. Powders obtained after drying process properties changes due to the physical and chemical properties of feeding fluid, design of the spray dryer and drying conditions as very thin powder (10-50 μm) and granule or agglomerate [18] (2-3 mm).

Advantages of spray drying could be listed as:

- if drying parameters are fixed, powders specifications could be stabilized,
- drying system can provide continuous and can be controlled automatically,

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- different dryers can be designed according to heat-sensitive, heat-resistant, corrosive or abrasive solutions.

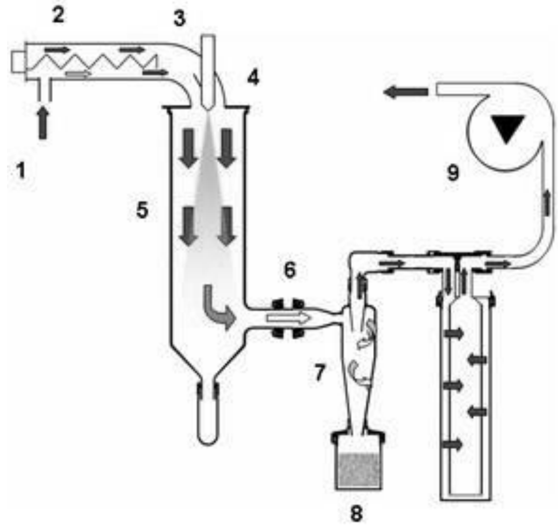

Fig. 1. General units of a spray drying system (1. air intake, 2. heating, 3. temperature sensor at air entry point, 4. atomizer, 5. drying chamber, 6. temperature sensor at air exit point, 7. cyclone: separation of the product from the air stream, 8. collection vessel for finished product, 9. aspirator)[14].

However, high installation costs, low thermal efficiency, energy consumption and workability of dried powders in humid conditions are the main disadvantages of spray drying process [2]. In addition to this, spray dried foods encounter with aroma losses and particle stickiness seen in high temperatures during the process. In order to solve these problems and enabling drying process thus producing the last powder in acceptable quality parameters; different applications can be combined such as processing spray dried powder to granules in fluid bed dryer. By this way, solubility of powders and physical resistance could be raised and flavorings could be added to the product. Another solution is microencapsulation of the raw material directly by spray drying with using different carrier agents. Microencapsulation protects the powder for oxidation reactions, prevents volatile flavor compounds and raises its storage stability. In microencapsulation, several gums such as arabic gum, carob gam, carboxymethyl cellulose (CMC), carrageenan, starch products like maltodextrins (MD19, MD12) and modified starches are generally used in order to obtain good product recovery [19,20].

Atomization constitutes the most important process step and atomization of the liquid as small droplets is carried out with pressure or centrifugal energy. For this purpose, different atomizer types such as pneumatic atomizer, pressure nozzle, two-fluid nozzle and sonic nozzle are used. The purpose of atomization is to create the maximum heat transfer surface which allows to optimum heat and mass transfer between dry air and the liquid. Proper atomization configurations depend on the viscosity, the nature of the feeding fluid and the desired properties on the final product. As the supplied energy increases, droplets obtained by atomization decreases [21].

Spray drying process can be designed according to atomizers settlement position corresponding to hot air distributors, as co-current or counter-current. In co-current flow, feeding fluid is sprayed in the same flow direction with hot air and inlet temperature changes between 150 – 220ºC, as it is suddenly evaporated. In these systems, dry powder product is subjected to moderate temperatures like 50 – 80ºC, and products thermal degradations are restricted. Thus, drying of some bacterial suspensions without harming any living organisms might be a possibility. Correspondingly, in counter-current systems, feeding fluid is sprayed in opposite directions to hot air flow. Dry powder product exposes to high temperature in this way. Therefore, drying of heat sensitive products is limited in this system. However, the most important advantage of this system is its economical properties with low energy consumption [3,22].

Nowadays, nanotechnology is a rapidly growing field which has impact on every area in science and technology. Especially some areas such as physics, engineering, chemistry, biology, agriculture, and food sciences are essential for the development of nanotechnology [23].

Nanotechnology has good potential to improve agriculture and food systems. Safety, efficiency, bioavailability and keeping nutritional values of foods and the molecular synthesis of new products or ingredients can be affected by nanoscale level. These principal links of nanotechnology are refining flavor and nutrition, food security and processing, functionality of foods, protection of the environment and the cost-effectiveness of storage and distribution [24]. Additionally, at the Second International Food Nanoscience Conference, the immense opportunities of nanoscience are asserted possible in previously mentioned areas [25].

In the food industry, significant advancements by nanotechnology are new functional materials, micro and nanoscale processing, product development, the design of methods and instrumentation for food safety and biosecurity [26]. In this context, nano-spray dryers which use nanotechnology in the design of the classical spray dryers, create particles in the nanometer range. Besides some challenges like high sensitivity of proteins during processing and storage and product recovery in pharmaceuticals brought a necessity of a new spray dryer design. To overcome these kinds of technical challenges, Bürki et al. [14], designed to generate very fine droplets resulting in particle sizes between 300 nm and 5µm. Therefore novel technologies at the spray head, heating system and particle collector made 'nano' spray drying a possibility. Differently from conventional dryers, nano-spray drying utilizes a vibrating mesh technology. With using a piezoelectric driven vibrating membrane in the spray head, millions of tiny droplets are generated every second. Dried particles are separated by the use of an electrostatic particle collector with high particle recovery rates even for nanoparticles of milligram sample amounts. However, substantial limitations of nano-spray drying were the particle size (minimum 2 µm), the yield (maximum around 70 %), and the sample volume (minimum 50 mL for devices in lab scale).

A typical spray-drying process consists of four steps that include; atomization of the liquid stream, vaporization/drying of the liquid stream through the drying gas, particle formation and separation and collection.

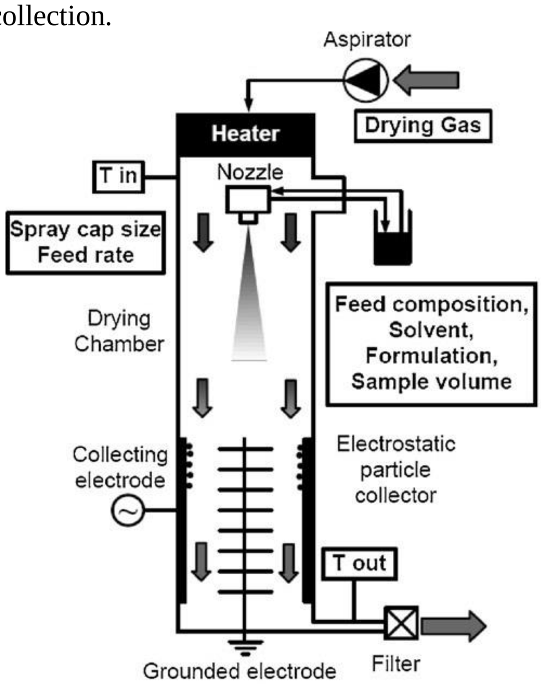

Fig. 2. Nano-spray dryer [14].

In nano-spray dryer technology, the unique feature is, the droplet generation through a piezoelectric driven actuator (with a thin stainless steel membrane and the membrane has an array of micron-sized holes; spray meshes of 4.0, 5.5 or 7.0 µm hole size) that operates at a specific ultrasonic frequency (60 kHz) and thus creating a mist of droplets with extremely ultra-fine particle size. The dried particles are electrostatically charged (solid particles are accumulated at the wall of the cylindrical particle collecting electrode by a strong electrical field, the electrical field is generated via high voltage) and gathered at the collecting electrode surface with minimal wastages and high formulation yields. Besides, a new heating system is used to provide the drying gas to produce the particles. The gas flow is laminar as in common spray drying. The advantage of laminar flow is that the particles fall straight down from the spray head and do not stick to the glass wall. Nano-spray dryer design is shown in Figure 2.

Later, these new design is used to evaluate the early stages of product development for a variety of applications including preparation of sub-micron particles of polymeric wall materials[27] producing protein nanoparticles [14,28], the encapsulation of nano-emulsions [29], as well as the drying of pharmaceutical excipients and model drugs [30].

In a study, Tewa-Tagne et al.[31] used a spray-drying method for the production of nanocapsules which partly reduced the moisture content of the product while the carrier concentration increased. Researchers also stated that moisture content of spray-dried powders depends on the nature of the carrier and its interaction with water molecules. Outlet temperature is another factor that effects the final products moisture content. Goula and Adamopoulos[32] reported that high outlet temperatures often reduce moisture content of product.

Liu et al.[27] spray dried micro and nano-scale particles in hybrid composites of alginate and silica nanoparticles in their study and observed uniform micro particles formed in a single step micro-fluidic jet spray drying. Here, evaporation induced self-assembly during spray drying then formed uniform micro particles with shells enriched with silica nanoparticles. Then the final structures of particles were determined by the drying temperature and the ratio of alginate to silica indicating that this could be used for manufacturing diverse structural motifs. As a result, combination of polymer-mediated self-assembly with a moderate temperature spray drying could be a versatile process to synthesize thermal sensitive biomaterials for food and pharmaceutical related applications.

Lately, there has been an interest in the development of protein nanotherapeutics for diseases such as cancer, diabetes and asthma. To meet that demand, Lee et al. [28] investigated spray drying technology for obtaining these kinds of powders. However, the separation and collection of protein nanoparticles with conventional spray dryer setups has been known to be extremely challenging due to its typical low collection efficiency for fine particles less than 2 μm. Accordingly, there has not been any approach to fabricate protein nanoparticles in a single step and with high yield (> 70 %). In their study, they explored the feasibility of the novel Nano Spray Dryer B-90, for the production of bovine serum albumin (BSA) nanoparticles. They reported that particle size and morphology were predominantly influenced by the spray mesh size and surfactant concentration while the drying air flow rate and inlet temperature had minimal impact.

Process parameters were determined respectively as, 4 μm spray mesh at BSA concentration of 0.1 % (w/v), surfactant concentration of 0.05 % (w/v), drying flow rate of 150 L/min, inlet temperature of 120 °C and the yield 72 ± 4 %. In conclusion, nano spray drying offered an alternative approach for the production of protein nanoparticles.

Li et al.[29], used nano spray drying technology in their research to provide submicron particles with high yields (70 % to 90 %) and small sample amounts (50 mg to 500 mg). For this aim, some polymeric wall materials (arabic gum, whey protein, polyvinyl alcohol, modified starch and maltodextrin) were spray dried and the resulting size distributions were shown to be below the 1 μm scale, attaining sizes as low as ~ 350 nm with a standard deviation of ~ 100 nm for arabic gum (0.1 wt.% solid concentration), which was a very noteworthy result. They also expressed, size and standard deviation depend on the nature and the type of the wall material and predominantly on the concentration of the spray dried solution. Consequently, they reported that, preliminary results of encapsulated nano-emulsions and formulated nano-crystals using this novel technology offer promising perspectives for new pharmaceutical applications using spray drying.

Nano and microparticle engineering of water soluble drugs was conducted using a novel piezoelectric spray-drying method in another research. Cyclosporin A (CyA) and dexamethasone (DEX) were encapsulated in biodegradable poly (D, L-lactide-co-glycolide) (PLGA) grades of different molecular weights. Spray drying process parameters such as spray mesh diameter, sample flow rate, spray rate and sample concentration were found to play a key role on the particle engineering and the obtained product yield. CyA was found to be molecularly dispersed within the PLGA nanoparticles while DEX's crystallinity varied according to the lactide/glycolide ratio. In concluding, this novel process proved to be efficient for nano and microparticle engineering of water insoluble active substances [30].

CONCLUSION

Nanotechnology offers new possibilities in food science especially in the field of functionality like enriched and fortified food products. One of these topics is obtaining nanoscale powders by spray drying which presents a platform for many applications in food technology. It can be applied to foods with nanoencapsulation of active compounds such as flavors, vitamins, minerals, antimicrobials, drugs, colorants, antioxidants, probiotic microorganisms, and micronutrients. The aim of nanoencapsulation is to maintain these active compounds at suitable levels for long periods of time. As a result, nanoparticles have better properties for encapsulation and release efficiency than traditional encapsulation systems. By this way optimization of powders inhalation properties would be useful to improve stable products and to keep aroma active subtances.

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ПРИЛОЖЕНИЯ НА СУШЕНЕТО ЧРЕЗ НАНОРАЗПРАШАВАНЕ В ХРАНИТЕЛНАТА ИНДУСТРИЯ

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(Резюме)

Трансформирането на суровия материал в подходящ продукт за индустриално приложение е комплексен процес, включващ сушене. Един от най-често срещаните процеси на сушене е сушене чрез разпрашаване, при което от разтвори, суспенсии и емулсии се получава прах и дефиниран размер на частиците. Обикновено той се използва във фармацията, хранителната промишленост, биотехнологиите ипри синтеза на други индустриални материали. Сушенето чрез разпрашаване притежава редица предимства, като операционна гъвкавост, приложимост на термо-чувствителни материали, достъпна цена, но то има ограничения по отношение на размера на частиците, обема и добива. В днешно време, нанотехнологиите, които се отнасят до обекти, имащи диаметри една милиардна част от метъра, придобиха значение като най-новите тенденции на приложения в областта на науката. В съответствие с това, сушенето чрез наноразпрашаване беше подобрено да създаде частици в нанометровия диапазон при ефективен процес на разпрашаване на малки количества, тясно разпределение на размера на частиците и най-високи добиви на фини прахови частици. В настоящото ревю ще бъдат дискутирани нови технологични развития на изсушителите чрез наноразпрашаване и някои от техните приложения в хранителната индустрия.