Middle-East Journal of Scientific Research 13 (10): 1377-1387, 2013
ISSN 1990-9233

DOI: 10.5829/idosi.mejsr.2013.13.10.1239

Whey Powder: Process Technology and Physical Properties: A Review

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Abstract: The world's production of cheese whey is much in year yielding an important source of environmental pollution. The main application of spray drying in the cheese industry is the further processing of whey. So, this investigates studied characteristics of different whey produced by spray drying. Also discusses spray-drying process of whey and effect of spray-dryer operating parameters, feed flow rate, atomizer type and inlet/outlet air temperature on food powder physical properties such as bulk density, particle size, moisture content, insoluble solids, wett -ability and morphology of powder particls. The results indicated that spray-dried whey is easier to storage, handling and transport and the quality of spray-dried whey is quite dependent on the spray-dryer operating parameters, so the spray-drying condition was the best way to explain the change quality factors of product powders.

Key words: Spray-drying · Operating parameters · Powder quality

INTRODUCTION

Large amounts of wastewaters emerge from milk processing in dairies, which are one of the largest sources of industrial effluents. Thus, wastewater and organic residues produced from dairy production have the potential to be converted into economic gain if the proper processing technology is employed [1]. The worldwide production of whey is greater portion remains unutilized, which causes an environmental pollution. An estimated 41 billion kilograms of whey was generated as a byproduct of cheese production in 2006 [2].

The world's production of cheese whey is much in year yielding an important source of environmental pollution [2-5]. For years, the disposal of liquid whey was problematic and often discharged into local waterways, ocean/seas and fields, or was used in animal feed. Discharging whey into lakes and rivers removed the economic burden of disposing of whey in waste treatment facilities [6]. However, as the whey contains organic substances, oxygen is required for the decomposition and dumping of whey will therefore have a great influence on the environment [7-8].

In terms of volume and weight, whey is in fact the largest amount of material resulting from the production of cheese. Instead of processing the whey in special plants some dairies have disposed large quantities of whey by spraying it over the fields, which is a non effective method giving benefit both to the factory and to the farmer.

Whey powder is a complex ingredient made up of protein, lactose, fat and minerals, [9,10]. This means that the keeping quality of the whey is prolonged, the solids content of the dried product is constant and seasonal variations in the supply are avoided. It has therefore been necessary to find alternative types of products made from whey that would be more attractive for consumers, together with alternative low-cost technologies that would be more attractive for producers [11]. Consequently, the factories are very often taking advantage of spray drying the whey thus transforming it into a powder.

Spray-drying is widely used to produce food such as whey powder, instant coffee, milk powder, tea and soups, as well as healthcare and pharmaceutical products, such as vitamins, enzymes and bacteria. Currently it is the preferred method for producing whey proteins in powder form [12,13]. The main application of spray drying in the cheese industry is the further processing of whey. Historically, whey has been regarded as a troublesome waste product and has been treated accordingly. 140 million tones of whey are produced annually that only 20% is dried corresponding to 1.8 million tones of powder [14].

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Table 1: Typically whey composition [14]

Material	Quantity
Sediment test	max. 0.1 mg/25 ml
pH	min. 6.3
Titratable acidity	max. 0.12%
True lactic acid	max. 20 mg/100 ml
Fat content	max. 0.05%
Lactose content	min. 70%, max. 74%
Protein content	min. 12%
Non condensable gases	max. 0.02% by weight
Calcium content:	max. 300 ppm
Magnesium content:	max. 100 ppm
Chloride content:	max. 1,200 ppm

Spray drying of quality whey needs to know the effect of operating condition and feed concentration on physical and morphological properties of produced powder. Process variables, the method and conditions of atomization, the type of spray/air contact, drying air temperature and feed parameters (concentration, temperature and the degree of feed aeration), have been important parameters. So in this paper the characteristic of whey, process of whey drying and effect of important spray dryer parameter was studied on powder properties and morphology of powder.

Characteristics of Whey: Whey is the greenish-yellow colored liquid which is drained off of the coagulated cheese curd during the cheese making process. Whey, theoretically has a bland flavor but rapidly oxidizes, forming stale off-flavors. Whey contains nearly half of all solids found in whole milk [15]. In there are general three types of whey: sweet whey (dry whey not over 0.16 %titratable acidity on a reconstituted basis), acid whey (dry whey with 0.35% or higher titratable acidity on a reconstituted basis) and casein whey. The composition of whey products varies depending on several factors, including the source of the milk, production method, type of cheese and manufacturer's specifications. Whey and whey components contain a number of valuable minerals. Generally the whey components will typically correspond to the table 1.

The main component of whey is the carbohydrate lactose that is supply energy [16]. Lactose is found in milk and is a major component of whey solids. Lactose purification is an example of producing useful products from biologically hazardous waste [9]. Lactose is a disaccharide quite different in its behavior from other common sugars, amorphous lactose is thermodynamically meta-stable and very hygroscopic, adsorbing moisture rapidly from the surroundings [17,18]. A distinctive feature of the lactose is its appearance in different modifications with physico-chemical interrelations determined by the temperature.

Practically all the mineral elements found in whey are essential for nutrition. Whey is an excellent source of calcium and phosphorus, both of which together with vitamin D are essential for bone formation. Whey is rather low in Iron, Copper and Iodine. Vitamins are accessory food factors, which are essential for normal growth, health and reproduction of living organisms. Whey is a good source of vitamin A, vitamin D, riboflavin etc. however whey is deficient in Vitamin 'C' [4,8,19].

Whey cannot be used in liquid form so it made into many products with various processes and technologies. Condensed whey, dried whey, dried modified whey, whey protein concentrate and isolates, as well as lactose (crystallized and dried) are the often cited whey products [7]. Liquid whey can come in a variety of forms depending upon the source and processing techniques. Whey can also be processed into a number of valuable products as well as some that are considered waste products. Some of these whey types include reduced lactose whey, demineralized whey, acid whey, sweet whey and whey protein concentrate (WPC)[20].

Whey protein is a complete, high quality protein with a rich amino acid (AA) profile which is important in tissue growth and repair [21]. Whey proteins refer to a group of individual proteins or fractions that separate out from the casein during cheese-making. These fractions are purified to different concentrations, depending on the end composition desired and can vary in their content of protein, lactose, carbohydrates, immunoglobulin, minerals and fat [15,23]. For example: WPCs, Whey Protein Concentrates, are whey protein concentrates in different grades of 35, 60 or 80 % and WPI, Whey Protein Isolated, is whey protein isolates with protein content higher than 90% on solid basis. Different types of whey proteins are shown in table 2 [22].

Spray-drying Equipment and Powder Manufacturing: pray-drying is the most convenient technique for producing powders directly from pump able feeds. Spray-drying is continuous in operation, applicable to heat sensitive material because of its short drying time, dried products specifications met by dryer design and operation and adaptable to automatic control. In a spray-drying process, hot air enters the drying chamber and due to moisture evaporation from the spray the air temperature falls as air passes through the chamber. Figure 1 shows a typical industrial spray drying process.

Table 2: Different type of whey protein [22,24]

Table: Definitions and Uses of Different Types of Whey Protein (percentages by weight)

Product	Protein concentration	Lactose	Fat	Notes and applications
Whey powder	11 - 14.5%	63 - 75%	1 - 1.5%	Produced by taking whey directly from cheese production, clarifying, pasteurizing and drying. Used in breads, bakery and snack items and dairy foods.
Whey protein concentrate (WPC)	25 - 89% (most commonly available as 80%)	4 - 52%	1 - 9% (as protein concentration increases, fat, lactose and mineral content decreases)	The most common and affordable form of whey. Used in protein beverages and bars, bakery and confectionary products, dairy foods and other nutritional food products.
Whey protein isolate (WPI)	90 - 95%	0.5 - 1%	0.5 - 1%	Used in protein supplementation products, protein beverages, protein bars, other nutritional food products.
Hydrolyzed whey protein concentrate	>80% (hydrolysis used to cleave peptide bonds.)	<8%	<10% (varies with protein concentration)	Used in sports nutrition products.
Hydrolyzed whey protein isolate	>90%	0.5 - 1%	0.5 - 1%	Highly digestible form containing easy-to-digest peptides that reduce risk for allergic reaction in susceptible individuals. Commonly used in infant formulas and sports nutrition products.

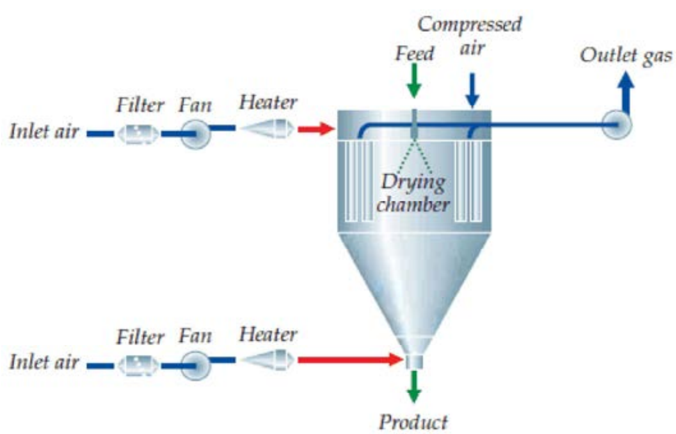

Fig. 1: A typical industrial spray drying process [14].

The spray-drying operation starts with feeding distilled water and the outlet temperature setting by adjusting the liquid feed rate. After atomization, the liquid droplets contact the inlet hot air and water evaporation takes place rapidly from the droplet surface, cooling the droplets to their wet bulb temperature, as well as cooling the surrounding hot air. Powder recovery is essential for both economic and environmental reasons that as much powder as possible have to be recovered from the air stream [25]. Various configurations of spray driers are presented in Figure. 2. [11] and more detailed information can be obtained in Pisecky [6] or Westergaard [7].

The high bacteria load and presence of active enzymes in the raw whey make it extremely important to separate fat and cheese particles and to pasteurize and cool the whey immediately after removal from the cheese vats [6,26]. Before the whey concentrate is spray dried, lactose crystallization is induced to reduce the hygroscopicity [16]. In order to understand the theoretic background for the crystallization process it is necessary to look into the physico-chemical properties of the lactose which about 3/4 of the solids of the whey. This is accomplished by quick cooling in flash coolers after evaporation [27]. Crystallization continues in agitated

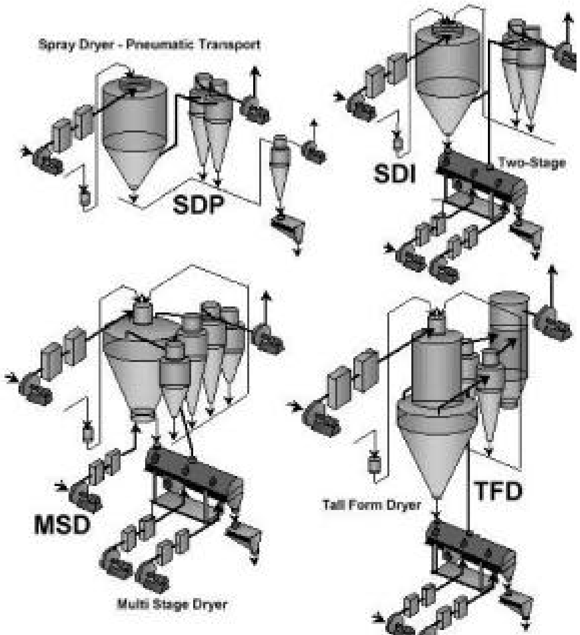

Fig. 2: Various types of spray dryers used for drying of whey products [6,11].

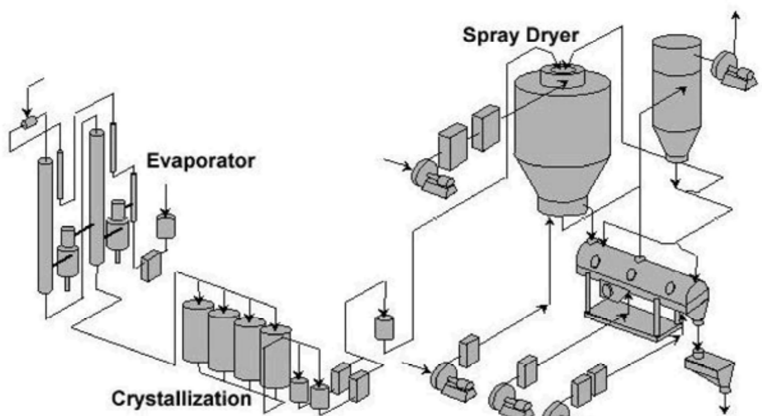

Fig. 3: Spray dryer with evaporator, crystallizers and vibrating fluid bed for whey powder [6].

tanks for 4 to 24 h. Figure 3 shows a process line of spray dryer with evaporator, crystallizers and vibrating fluid bed for whey powder.

The Effect of Spray-Dryer Operating Parameters on Powder Product: The quality of spray-dried food is dependent on the spray-dryer operating parameters, so the spray-drying condition was the best way to explain the change quality factors of product powders [28-30]. The physical and morphological properties of produced powder can show proper course of drying process. Some parameters are important on quality of spray-dried powder such as: Inlet/outlet air temperature, atomizer speed and feed flow rate, type of atomizer and scale of dryer. The drying rate may be altered by changing the air flow rate, the air temperature or the feed rate [31].

Inlet/Outlet Air Temperature: Inlet/outlet air temperature affects some properties of spray-dried particles such as: particle size, average time of wet-ability, insoluble solids content, bulk density and moisture content. Also the size distributions and morphology of the spray-dried particles are controlled by the air temperature.

The results of previous research indicate that increasing inlet/outlet air temperature increases the particle size, average time of wett-ability and insoluble solids (Fig. 4) and decreases the bulk density and powder moisture content [21,32,33]. The outlet temperature of

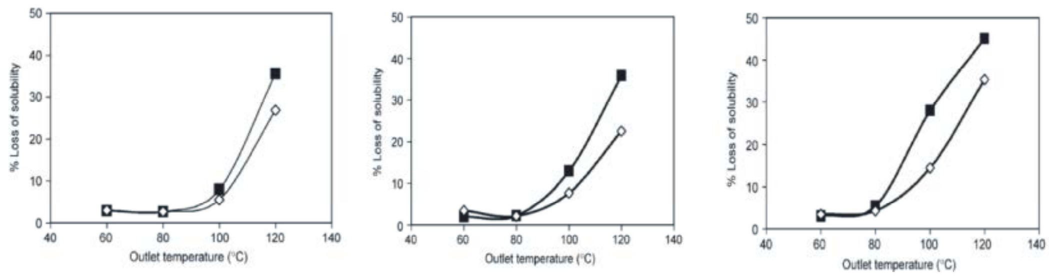

Fig. 4: Effect of spray dryer outlet temperature on the loss of solubility of α-lactalbumin (◇) and β-lactoglobulin (■) for (a) 20% feed concentration, (b) 30% feed concentration and (c) 40% feed concentration

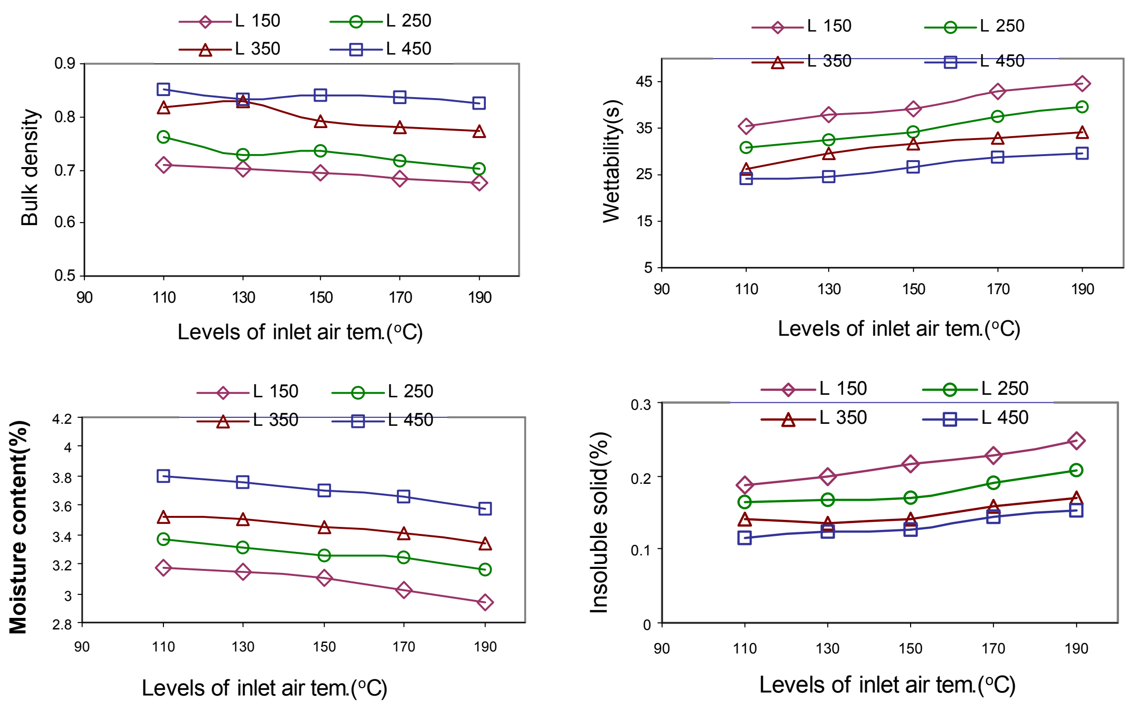

Fig. 5: The effect of inlet air temperature in different feed flow rate on: a) bulk density b) wettability c)moisture content d) insoluble solid

the air leaving the drying tower is used for control and provides a measure of the severity and rate of drying [34]. Goula and Adamopoulos [35] concluded that higher compressed air flow rate caused an increase in outlet air temperature. This observation suggests a direct relation of the outlet temperature not only with the inlet temperature but with the compressed air flow rate, as well [32, 35].

Figure 5-a indicated that by increasing inlet air temperature the bulk density is decreased [36]. Increase in inlet air temperature often results in a rapid formation of dried layer at the droplet surface and particle size was due to skinning over or casehardening of the droplets at the higher temperatures. This leads to the formation of vapor-impermeable films on the drop surface, followed by the formation of vapor bubbles and consequently droplet expansion [30,37,38]. Figure 5-b indicated that an increasing the inlet air temperature results in increasing the wettability. That it is come back to decreasing of product residual moisture content [37,38]. Figure 6-c shows that an increasing in inlet air temperature and reducing in feed flow rate, the moisture content reduces. Figure 5-d show that an increasing in inlet air temperature and reducing in feed flow rate the insoluble solids increases. At higher temperature, a hard surface layer is formed over the powder particles that prevent water to enter inside particles and therefore the percentage of insoluble solids is increased. The air temperature mainly showed effect on the particle morphology and on the amount of residual solvent for the particles produced.

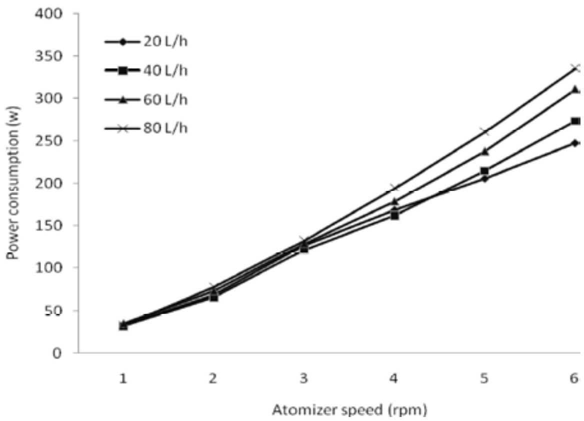

Fig. 6: Effect of atomizer speed on power consumption in different feed flow rate.

For the powders produced, the air temperature mainly influenced on the particles size [39]. The morphology and particles size distributions can be controlled by the inlet/outlet air temperature [40]. When the drying temperature is sufficiently high, moisture is evaporated very quickly and the skin becomes dry and hard, so that the hollow particle cannot deflate when vapor condenses within the vacuole as the particle moves into cooler regions of the dryer [18]. 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 [18].

Atomizer Type: The atomizer is a critical component of the spray dryer. The degree of atomization influences the drying rate, the required particle residence time, particle size and particle size distribution, which in turn relates to dispersibility of the product for rehydration [34, 41]. Type of atomizer effect on properties of spray-dried particles such as: moisture, insoluble solid and particle size. There is an extensive range of atomizers utilized for spray formation in industry and the advantages and disadvantages of each one have been well documented [42]. The rotary atomizer provides versatility in that the droplet sizes of liquid can be easily controlled by simply adjusting the atomizer rotational speed [43-45]. It is unique in that it permits the simulation of both droplet linear velocities and shearing forces [46].

The low atomization speed leads to larger dried powder particles. When operating with a rotary atomizer the air disperser creates a high degree of air rotation promoting uniform temperatures throughout the drying chamber. However an alternative non-rotating airflow is often used in tower-type spray dryers using nozzle atomization [47]. If different size droplets are present, by the time the largest droplet is dried, the smallest droplet will have been exposed longer than necessary. Thus, a narrow particle size distribution would improve the quality of any heat-sensitive component of the product, such as vitamins, color, or flavor [31].

Figure 6 shows the effect of atomizer speed on power consumption in different feed flow-rate. With increasing the atomizer speed and feed flow-rate, obviously power consumption increases. As can be seen in figure 6, at low feed flow-rate there are not significant differences between levels, but these differences is very clear in higher speeds [41].

A lower atomizer speed shows a higher density than a with higher atomizer speed. At higher atomizer speed, smaller droplets are produced and more moisture is evaporated resulting from the increased contact surface. Figure 7 show the effect of atomizer speed on the physical properties of powder in different feed flow rate. Figure 7 indicated that at a constant feed flow rate by increasing of atomizer speed the moisture content and insoluble solid is decreased and wettability and bulk density is increased[36] It is shown that at higher atomizer speed, the insoluble solid is decreased. Higher atomizer speed resulted in smaller particle size and quick drying due to the larger surface area and consequently. By increasing the atomizer speed of the droplet spread on a larger surface, the particle size is reduced and increasing the atomizer speed of the droplet spread on a larger surface decreases bulk density.

Feed Flow Rate and Drying Air Flow Rate: Feed flow rate and drying air rate effect on properties of spray-dried powder such as: particle size, insoluble solids, bulk density and moisture content. Also feed flow rate effect in product total solid and drying ratio.

An increase in feed flow rate causes a decrease in product total solid with an increase in bulk density and particle size [40]. On increasing the feed flow rate, the particles contain higher residual moisture and become wet faster in water. Increasing the feed flow rate reduces the percentage of insoluble solids, because of the higher droplet moisture content and thinned dried layer on the powder particles [48]. Drying ratio increased when lower feed flow was used [49]. The particle size was influenced by the concentration of solids in the feed flow rate [39].Reducing drying air flow rate produces a linear decrease in the product powder yield. There was a corresponding visual increase in deposit on the inside wall of the drying chamber. The drying air flow rates have little influence on powder properties and spray-dryer yield and should be run on its maximum value [50].

Scale of Dryer: More importantly, the drying chamber will affect the quality of the products. Many components of food are heat sensitive, so it is important to keep the residence time to a minimum, especially once the dry particle is formed and the desired amount of moisture has been removed [34,51]. Spray dryers can be divided into two basic types, short form and tall-form designs. Product quality and physical properties can be influenced by the total process of which the spray-drying tower is only one element [52]. The kind of tower spray-dryer depends on the specific properties of the product to be dried (high fat content, starches, malt dextrin, egg products, hygroscopic products, etc.) and the choice of the technology used depends on the thermal efficiency (calculated according to different methods), the qualities and properties of the product to be dried and the powders to be obtained [13,53]. When different numbers of the nozzles are used at the different levels in the tower the drops will be exposed to different drying temperatures and air flow velocities. Moving the atomization position down the tower means exposure to higher air temperatures and therefore faster drying rates [52].

Properties of Spray-Dried Whey Products: A whey powder is not only characterized by its composition (proteins, carbohydrates, fats, minerals and water) but also by its microbiological and physical properties such as bulk and particle density, instant characteristics, flow-ability, hygroscopicity, stickiness, degree of caking, whey protein nitrogen index, heat number, thermo stability, insolubility index, dispensability index, wet-ability index, sink-ability index, free fat, occluded air, interstitial air, particle size, flavor and aroma which form the basic elements of quality specification and there are well defined test methods for their determination according to international standards [54-59].

Three powder properties that feature in the majority of dried product specifications are residual moisture content, particle size and size distribution, bulk density, that bulk density influenced by powder temperature, particle size/size distribution, residual moisture, drying and cooling medium temperatures, drying medium flow and temperature profiles in the drying chamber, powder after-treatment in two/ three stage processing, powder handling during conveying [47].

Moisture Content: Dryer capacity is limited by the total moisture in the air leaving the spray-drying chamber. In simpler terms, if the air leaving the chamber is too moist, a viable stable particle is not produced and the product tends to be sticky. If the air leaving the chamber is too dry, some drying capacity remains unused. To maximize dryer capacity, the dryer should be operated as close as possible to the maximum total moisture of the chamber outlet air, a parameter measured in pounds of water per pound of dry air [7,13].developing a spray-dried powder product, knowledge of how the spray-drying conditions affect the powder's residual moisture content is prerequisite. By analysis of the vapor pressure and mass transfer, the effect of spray drying conditions on the powder's final moisture content can be elucidated [53].

Moisture content of powder influenced by available drying time, outlet drying medium humidity and temperature, equilibrium residual volatile content conditions and the product handling effects on powder outside the drying chamber[47]. Powder packing, flowability, bulk density and particle agglomeration of the powder, are all affected by moisture content [Walton, 2000]. As a general rule, in a spray drying system, the feed water content controls the residual moisture in the powder. Lower moisture content can be reached by higher feed solids contents for fixed values of the other process conditions [35]. Results from analysis of moisture content and particle size of the dried product both suggest that higher feed concentrations result in a stronger crust [21]. Combined interactions of dry solids flow rate, inlet air temperature and Atomization speed describe well changes in the residual powder moisture content in the experimental range studied [30]. For permeate powder, drying conditions had no effect on moisture content [17].

Particle Size and Size Distribution: Generally, in a spray-drying system particles size depends on the size of the atomized droplets. The droplet size on atomization depends upon the mode of atomization, physical properties of the feed and feed solids concentration. Droplet size usually increases as the feed concentration or viscosity increases and the energy available for atomization (i.e. rotary atomizer speed, nozzle pressure, air-liquid flow ratio in a pneumatic atomizer) decreases. Thus, the effect of feed solids concentration on dried particles size is due to its effect on spray droplets size [51,60,61].

Particle size and size distribution also influenced by the feed formulation properties, atomizer type and energy available for spray formation, drying chamber design and wall deposit occurrence, air/spray contact, drying characteristics of the spray droplets as regards size/shape change, existence of a sticky particle surface phase during evaporation of volatiles and hygroscopic properties even when dry [47].

The powder particle size depends upon the degree of moisture removal during drying, in addition to the atomized droplet size [61]. A high degree of moisture removal is associated with a high size difference between product before and after drying. So, in the modified system, the constant and lower, in comparison with those in the standard dryer, percentage of size increase may be due to the constant and higher percentage of powder moisture decrease. In addition, in the standard system, the percentage of size increases inversely with that of moisture decrease. These observations prove the dependence of particle size on degree of moisture removal during drying [35,62].

This is not totally independent of bulk density, as a larger mean particle size generally means a lower density. Mean particle size can be reduced by smaller nozzles at higher spray pressure, higher slurry temperature and a thinner mix. It can also be affected if the air flow and temperature profile into the tower are not uniform. This is where system understanding and modeling can be of great value [52]. The method of contact air-droplet effect on particle size, concurrently spray dried powder had a lower mean particle size and slightly broader particle size distribution than counter current [60].

Morphology: Depending on the operating spray drying conditions, a powder can be obtained that consists of particles characterized by a different morphology which consequently has different physical properties. It is clear that the final particle morphology and therefore the properties of a particle will depend on a range of factors including drying rate, drying temperature, quantity of entrained or dissolved gas, degree of solubility of solids and so on. These will also have an impact on drying time requirements since the nature and integrity of the surface of the particle will determine its drying kinetics [13,36].

The micrographs of spray-dried particles exhibit a wide distribution of particle size, with apparently a low degree of particle aggregation for all the feed concentrations and outlet temperatures. Results from the morphological study of powder products can be used to understand better the effects of operating spray-dryer variables on the powder properties, which are directly related to the product quality [62-63]. It was possible to explore relations of morphology and moisture content of particles with drying temperature along the actual drying operation, especially those related to breakage and inflation (intermediate and high drying temperatures) and with collapse (low temperature drying) [64].

The shape and morphology of the particles upon spray-drying determine by two factors, the rate of droplet evaporation and formulation composition. The rate of solvent evaporation dictates particle quality: Fast drying usually forms deformed or defective particles, but slow drying may result in particles that are too wet and too sticky to be collected effectively. These quality factors are a direct result of the design and operating conditions of the spray-dryer, such as the type of atomizer, drying air temperature, feed rate and feed concentration [55]. The shell structure of a drying droplet played an important role in determining the final dried particle morphology. In addition, the shell structure of a drying droplet varies from material to material, which increases the difficulty in the modeling prediction. Materials that formed an elastic shell structure led to hollow particle formation. Material with high solubility led to small, dense, irregularly-shaped particles [62].

The rate of droplet evaporation may also affect the film properties at the droplet's surface. A fast drying rate will promote the formation of a more viscous film at the earlier phase of drying. Because water pressure increases rapidly inside the droplet, the film is prone to burst; therefore, the fast drying conditions result in a large fraction of the particles containing dimples or holes [53,65].

Technological properties of powders (bulk density, flowability, surface area etc.) as well as the potential areas of their application depend on the particles size and shape. Smaller particles are denser, but this difference does not affect the flow ability. Surface area is affected by the type of atomizer. The nozzle atomizer produces micro particles with large surface area compared to the rotating disc atomizer, probably because of the holes and cracking of the particles produced with nozzle atomizer [57]. It is possible to observe that when drying at low temperatures it is noticeable a greater degree of shrinkage when drying under this, also mean particle size tends to be lower than the one corresponding to material obtained at higher temperatures. Besides, there is a tendency to obtain particles with a higher mean diameter when the process was conducted at high temperatures [64]. Solid precipitation occurred by the formation of a skin. This covered the whole droplet surface within seconds trapping the bulk of the droplet liquid internally. During evaporation the particle gradually decreased in size and became darker and finally opaque as the skin thickened to form either a solid or hollow particle depending on the material being dried. Taheri *et al*. concluded that the whey was sprayed from a concentrated high solution at a high atomization pressure; the increased whey concentration would allow a physically stable spherical particle shape to be maintained (Fig. 8-a). In comparison, the whey, produced from a reduced feed concentration, at lower atomization pressures, reduced evaporation and increased likelihood of particle collapse (Fig. 3-b) [66]. Fig.8. Spray-dried whey powder; a) concentrated high solution at a high atomization pressure, b) concentrated low solution at a low atomization pressure

CONCLUSION

Spray-drying has found application in all major industries. There is still a gap between the knowledge and reality of spray-drying. Thus many unknown areas must be studied further, such as drying dynamics, drying simulation of irregular panicle. This investigate discusses the complexity of the spray-drying process for whey manufacturers who want to optimize their production. Study of more interaction processes, the production and functions of dairy products is necessary in order to increase our knowledge of the mechanisms of water transfer, drying parameters, storage conditions and rehydration of whey powders. The results indicated that the quality of spray-dried whey is quite dependent on the spray-dryer operating parameters, so the spray-drying condition was the best way to explain the change quality factors of product powders.

ACKNOWLEDGEMENT

The authors would like to thank the college of Aboureihan, University of Tehran for supporting of this research project.

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