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Review Article

A REVIEW ON SPRAY DRYING: EMERGING TECHNOLOGY IN FOOD INDUSTRY

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ABSTRACT
Spray drying is a common drying technique in food industries to convert liquid to powder form. A good understanding on the dynamic behavior of the process is important to ensure proper control. The aim of this study is to develop empirical models for spray drying of whole milk powder and orange juice powder. A preliminary study is necessary to study the effect of several inputs such as inlet air temperature, feed flow rate, the moisture content, the bulk density, and the solubility of powders. The selection of suitable inputs is important to ensure the desired quality of final products (moisture content). It was found that inlet air temperature gave more significant effect on outlet air temperature and powder moisture compared to other two inputs. Inlet air temperature and outlet temperature were selected as the manipulated variable and controlled variables respectively. Spray drying system proved advantageous over the standard laboratory dryer.

Keywords: *Empirical Model, Milk Powder, Orange Juice, Spray drying, Temperature*

INTRODUCTION
Spray drying is presently one of the most exciting technologies for food, pharmaceutical industry, being an ideal process where the end-product must comply with precise quality standards regarding particle size distribution, residual moisture content, and bulk density. The fruit and vegetable juices are dried in order to produce such a form which is stable and can be handled easily, which reconstitutes rapidly to a quality product resembling the original juice. Dried juice products today are used mainly as convenient foods and have long storage life at ordinary temperatures. Completely dried fruit powders are often used for making many delicious food products. The preparation of instant food powders, such as milk, soups, juices and coffee, needs a further step of agglomeration after spray drying. This operation is used to get larger particles (from 50–80 μm to 250–500 μm) with a narrower size distribution in order to improve flow ability; and to modify particle structure (porosity) to obtain good instant properties (wettability, dispersability and solubility). Fruit powders less than 4% (wb) moisture content can be used to make candy, toffee, furge.

There are several drying techniques for production of food powders. They are: hot air, vacuum, freeze and spray drying. Among them spray drying is the simplest and commercially used method for transforming a wide variety of liquid food products into powder form. Spray dryer uses hot air and can use fairly high air temperatures. Because of this temperature water evaporates from the product being dried.

The drying process can be completed within a short period of time, thus enabling to prepare dried fruit powder without heat degradation even at comparatively high air temperatures. As in conventional drying, spray drying takes place in two stages; the constant rate and the falling rate. Since the particles are finely divided in the spray dryer, the time element involved in each of these stages is very small. In the constant rate period, evaporation takes place at the surface of the particle and the evaporation rate is controlled by the diffusion rate of the vapor through the surrounding air film. The primary driving force is the temperature differences between the surrounding air and the temperature of the particle, which can be considered as the wet bulb temperature of the inlet air. In the constant rate period, the diffusion rate of the water through the particle is capable of being greater than the evaporation rate (Adhikari, 2003).

Principle of Spray Drying Technique

The first spray dryers were manufactured in the USA in 1933. Spray drying is one of the best drying methods to convert directly the fluid materials into solid or semi-solid particles (Dolinsky, 2001). Spray drying is a unit operation by which a liquid product is atomized in a hot gas current to instantaneously obtain a powder. The gas generally used is air or more rarely an inert gas, particularly nitrogen gas. The initial liquid feeding can be a solution, an emulsion or a suspension (Gharasallaoui, 2007). It can be used to both heat-resistant and heat sensitive products. Spray drying involves in the complex interactions of process, apparatus and feed parameters which all have an influence on the final product quality (Masters, 1986). The spray drying process can produce a good quality final product with low water activity and reduce the weight, resulting in easy storage and transportation. The physicochemical properties of the final product mainly depend on inlet temperature, air flow rate, feed flow rate, atomizer speed, types of carrier agent and their concentration.

Spray Dryer

The spray dryer is a device used to produce the powdered form of any liquid. It takes a liquid stream and separates the solute or suspension as a solid and the solvent into a vapor. The solid is usually collected in a drum or cyclone (Maltini, 1986). The liquid input stream is sprayed through a nozzle into a hot vapor stream and vaporized. The solid as forms as moisture contents quickly leave the droplets. A nozzle is usually used to make the droplets as small as possible to maximize the heat transfer and rate of water vaporization. The spray dryers can dry a product very quickly compared to other methods of drying. They also turn a solution or slurry into a dried powder in a single step, which can be the advantage for maximizing the profit and minimize the process (Kwapinska, 2005).

Basic Steps of Spray Drying

Concentration of Fruit Juice

Generally, the feedstock is concentrated before introducing into the spray dryer. By concentrating process there was increased in solid contents thereby reducing the amount of liquids and that must be evaporated in the spray dryer. The feedstock in conventional large scale spray dryer normally concentrates to 50%-60% before introducing to spray dryer. However, the small scale laboratory spray dryer will have more diluted feedstock because it will be clogged easily if the feed have high viscosity (Chegina, 2008).

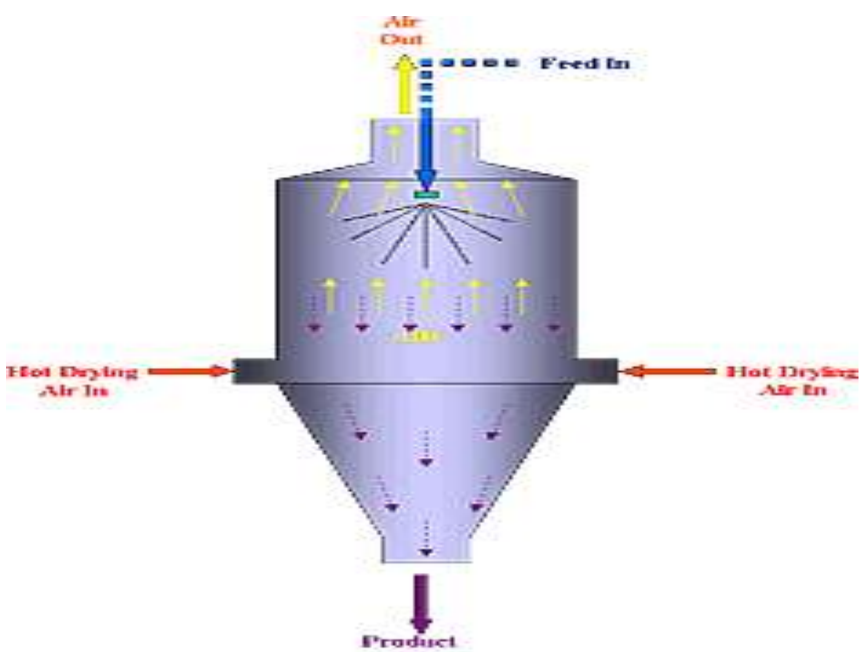

Figure 1: Spray drying system

Atomization

Atomization refers to the conversion of bulk liquid into a droplets or mist, often by passing the liquid through a nozzle. The liquid which sprayed through nozzle will increase the surface area of the liquid which later will be contacted to hot air and dried into a powder. The nozzle size may differ according to the size of spray dryer. Droplet size ranges from 20 µm to 180 µm and it depends on the nozzle. Smaller spray dryer occupies smaller nozzles and reverse in the industrial scale spray dryer. The aim of this stage is to create a maximum heat transferring surface between the dry air and the liquid, in order to optimize heat and mass transfers. The choice upon the atomizer configuration depends on the nature and viscosity of feed and desired characteristics of the dried product (Master, 1986; Patel, 2009).

Droplet-air Contact

Chamber is the important component of spray dryer, here the sprayed droplet is contacted with the hot air and the drying process begins. Air is heated by the heating element which situated before entering the chamber to a predefined temperature depending upon the characteristics of the feed fluid. The hot air is brought in contact with the spray droplets in the following ways through the air distributor.

1. Co-current
2. Counter-current
3. Mixed flow

The thermal energy of the hot air is used for evaporation and the cooled air pneumatically conveys the dried particles in the system. For few seconds hot air and spray droplet comes in contact, once the drying is achieved and the air temperature of air drops instantaneously. The nozzle increases the contact area of droplet and hot air influences in the huge heat transfer between droplet and hot air. The hot air evaporates moisture content in the droplet and changes into powder form. In co-current process the liquid is sprayed in the same direction as the flow of hot air through the apparatus, hot air inlet temperature is typically 150-220^{o}C, evaporation occurs instantaneously and then dry powders will be exposed to moderate temperatures (typically 50-80^{o}C) which limits the thermal degradations. In counter- current drying, the liquid is sprayed in the opposite direction of hot air flow for high temperature process. Thermo-sensitive products are usually restricted to in this process. However, the main advantage of this process is considered as more economic in term of consuming energy (Maltini, 1986; Duck, 1997).

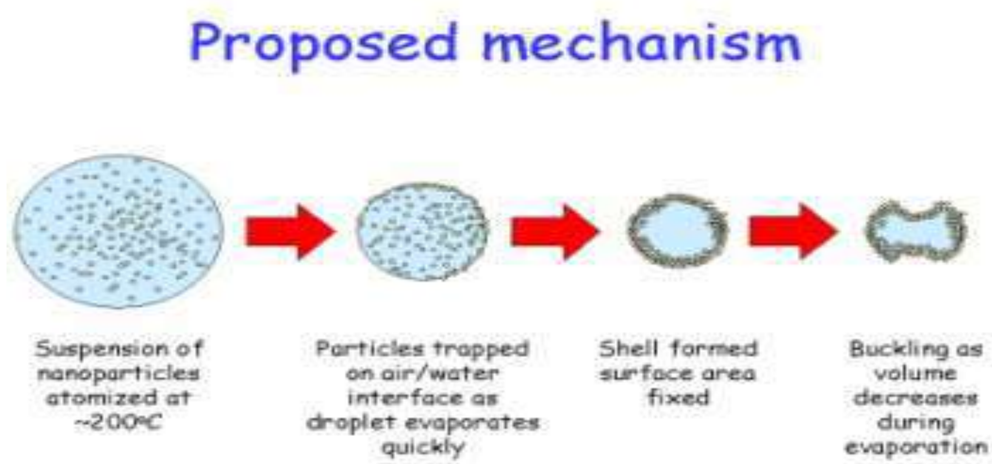

Figure 2: Representation of droplet drying process

Droplet Drying

When hot air contacts between the liquid and gas phases and balances the temperature and established the vapor partial pressure at this stage droplets formation occurs. Heat transfer is carried out from the air towards the product and thus induces the difference in temperature. Water transfer is carried out in the opposite direction due to the vapor pressure difference. Based on the drying theory, three successive steps can be distinguished. Just after the hot air - liquid contact, heat transfer majorly causes the increase of droplets temperature up to a constant value. This value is defined as the air drying humid thermometer temperature; after that, the evaporation of water droplet is carried out at a constant temperature and water vapor partial pressure. The rate of water diffusion from the droplet core to its surface is usually considered as constant and equal to the surface evaporation rate. After a certain critical value, a dry crust is formed at the droplet surface and the drying rate rapidly decreases with the drying front progression and becomes dependent on the water diffusion rate through this crust. Drying is finished when the particle temperature becomes equal to that of the air. Each product has a difference of particle-forming characteristics such as expand, contract, fracture or disintegrate. The resulting particles may be relatively uniform hollow spheres, or porous and irregularly shaped (Maltini, 1986).

Separation of Dried Particles

Separation is done by cyclone to reduce product loss in the atmosphere. The dense particles are recovered at the base of the drying chamber while the finest ones pass through the cyclone to separate from the humid air. In addition to cyclones, spray dryers are commonly equipped with the filters, called ‘‘bag houses’’ that are used to remove the finest powder, and the chemical scrubbers remove the remaining powder or any volatile pollutants (e.g. Flavourings). The obtained powder is made up of particles which originate from spherical drops after shrinking.

Carrier Agent

The problem of powder stickiness is mainly due to the low glass transition temperature (Tg) of the low molecular weight sugars present in such products, essentially sucrose, glucose, and fructose. The glass transition temperature (Tg), is the temperature at which the amorphous phase of the polymer is converted between rubbery and glassy states.

Fruit juice powder obtained by spray drying might have some problems with their property, such as stickiness, hygroscopic and solubility, due to the presence of low molecular weight sugars and acids, which have a low glass transition temperature (Bhandari and Jittanit, 2010).

Thus, they can stick on the dryer chamber wall during drying, leading to low product yield and operational problems. The low glass transition temperature (Tg), high hydroscopic, low melting point, and high water solubility of the dry solids produce the highly sticky products (Roos, 1991) stated that these solid materials are very hygroscopic in amorphous state and loose free flowing character at high moisture content.

These problems can be solved by the addition of some carrier agents, like polymers and gums, to the product before being atomized. Moreover, carrier agent is also used for microencapsulation. It can protect sensitive food components against unfavorable ambient conditions, mask or preserve flavours and aromas, reduce the volatility and reactivity and provide additional attractiveness for the merchandising of food products (Jittanit, 2010).

Maltodextrins are low cost and very useful for spray drying process on food materials. The use of different carrier agents and different drying conditions produces the different physicochemical properties of powders. Knowledge of food properties is essential to know and thus will help to optimize the processes, functionalities, to reduce costs, mainly in the case of powders produced or used in pharmaceutical and food industries. Properties such as moisture content and water activity are essential for powder stability and storage. Bulk density is important for packaging and shipping considerations.

Factor Affecting Drying Process

Inlet Temperature

Powder properties such as moisture content, bulk density, particle size, hygroscopicity and morphology were affected by inlet temperature. Normally, the inlet temperature uses for spray dry technique for food powder is 150-220^{o}C. Chegini (2005) studied the effect of inlet temperature (110-190^{o}C) on the moisture content of orange juice powder. It was found that at a constant feed flow rate, increasing the inlet air temperature reduced the residual moisture content.

At higher inlet air temperatures, there is a greater temperature gradient between the atomized feed and drying air and it results the greatest driving force for water evaporation. The use of higher inlet air temperature leads to the production of larger particles and causes the higher swelling. If temperature is low, the particle remains more shrunk and smaller. Nijdam (2006) were obtained the similar results in the production of milk powder at 120^{o}C and 200^{o}C. The higher drying temperature is lower the moisture content and increase its hygroscopicity. This is related to the water concentration gradient between the product and the surrounding air, which is great for the less moist powder. The increase of inlet temperatures has given the higher process yield and it was due to the greater efficiency of heat and mass transfer processes occurring when higher inlet air temperatures were used.

When the drying temperature is sufficiently high and the moisture is evaporated very quickly and the skin becomes dry and hard. As a result, the hollow particle cannot deflate when vapor condenses within the vacuole as the particle moves into cooler regions of the dryer. However, when the drying temperature is lower, the skin remains moist and supple for longer, so that the hollow particle can deflate and shrivel as it cools.

Air Flow Rates

The rate of air flow must be at a maximum in all cases. The movement of air is decided the rate and degree of droplet evaporation by inducing, the passage of spray through the drying zone and the concentration of product in the region of the dryer walls and finally extent the semi-dried droplets and thus re-enter the hot areas around the air disperser. A lower drying air flow rate causes an increase in the product halting time in drying chamber and enforces the circulatory effects.

The effect of drying air flow rate on powder solubility depends on its effect on powder moisture content and density of powder. Density variation can arise from temperature changes and migrating pollution. By using COMSOL multi physics we can able to get the exact solution which is used for both temperature and concentration changes. The rising of air flow rate was led to the increased of powder moisture content and decrease in powder solubility (Papadakis, 1998).

Atomizer Speed

At higher atomizer speed, the smaller droplets were produced and more moisture was evaporated resulting from an increased contact surface.

Feed Flow Rate

Higher flow rates imply in a shorter contact time between the feed and drying air and making the heat transfer less efficient and thus caused the lower water evaporation. The higher feed flow rate showed a negative effect on process yield and that was resulting the decreased heat, mass transfer and the lower process yield. In addition, when higher feed rates were used, a dripping inside the main chamber was observed, when the mixture was passed straight to the chamber and that was not atomized and finally resulting the lower process yield.

Type of Carrier Agent

The addition of high molecular weight additives to the product before atomizing is widely used as an alternative way to increase Tg of powder (Truong, 2005). The use of carrier agents such as maltodextrins, gum Arabic, waxy starch, and microcrystalline cellulose, was influenced the properties and stability of the powder. The result showed that the higher the maltodextrins dextrose equivalent (DE) causes higher the moisture content in the powder. This probably due to the chemical structure of high-DE maltodextrins, which have a high number of ramifications with hydrophilic groups, and thus can easily bind to water molecules from the ambient air during powder handling after the spray drying. Additionally, higher maltodextrins DE caused the increase in bulk density in the powder due to its stickiness.

Concentration of Carrier Agent

The concentration of the carrier agent also affected the powder properties. Low concentration of carrier agent may obtain the stickiness powder. The addition of maltodextrins could increase the total solid content in the feed and thus, reduce the moisture content of the product. It was suggested that maltodextrins could alter the surface stickiness of low molecular weight sugars such as glucose, sucrose and fructose and organic acids, therefore, facilitated drying and reduced the stickiness of the spray dried product. However, if the added maltodextrins was more than 10%, the resulted powders lost their attractive red-orange colour. An increased in maltodextrins concentration led to a decreased in bulk density in tomato juice powder and orange juice powder. This effect could be the addition of maltodextrins was minimized the thermoplastic particles from sticking and the sticky or less free-flowing nature of a powder was associated with a high bulk density (Murugesan, 2011).

Process for Spray Drying

The pulp is pumped to the duplex filter, to remove suspended particles by centrifugal pump. Pulp was pumped to the nozzle assembly with required high pressure where the pulp was atomized into fine droplets in the drying chamber. The high pressure of the feed was built by the triplex reciprocating pump. A pressure gauge was provided at the discharge line of the pump. The pressure of the feed could be changed by adjusting the rpm of the pump through frequency controller provided on the control panel. The drying medium, air was sucked by the supply fan through the filter and was supplied to the air heater. The air was indirectly heated by dry, saturated steam to the required inlet temperature and the hot air was passed to at the top of the drying chamber through insulated inlet air duct. The amount of air supplied to the dryer for complete drying could be adjusted by changing the position of the damper provided at the supply fan outlet. The mixture of air and dry powder were sucked by the exhaust fan through exhaust air duct from the bottom of the drying chamber and passed to the cyclone where the powder and air were separated.

The powder is collected from the cyclone and air is left to the atmosphere. Electro-magnetic hammers are also provided both at the drying chamber cone portion and at the cyclone for ensuring regular powder discharge. Normally, the plant is operated with slight negative pressure of, approx. 5 mm water column, to avoid dusting of the powder to the environment. Content of the fruit pulp will be calculated on the basis of the weight loss from the sample (BIS, 1989). The procedure was similar to the determination of moisture content of fruit pulp (BIS, 1989). Reconstitution of fruit powder is observed by taking a known quantity of 4 g fruit powder and dissolved in 100 ml warm water at 40^{o}C. The powder is completely stirred and observed.

Table 1: Variation of different parameters for orange juice

Inlet air temperature ^{0}C	**outlet air temperature ^{0}C**	**Feed flow rate ml/min**	**Bulk density gm/cm^3**	**Moisture content (%)**	**Insoluble solid (%)**	**Yield (%)**
130	70	15	0.5	2.5	20.00	35
130	71	20	0.45	2.2	21.10	34
130	73	25	0.42	2.1	22.15	34
130	75	30	0.40	2.1	22.20	32
140	85	15	0.38	2.45	24.42	33
140	85	20	0.34	2.42	25.12	32
140	83	25	0.32	2.40	25.35	30
140	84	30	0.30	2.35	25.38	28
150	95	15	0.27	2.25	26.10	25
150	92	20	0.25	2.20	26.25	22
150	96	25	0.23	2.15	26.35	19
150	95	30	0.21	2.10	26.40	18

For Milk Powder

Milk powder heat treatment varies depending on the finished product specification. Infant formula milk powder treatment is higher than most other powders. The aim is to destroy all pathogenic and as many of the other microorganisms present and to inactivate enzymes, particularly lipase, which can cause fat lipolysis during storage resulting in "off odours". This also reduces the risk of oxidative changes during storage.

The table indicated that increasing the inlet air temperature reduced the yield and increased the insoluble solid. Increasing the inlet air temperature often caused the melting of powder and cohesion wall so the amount of powder production and yield reduced. Also because of creating a rapid formation of dried layer at the droplet surface, no water influenced the inner of particle when dissolved in the water.

CONCLUSION

The inlet air temperature and feed flow rate have significant effect on yield and deposit of powder. With increasing these parameters, the wall deposit increases and yield is reduced. The important parameters that play role on powder deposit are the sticky point temperature that for orange juice powder at 2% moisture at 44°C. For correct design of fruit juice industrial spray dryer, the wall temperature must be controlled at under sticky point temperature.

Fruit juice powders have many benefits and economic potentials over their liquid counterparts such as reduced volume or weight, reduced packaging, easier handling and transportation, and much longer shelf life. The quality of spray dried food is quite dependent on the operating parameters. Thus, an understanding of factors affecting the product properties is required for the process optimization, in order to obtain products with better nutritional characteristics and process yield. The process of optimization can be achieved by using Darcy's Law and solute transport in COMSOL metaphysics where we can study the variation of density with concentration.

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