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Stickiness Problem Associated with Spray Drying of Sugar and Acid Rich Foods: A Mini Review

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Abstract

Spray drying is the most common technique used in food industries for large scale production of milk powders, fruit juice powders, encapsulated flavor etc. However spray drying of sugar and acid rich food materials is associated with stickiness problem. On spray drying of these food materials, the powder particles stick to one another and to the walls of the dryer, leading to the operational problems and low product yield. The sticky behavior is attributed to presence of low molecular weight sugars and organic acids which have low glass transition temperature. In order to achieve successful drying, various methods like addition of high molecular weight drying aids to increase glass transition temperature of feed mixture, use of low humidity and low temperature conditions, scrapping of dryer surfaces, cooling of dryer wall by using dehumidified air and surface modification by proteins to encapsulate sugars can be used.

Keywords: Spray drying; Stickiness; Glass transition temperature; Drying aids; Dehumidified air

Introduction

Spray drying is a common technique utilized in food and pharmaceutical industries to obtain powders [1]. It has been widely utilized for commercial production of fruit and vegetable juice powders. Spray drying involves the conversion of feed material in liquid or slurry form to dry powder. The feed material is atomized into a drying chamber where the resulting spray mixes with hot air, which evaporates the liquid part of the spray leaving behind the dried particles [2]. The spray dried powders have gained much attention because of numerous benefits over their liquid ones like longer shelf life, easier handling and transportation, reduced packaging and reduced volume or weight [3,4]. The quality characteristics of spray dried product depends on spray drying conditions including inlet air temperature, feed flow rate, concentration of drying aid used, feed characteristics etc. [5].

The foods that are spray dried can be divided into two main groups viz. non-sticky and sticky. Non-sticky food materials can be easily spray dried using a simple dryer design and the final powder remains free flowing. The examples of non-sticky materials include egg powders, dairy powders and solutions such as maltodextrin, gums, and proteins [1]. In case of sticky foods, there occurs a problem in drying under normal spray drying conditions. According to Bhandari and Howes, [6] and Hennings et al., [7], the sticky foods generally get stick on the dryer wall or they may get transformed into unwanted agglomerates in the dryer chamber and conveying system which leads to operating problems and low product yield [6,7]. The examples of sticky foods include sugar and acid-rich foods.

Powder stickiness

Stickiness is a phenomenon frequently encountered during spray drying of sugar and acid rich food materials. Powder stickiness is a cohesion-adhesion property. It can be explained in terms particle–particle stickiness (cohesion) and particle–wall surface stickiness (adhesion) [8]. The measure of the forces with which the powder particles are held together is due to its internal property called cohesion which leads to lump formation in the powder bed. Thus the force required to breakdown the powder agglomerates should be greater than the cohesive force [9]. Adhesion is an interfacial property and is the tendency of powder particles to stick with the wall surface of spray dryer. The cohesion and adhesion forces are key parameters for design of dryers and drying conditions. The surface composition of the powder particles is mainly responsible for stickiness problem. According to Boonyai et al. [10] tendency of cohesiveness or adhesiveness of surface material of powder particles cannot be necessary same as bulk because during drying migration of solutes to the surface of particles makes the surface composition different as that of bulk [10]. Both stickiness characteristics (cohesion and adhesion) can co-exist during the spray drying of sugar-rich food materials [11,12]. The inter particle stickiness i.e. cohesion is due to formation of immobile liquid bridges, mobile liquid bridges, mechanical interlocking namely intermolecular and electrostatic forces and solid bridges [10]. Adhesion of powder particles with the walls of drying chamber is the main cause for material loss in spray drying of sugar and acid rich foods [13,14]. The powder losses its quality when retained for a longer time on walls of dryer.

Cause of stickiness

Powder recovery in spray drying of sugar and acid rich foods is a big challenge in utilizing the spray drying technology due to presence of low molecular weight sugars (Glucose, fructose) and organic acids (citric, malic and tartaric acid) [11]. The high hygroscopicity, thermoplasticity, and low glass transition temperature (Tg) of these low-molecular-weight substances contribute to the stickiness problem. At a spray drying temperature higher than Tg +20°C, these components tend to form soft particle with a sticky surface, leading to powder stickiness and finally forming a paste-like structure instead of a powder [15]. The molecular mobility of such molecules is high because of their low glass transition temperature (Tg) and thus leads to stickiness problem at temperatures normally prevailing in spray dryers [14,16]. Glass transition temperature is the main characteristic transformation temperature of the amorphous phase. The glass transition event occurs when a hard, solid, amorphous sugar undergoes a transformation to a soft, rubbery, liquid phase [3]. In surface energy terms, a solid glass will have low surface energy and will not stick to any other low energy solid surfaces. Due to the transition from glassy to rubbery (or liquid) state, the surface energy of the material increases and the molecules start interacting with the solid surface. In a food drying operation, the product is in a liquid or rubbery state and due to the removal of plasticizer (water) the liquid/ rubbery food is converted to the glassy state. If the food material does not go through the transition due to a higher drying temperature than the glass transition temperature, the product will remain in a high energy sticky state. If this food comes in contact with a high energy solid surface it will stick or cling to it [6].

Control of stickiness

To minimize the stickiness problem material science and process based approaches are in place. The material science based approach includes addition of high molecular weight drying aids to the feed solution thereby increasing the glass transition temperature while the process based approach includes mechanical scraping of the chamber wall, use of cold air at the bottom etc. [17].

Material science based approach

This method includes the addition of high molecular weight additives to the feed material before atomizing it so as to increase its glass transition temperature [18]. The most commonly used addictives/drying aids used in spray drying include maltodextrins, gum arabic and starch due to their high solubility and less viscosity [19]. Due to its emulsifying property because of protein content, gum Arabic is more effective than maltodextrin [20,21]. Using gum Arabic-maltodextrin blend has proved to be more effective in spray drying [22]. These carriers not only overcome the stickiness problem and reduce powder hygroscopicity but also protect sensitive components of food material including phenolics, vitamins and caroteinoids [23].

Process based approach

Low humidity and low temperature conditions: Spray drying process involving the use of low humidity-low temperature air can be used to reduce the stickiness problem during spray drying [24]. The low drying temperature means that product will not be plastic. Drying rates in this process are slow because of low temperature. Therefore the height of the drying chamber has to be increased to provide enough time for complete drying. However this process has not been utilized commercially.

Introduction of cold air: Introduction of cold air towards the end of drying process especially at the lower end of the drier chamber can result in the formation of a solid particulate surface and considerably reduces the stickiness of the powder particles [25]. However introduction of high amount of cold air causes an increase in relative humidity of the air that can increase the surface moisture of powder particles and thus decreases the glass transition temperature of the resulting powder and hence increases the chances of stickiness.

Cooling of walls of dryer chamber: The cooling of walls of dryer chamber minimizes the thermoplastic particles from sticking because the wall will be enough cold to cool and solidify the outer surface of the thermoplastic materials coming in contact with it [11]. This method was found satisfactory in improving the drying process but not 100% because cooling of chamber wall will also cool the surrounding air and increases the relative humidity of the air close to the wall surface.

Scrapping of chamber wall: An intermittent sweeping of the chamber wall with dehumidified cold air can remove loosely sticked particles on the chamber wall. This method can be useful for relatively less thermoplastic sugar such as lactose or sucrose. An experimental spray drier with a chamber wall scraper specifically to dry tomato juice was developed by Karatas [25].

Drier design: The conical form of spray drier is most suitable for thermoplastic product. According to Masters spray dryer with co-current regime is suitable for sticky products [14].

Process based approaches are economically non-viable because at lower outlet air temperature as stickiness can be prevented but production of powder becomes non-viable. The material science approach also has limitations as addition of a large amount of drying aid (40 to 60% maltodextrin w/w) was required to convert sucrose solution into powder form [26] and 35% to 45% (w/w) of maltodextrin was required for production of blackcurrant, apricot and raspberry juice powders [27]. More than 60% of maltodextrin was needed for production of orange juice powder [4]. Addition of such large amount of drying aid alters the resultant powder quality and risks consumer disapproval surface modification with proteins, taking into consideration both the film forming and the surface activity of protein is a novel way to minimize the stickiness problem during spray drying [28]. Proteins such as whey, casein, and soy protein are used to minimize the stickiness problem by modifying the surface properties of the atomized droplets and particles Because of the surface active and film forming property, protein migrates to the air water interface of atomized feed droplets, forming a protein film upon drying which overcomes the stickiness of sugar protein solutions. This film is converted into a glassy skin with high glass transition temperature when subjected into hot and dry air. The resultant skin is capable of overcoming the coalescence of droplets as well as sticky interactions of the particles at the drying chamber of the spray-dryer [29-31].

Conclusion

It may be concluded that spray drying of sugar and acid rich food materials is difficult due to the presence of inherent low molecular weight sugars and organic acids, having low glass transition temperature. Addition of high molecular weight drying aids, process based approaches like use of low humidity and low temperature conditions, cooling of dryer chamber wall and surface modification by proteins are the possible ways to solve the stickiness problem and hence to increase the product recovery.

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