Recent Advances in Agglomeration during Spray Drying

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The quality requirements to Instant Food Powders in general and Instant Milk Powders in particular are constantly getting stricter as an increasing number of properties must be optimized simultaneously - to the extent that this is possible - and controlled within still narrower limits in order to obtain a high quality product with the highest degree of uniformity, fulfilling the requirements set by customers, organizations and industrial and/or legislative standards.

This situation is very demanding for powder production people, powder technologists and others responsible for product quality, and a thorough knowledge of powder technology and an understanding of all processes or unit operations taking place simultaneously in a spray dryer are required.

The present paper describes qualitatively some processes and unit operations and their interaction in different drying processes and the importance of certain components on agglomerate structure and thereby on the final product quality.

Vibrating fluid bed for agglomeration of food powders.

Agglomeration during spray drying

Agglomeration is often defined simply as the association of smaller particles into clusters or *agglomerates*.

Generally the process of agglomeration involves:

1. bringing independent particles into contact with one another,
2. enhancing or controlling interparticle adhesion, and
3. stabilizing the created agglomerates in some cases under the action of external forces.

Assuming that agglomeration occurs as a series of binary interactions the rate of agglomeration of i and j-type particles can be expressed by

$$g_{ij} = K_{ij} E_{ij} n_i n_j$$

where K_{ij} is a collision frequency rate constant,

E_{ij} is a collision efficiency factor (probability of adhesion), and

n_i and n_j are the respective number concentrations of the two types of particles (Hogg, 1992).

K_{ij} is primarily determined by certain Fines Return design parameters, and E_{ij} is to a large extent determined by the chemical composition of the particles and in particular their moisture content which affect the adhesiveness of the particles. n_i and n_j represent f. inst returned fines particles and primary spray particles, respectively.

The concentration of primary spray particles at a given location in the vicinity of the atomizing device is determined by the flow of feed to the atomizer (plant capacity) and atomization efficiency (spray particle size distribution).

The concentration of returned fines particles is somewhat more complicated to estimate as it depends on a number of secondary unit operations, shown in Fig. 1, which is a schematic presentation of the *primary* drying processes, here defined as the different subprocesses comprising the total spray drying process, the *secondary* unit operations as defined below, the state of the product (agglomerates or fines, where fines are often arbitrarily defined as particles < 125μm), and the fines return system.

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The secondary unit operations are defined as follows:

Agglomeration is defined above. Agglomenrates are often defined as particles > 125 μm. A survey of different agglomeration processes is given in Table 1.

The primary droplets created by the atomizing device may collide shortly after atomization due to different size and/or mass and consequently different deceleration or because they are suspended in a turbulent air stream. This is called *spontaneous, primary* agglomeration. *Forced, primary* agglomeration can also be obtained, f. inst. by designing a multiple-nozzle atomization device in a way that facilitates collision of primary spray particles from different nozzles.

Generally more important is the *forced, secondary* agglomeration, which occurs as a result of collision between primary particles or agglomerates and the fines collected by *separation* and *classification* (see below) and returned to the atomization zone. *Spontaneous, secondary* agglomeration occurs in some types of dryers, f. inst. the Multi-Stage Dryer (Fig. 5), where some of the fines resulting from *classification* in the integrated fluid bed and *separation* will get in contact with primary spray particles due to the special air flow pattern in that type of dryer.

Separation is the process separating the part of fines which is entrained in the main drying air leaving the drying chamber. The efficiency of separation is determined by the air flow pattern and air velocities in the drying chamber and is therefore closely related to the chamber design and can only be marginally affected at normal running conditions, f. inst. by air disperser adjustments and variations in drying air rates.

Attrition is defined as the partial break down of agglomerates in fluid beds or powder conveying systems resulting in creation of either fines and smaller agglomerates (abrasion) or of a number of smaller sized particles (fragmentation). This often overlooked phenomenon is the result of mechanical motion between the agglomerate and another body which may be the walls of the fluid bed or another particle. The most likely cause of attrition in fluid beds is particle/particle interaction as interparticle impact velocities can be very high, caused by high air jet velocities out of the holes in the perforated plate that forms the bottom of the fluid bed. Factors affecting the extent of attrition is the jet velocity, determined by the pressure difference across the perforated plate, the fluidization velocity and the actual design of the perforated plate.

Classification is defined as the separation of fines in fluid beds. The efficiency of classification is mainly determined by the fluidization air velocity, but also fluid bed design features are of importance in securing that separated fines are kept airborne and entrained in the exhaust fluid bed air.

A quantitative estimation of the net result of the above mentioned unit operatiorts expressed as particle size distribution or just amount of fines in the final product is not possible with the present state of agglomeration theory, and even a qualitative evaluation may fail in extreme cases when f. inst. an attempt to reduce the amount of fines in a product by increasing the fluid bed air rate and thereby the classification is offset by an even larger increase in attrition.

Agglomerate structure and powder properties

Depending on the design and adjustment of the Fines Return system - particularly the location of the introduction of the fines in relation to the atomization device - different agglomerate structures result, which influences certain powder properties (Pisecky and Hansen, 1990), such as Bulk Density, Mechanical Stability, Dispersibility and Slowly Dispersible Particles.

The relation between agglomerate structure and certain powder properties is illustrated in Fig. 2.

If the fines are introduced close to the atomizing device the moisture content of the primary spray particles is high and thereby their plasticity and stickiness, and the fines particles may penetrate primary particles or be completely covered by concentrate (Fig. 3). Such agglomerates have been termed 'onion'-structured. When collision takes place at a progressively longer distance, away from the atomizing device, less compact agglomerate structures are obtained. Such structures have been termed 'raspberry'- and 'grape'-structures in decreasing order of compactness.

TYPE	DEFINITION	EXAMPLES
Spontaneous primary	Random, unprovoked collision of primary spray particles	All atomization devices
Forced primary	Intended collision between primary spray particles from different atomization devices	Collision of sprays from different nozzles
Spontaneous secondary	Random, unprovoked collision of primary spray particles and fines	Multi-Stage Dryers
Forced secondary	Intended collision between primary spray particles and fines returned to the atomization zone	Normal type when Fines Return is applied

Table 1. Different agglomeration processes

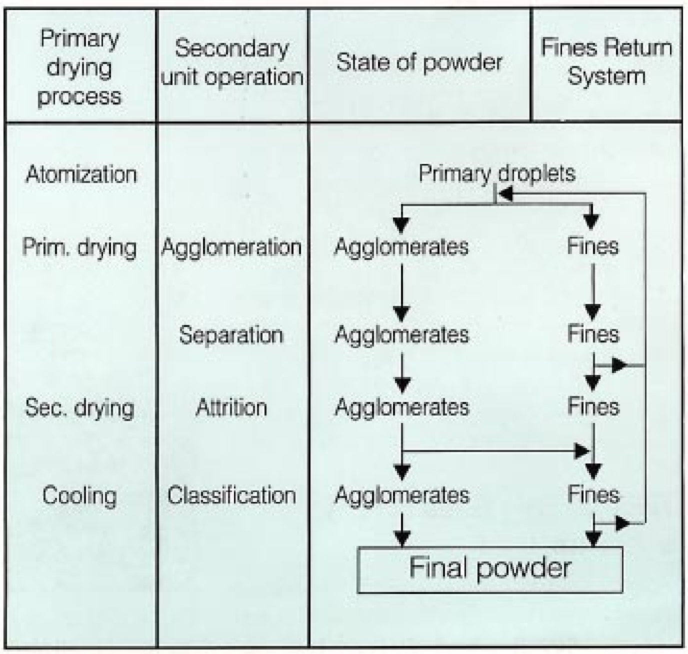

Fig. 1. Unit operations during spray drying/agglomeration.

Onion'-structured agglomerates are characterized by a high Mechanical Stability and a high Bulk Density, but they will often appear as Slowly Dispersible Particles after reconstitution. They may also be collected during the different Dispersibility tests in use and jeopardize the general quality evaluation of the product.

AGGLOMERATE STRUCTURE:

Onion → Raspberry → Compact grape → Loose grape

PARTICLE MOISTURE CONTENT AT COLLISION:

High → Low

MECHANICAL STABILITY:

High → Low

BULK DENSITY (no attrition):

High → Low

BULK DENSITY (after attrition):

High → Low → High

SLOWLY DISPERSIBLE PARTICLES:

Many → Few

DISPERSIBILITY (after attrition).

Poor → Good → Poor

Fig. 2 Agglomerate structure/Powder properties relationship.

With progressively looser agglomerate structures the Bulk Density and Mechanical Stability decrease gradually and the overall instant properties improve. However, if a 'loose grape'-structure is eventually obtained, the Mechanical Stability may be so low that the powder becomes very susceptible to attrition resulting in deteriorated instant properties. A 'compact grape'-structure (Fig. 4) is regarded as the ideal compromise where the powder has simultaneously good instant properties and sufficient mechanical strength to enable nécessary transport and packaging.

New flexible fines return systems

Agglomeration processes in conventional spray dryers or agglomeration as a separate, consecutive process have been re-

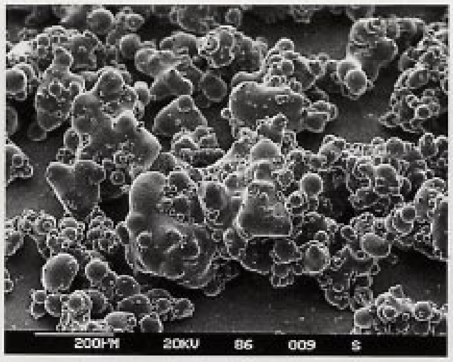

Fig. 3. Scanning electron micrograph of 'onion'-structured agglomerate.

viewed elsewhere (Jensen, 1975). Following the development of the new generation of spray

dryers (the Multi-Stage Dryer and the compact Dryer, (Pisecky, 1983)) the need for improved and more flexible agglomeration systems appeared, resulting in the development of two quite different systems for the two types of dryers.

Multi-Stage Dryer (Fig.5)

Due to the special air flow pattern a considerable *spontaneous, secondary* agglomeration takes place in this type of dryer. For production of high quality Instant Whole or Skim Milk Powder this spontaneous agglomeration suffices and the fines are just returned to the integrated fluid bed. However, the agglomeration may be further enhanced by *forced, primary* agglomeration (collision of sprays from different nozzles in a multi-nozzle atomization unit) and/or by returning the fines to the atomization zone *(forced, secondary* agglomeration). Further flexibility can be gained by designing the atomization unit in a way that allows the distance between the single nozzles or between the nozzles and the fines return tube to be altered (Fig. 6).

A similar atomization unit and Fines Return system can also be used in Tall-

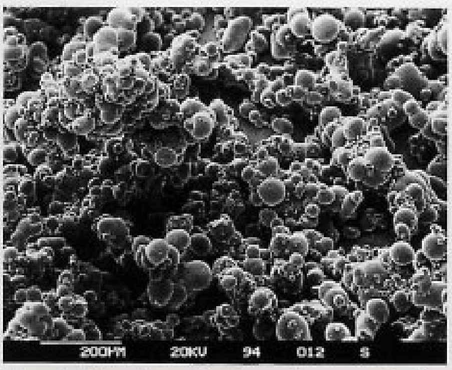

Fig. 4. Scanning electron micrograph of 'grape'-structured agglomerate.

Form Dryers, which are often chosen for manufacture of baby food and protein powders.

Compact Dryer (Fig. 7)

For this type of dryer, operating with rotary atomization, a new, flexible Fines Return apparatus called FRAD (Fines Return Air Disperser) (Fig. 8) was developed and a patent applied for (Pisecky and Hansen, 1990). In this apparatus the fines stream is split up in usually four streams, each passing through its own FRAD tube on which ends are mounted turnable powder deflectors. By adjusting these deflectors the point of collision between fines and primary particles can be controlled within certain limits and thus the powder properties varied.

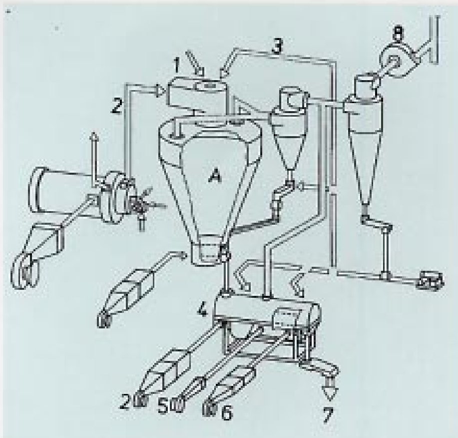

Fig. 5. Multi-Stage Dryer.

A. Spray dryer chamber
1. Feed
2. Drying air
3. Fines return
4. VibroFluidizer
5. Ambient air
6. Dehumidifying air
7. Final product outlet
8. Exhaust air

The FRAD can also in most cases be adopted to conventional dryers, where it can replace the traditional Fines Return tube in the centre of the chamber. Even though this old Fines Return system has worked quite well over the years, it has in many cases been a nuisance from an operational point of view and has often been a source of lumps because of the accumulation of powder deposits on it.

Obtaining desired product properties

Today's strict quality requirements to tailor-made products where an increasing number of properties must be met simultaneously, are very demanding. Although theoretical studies of agglomera-

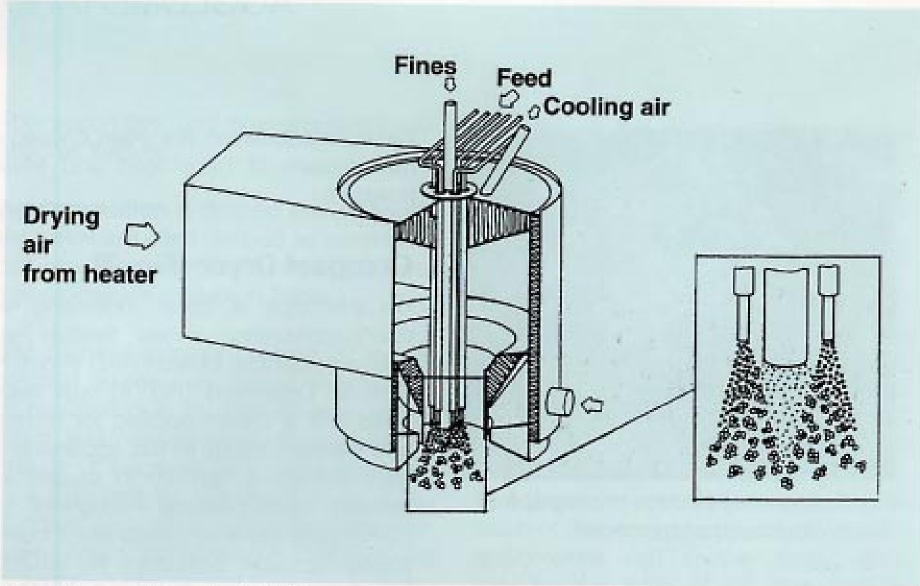

Fig. 6. Fines Return to Multi-Stage or Tall-Form Dryer.

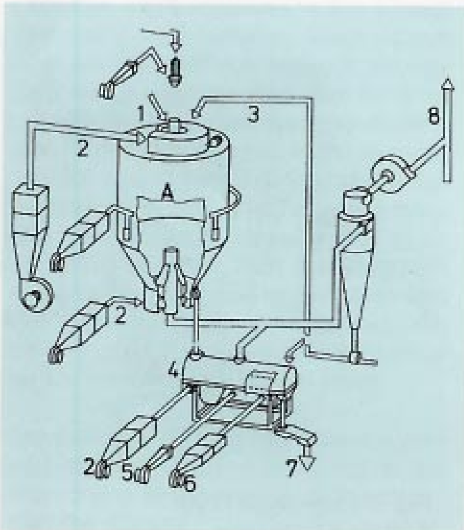

Fig. 7. Compact Dryer.

tion processes may provide inspiration and a better understanding of how to influence and improve powder properties, agglomeration theory is still in its infancy and cannot yet be applied in process control.

Consequently experience and industrial scale experimentation - particularly when new products and/or drying equipment are being implemented - are still essential in achieving and controlling desired powder properties.

A. Spray dryer chamber
1. Feed
2. Drying air
3. Fines return
4. Vibro-Fluidizer
5. Ambient air
6. Dehumidifying air
7. Final product outlet
8. Exhaust air

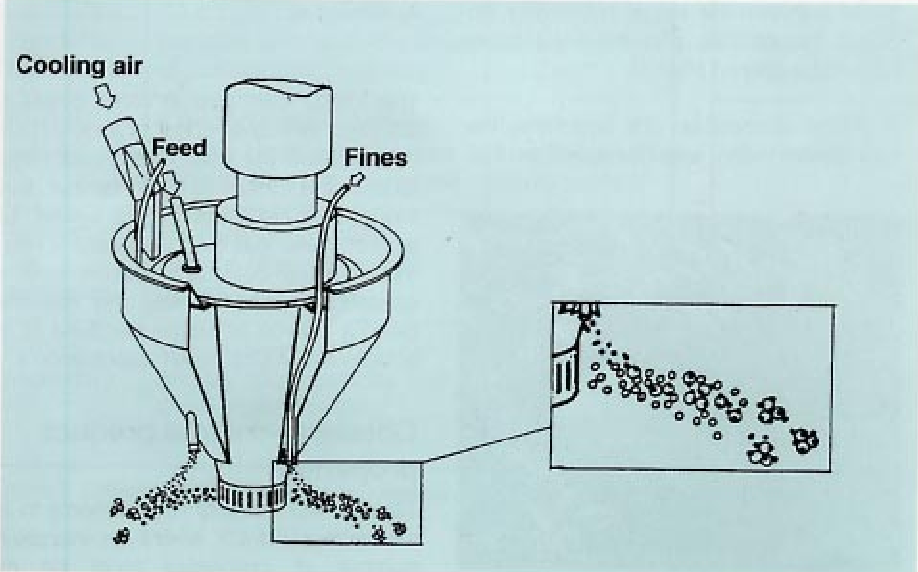

Fig. 8. Fines Return Air Disperser (FRAD).

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