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Review

Spray-drying of fruit and vegetable juices: Effect of drying conditions on the product yield and physical properties

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ABSTRACT

Background: Spray-drying is one of the highly utilized techniques to increase the shelf-life of food products. However, there are problems during spray-drying of sugar-rich fruit and vegetable juices due to the low glass transition temperature of sugars present in these products (Bhandari, Datta, & Howes, 1997). The sugars transform into a sticky form which increases the deposition at the surface of the drying chamber, which eventually decreases product yield. To achieve an effective drying and to obtain an acceptable product, drying conditions must be optimized.
Scope and approach: Product yield and physical properties of the final powder are affected by various factors, including carrier material and its concentration added into the feed, feed flow rate, atomization speed/pressure, and drying temperature. This paper reviews the effects of these conditions on yield and the physical properties of the final product.
Key findings and conclusions: Recent studies have clearly shown that milk-based protein isolates as carrier materials are more effective, according to product yield in lower ratios, than carbohydrate-based carrier materials. Physical characteristics of the final powder vary according to process parameters.

1. Introduction

Fruits are important sources of vitamins, minerals, and carbohydrates. Vitamins are essential compounds that must be consumed constantly with the diet. However, fruits have a short shelf-life, and especially their vitamins could degrade during storage. Therefore, to increase the shelf-life of fruits, and to prevent the degradation of vitamins, care must be taken. For this purpose, different techniques, such as drying, modified atmosphere packaging, and edible coatings, can be applied. Among these techniques, drying is the oldest and a well-known technique to preserve fruits by reducing moisture content and, hence their water activity. Different techniques, such as natural convective drying, sun drying, forced convective drying, microwave drying, freeze-drying and spray-drying can be used to dry fruits and vegetables. Spray-drying is a well-established and widely used technique to transform liquid foods into powder form. The initial feed must be liquid. It can be a solution, an emulsion, or a suspension. Both heat-resistant and heat-sensitive products can be spray-dried (Phisut, 2012).

2. Spray-drying

The spray-drying process mainly involves the following 5 steps:

1. Preparation of feed (generally the concentration of juice and addition of carrier materials)
2. Atomization of the feed
3. Droplet-hot air contact
4. Drying of atomized droplets
5. Separation of dried particles from the humid air (Verma & Singh, 2015).

2.1. Preparation of feed

Feed is concentrated before spray-drying to achieve a cost-effective drying operation. Increasing feed concentration decreases the amount of moisture and hence, the energy needed to evaporate water.

Additionally, some carrier materials are added to increase

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product yield and to improve physical characteristics of the final product. The common carrier materials used in spray-drying of fruit juices are maltodextrin, gum Arabic, milk proteins (whey protein isolate, sodium caseinate) and plant proteins.

2.1.1. Hydrolyzed starch

Hydrolyzed starch, produced by hydrolysis of starch using acids or enzyme, are cheap, odorless, and useful carrier materials. They have low viscosity at higher concentrations. Hydrolyzed starches are described by dextrose equivalent (DE) which shows the hydrolysis level of the starch. Hydrolyzed starch with lower than 20 DE is called maltodextrin, while hydrolyzed starch with higher than 20 DE is called dried glucose syrup. Higher-DE hydrolyzed starches have lower oxygen permeability and they have a more protective effect, but they are subject to caking during storage (Shahidi & Han, 1993).

2.1.2. Gum Arabic

Gum Arabic is one of the oldest and a well-known natural gum produced from exudates of Acacia trees. Apart from the other gums, it has low viscosity and high solubility (up to 50%) in both cold and hot water. It consists of a complex heteropolysaccharide with a highly ramified structure and a protein content of approximately 2%. The proteins in the structure are responsible for its functional properties (McNamee, O'Riordan, & O'Sullivan, 1998; Turchiuli et al., 2005), while the arabinogalactan fraction has film-forming properties (McNamee et al., 1998). However, gum Arabic is expensive, has limited production, and contains impurities.

2.1.3. Proteins

Proteins have many different chemical moieties, amphiphilic properties, the ability to self-associate and also to interact with a variety of different types of substances, they have large molecular weights, and display molecular chain flexibility. Therefore, proteins have excellent functional properties, including solubility in various solvents, acceptable viscosity, emulsification ability, and film-formation capability. Due to these properties, proteins are good alternatives for hydrolyzed starch and gum Arabic as carrier materials for spray-drying of sugar-rich product (Jafari, Assadpoor, He, & Bhandari, 2008; Shahidi & Han, 1993).

2.2. Atomization

The primary objective of atomization is to increase the effective drying area by conversion of a liquid into a spray or mist. The larger surface area results in a more efficient heat and mass transfers. Atomization can be achieved by rotary atomizers, hydraulic nozzles, pneumatic nozzles, and ultrasonic nozzles (Cal & Sollohub, 2010).

2.2.1. Rotary atomizers

Rotary atomizers are horizontally placed wheels or discs that have grooves on the perimeters. The feed is supplied to the center of the rotating disc and the feed is catapulted to the grooves due to the centrifugal force. These grooves cause homogeneously shaped and sized droplets (Cal & Sollohub, 2010). The product yield is lower in rotary atomizers compared to other atomization types. Therefore, it is unsuitable for expensive feeds (Huang, Kumar, & Mujumdar, 2006).

2.2.2. Hydraulic nozzles (one-fluid nozzles)

In this type of nozzles, the feed is flowing under pressure through a nozzle with decreasing diameter. Hydraulic nozzles are not suitable for the feeds with higher viscosities. The only parameter which can be adjusted with this type of nozzles is feeding rate (Cal & Sollohub, 2010).

2.2.3. Pneumatic nozzles (multi-fluid nozzles)

In pneumatic nozzles, atomization of the feed was achieved by the pressure of the compressed carrier gas. Creation of high frictional forces over feed causes disintegration of the solution into the droplets. The shape and size of the formed droplets are dependent on the feed properties (surface tension, density, and viscosity) and, velocity of compressed gas (Cal & Sollohub, 2010).

2.2.4. Ultrasonic nozzles

Ultrasonic nozzles are relatively new technology in atomization. Ultrasonic waves create vibration and cause atomization of the feed. The advantage of these nozzles is the ability to self-clean and narrower particle size distribution. The formed droplets are dependent on the working frequency. Additionally, the formed droplets moving with a low velocity that increases the product yield (Cal & Sollohub, 2010).

2.3. Droplet-air contact

Droplet-air contact takes place in drying chamber just after the atomization of the feed in three basic steps:

1. Thermal energy transferred from the hot air to the droplets, used for evaporation
2. Air temperature drops instantaneously due to evaporation
3. Cooled air pneumatically transports the particles along the drying system (Phisut, 2012)

Drying can be classified in three models according to the direction of drying air and feed. In the co-current model, which is the most common drying model used in food industry, feed sprayed in the same direction with the hot air. In this model, powders supposed to be exposed up to wet bulb temperature. In counter-current drying, atomization direction is opposite to the drying air flow. Therefore, atomized droplets firstly meet the coldest air that ensures gradual increasing in the temperature of the particle. However, this model is not suitable for sensitive feeds to the temperature. In the combined (mixed) model, both co-current and counter-current drying was used (Cal & Sollohub, 2010; Gharsallaoui, Roudaut, Chambin, Voilley, & Saurel, 2007; Masters, 1991; Murugesan & Orsat, 2011).

2.4. Drying of droplets

Drying of droplets occurs in three steps:

1. Just after droplet-air contact, temperature of the droplets increases up to wet-bulb temperature
2. Evaporation of water continues at constant temperature and water vapor partial pressure. This step leads until the rate of diffusion is equal to the drying rate.
3. At the final step, after the formation of dry crust at the droplet surface the drying rate decreases and become dependent on the water diffusion rate. Drying is completed when the temperature of the drying air and particle temperature equalized (Gharsallaoui et al., 2007; Masters, 1991).

2.5. Separation of dried particles

Separation of the dried particles from the humid air was achieved by cyclones, bag filters, wet scrubbers, and electrostatic precipitators (Verma & Singh, 2015).