Simulation of agglomeration in spray drying installations: the EDECAD project

R.E.M. Verdurmen, M. Verschueren, J. Straatsma and M. Gunsing

NIZO food research, Department of Processing, Quality & Safety
PO Box 20, 6710 BA Ede, The Netherlands
e-mail: Ruud.Verdurmen@nizo.nl phone: +31-318-659-563 fax: +31-318-650-400

Abstract

Spray drying is used for the manufacture of many consumer and industrial products. During spray drying, agglomerates of powder particles are formed which determine the instant properties of the powder. Agglomeration during spray drying is considered to be a difficult process to control. The main cause of this is the complex interaction of the process variables: the atomisation process, the mixing of spray and hot air, the drying of suspension droplets and the collision of particles which might lead to coalescence or agglomeration. As a consequence, agglomeration during spray drying is operated by trial-and-error. In 2001 an EC-sponsored project started with the aim of developing an industrially validated (computer) model, using CFD technology, to predict agglomeration processes in spray drying machines. An Euler-Lagrange approach with appropriate elementary models for drying, collision, coalescence and agglomeration of the dispersed phase is used. The project is expected to finish early 2004. This paper introduces the background and approach of the project in general terms. Detailed information will be given in several presentations by the academic project partners.

1. Introduction

Spray drying is an essential unit operation for the manufacture of many products with specific powder properties. It is characterised by atomisation of a solution or suspension into droplets, followed by subsequent drying of these droplets by evaporation of water or other solvents. Spray drying is used for the manufacture of many consumer and industrial products such as instant food products, laundry detergents, pharmaceuticals, ceramics and agrochemicals. The most well known example of an instant food product is milk powder, but also instant beverages (e.g. coffee) can be prepared by spray drying. The instant products for the so-called convenience market form an important group of food powders. Consumers desire a quick dissolution or dispersion of the powder in water or milk without the formation of lumps. But also manufacturers have their wishes. They require free flowing powders and absence of dust in such a way that it facilitates the handling of the powders. Both requirements are met by applying agglomeration of food powders [1-3].

Agglomeration is a size enlargement process of powders, where small particles combine to form large relatively permanent masses, in which the original particles are still identifiable, see also Fig.1. In this way the characteristics of a single particle are maintained while the bulk powder properties are improved by the creation of the larger agglomerates.

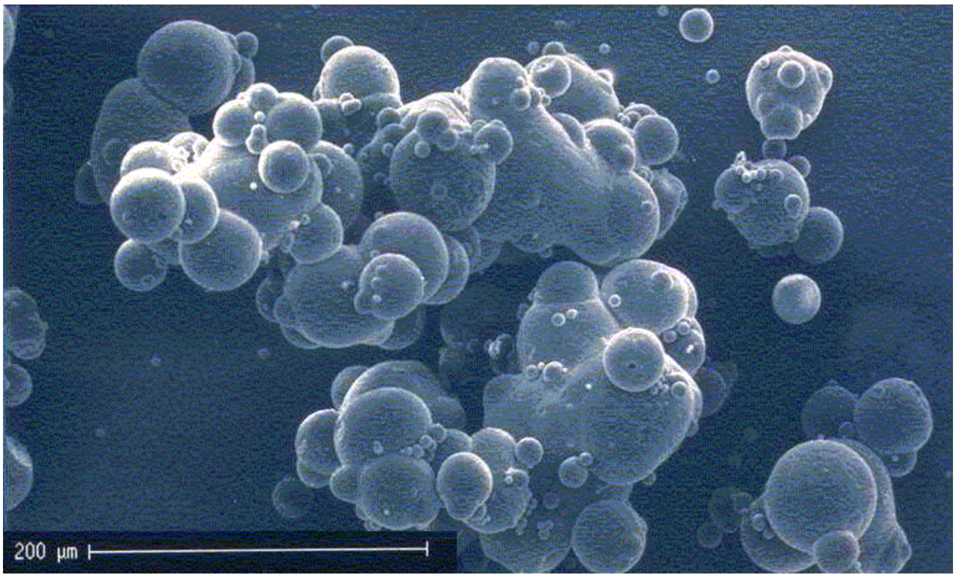

Fig.1: SEM-photograph of spray dried and agglomerated powder

The rehydration behaviour of the powder is improved because the open porous structure of the agglomerate allows water to penetrate and disperse throughout to its original constituting particle, forcing the particle to sink [1]. In this way a better dissolution behaviour is obtained compared to dissolving separate particles.
Agglomeration in spray dryers can be achieved by different methods. In the drying chamber agglomeration can take place within the spray of an atomiser, between sprays of various atomisers and between sprays and dry material being introduced into the drying chamber. In the industry two atomisation systems are used: stationary pressure nozzle and rotating atomisers.

Two types of agglomeration processes can be distinguished [4]:
1. primary agglomeration, caused by collision of primary spray particles with each other
2. secondary agglomeration caused by collision of primary spray particles with fines (dry particles).

Both processes can be either spontaneous (random unprovoked collisions) or forced.
Forced primary agglomeration occurs when sprays from different nozzles collide and depends on the atomiser type, and in case of nozzles on their configuration and nozzle type.
Forced secondary agglomeration takes place when fines from the spray dryer outlet are returned to the atomisation zone.

2. Spray drying equipment

Spray drying equipment for simultaneous drying and agglomeration is widely used in industry, for example in the production of skim milk [5-7]. This type of dryer is operated in

such a way that a powder with about 5 % moisture is obtained. The agglomeration is significantly enforced by secondary agglomeration.
Fines are returned into the dryer near the atomising device where they will meet and collide with atomised wet droplets thus forming agglomerates consisting of many particles connected together. Finally the agglomerates are dried and cooled in a fluid bed [5,7]. In Fig. 2 an example of an industrial spray dryer for the production of agglomerated powder is given. Powder properties as bulk density, mechanical stability, and instant behaviour such as dispersibility and wettability can be controlled by forced (secondary) agglomeration. The agglomerate properties are depending on the distance from the atomising device(s) where the introduction of the recycled fines takes place. In case the fines are introduced near the atomising device, the droplets in the spray from the nozzle will completely cover the fines. As a result the particles formed are onion-like with a good mechanical stability but bad instant properties. In contrast when the fines are introduced at a long distance from the atomiser, mechanically unstable particles are obtained that are very susceptible for attrition, which also deteriorates the initially good instant properties [4,8].

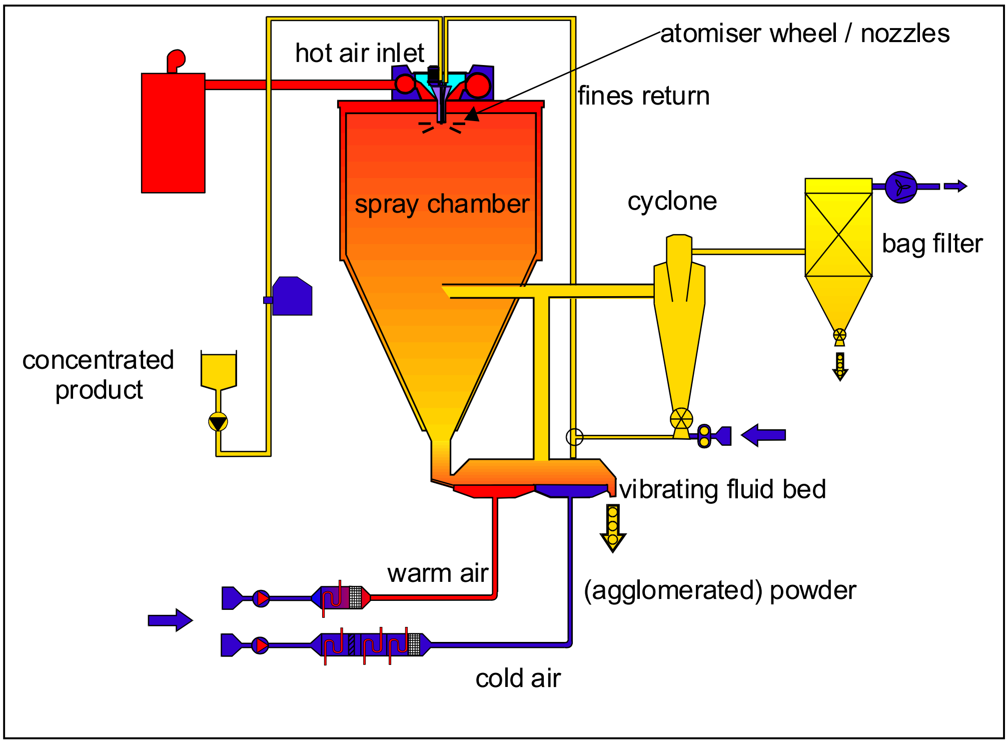

Fig. 2: An industrial 2-stage spray dryer with fines return (courtesy of Anhydro)

In practice a compromise has to be found by introducing the fines in the area between the two mentioned extremes. The ideal compromise is a compact grape structure (see Fig. 1) that has a relatively good mechanical stability, but also shows good instant behaviour.
Several designs have been made in order to establish the formation of ideal agglomerates by optimising the position of returning fines to the atomisation zone [8-9] or by adjusting the spray nozzles [10]. In the latter case, the spray nozzles are adjusted in such a way that their spray patterns intersect at a location distant enough from the nozzles to prevent the formation of lumps, at the point where the particles are sticky enough to form agglomerates upon collision. In all these cases, an empirical or semi-empirical "trial-and-error" approach is used.

The main cause of this is the complex interaction of the process variables: the atomisation process, the mixing of spray and hot air, the drying of suspension droplets (leading to changes of material properties) and the collision of particles which might lead to coalescence or agglomeration, depending on the actual material properties and the energetic collision circumstances, see also Fig. 3.

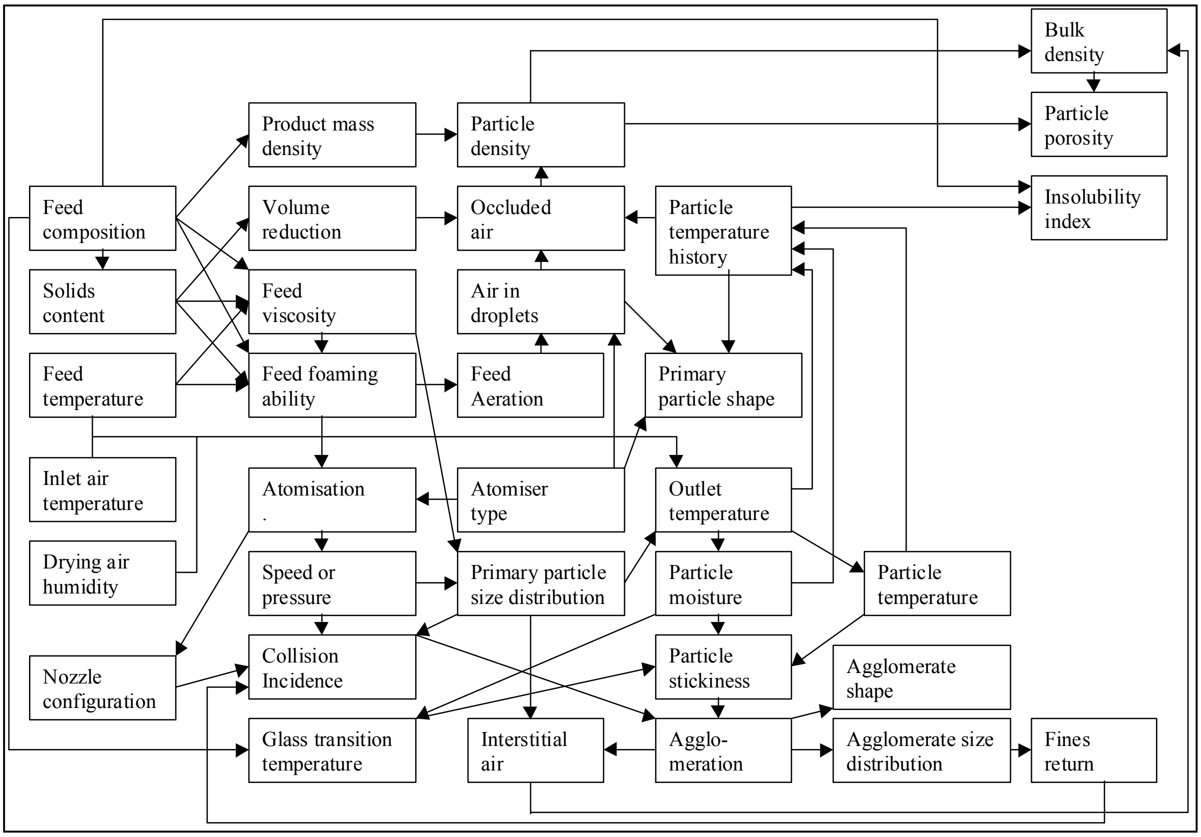

Fig. 3: The effect of various parameters on agglomeration and powder properties, adapted from [6]

3. EDECAD approach

At the beginning of 2001 a large international research and technological development project started with the aim of developing an industrially validated (computer) model, using CFD technology, to predict agglomeration processes in spray drying machines. An Euler-Lagrange approach with appropriate elementary models for the drying, collision, coalescence and agglomeration of the dispersed phase is being used. This project, initiated and co-ordinated by NIZO food research, is titled EDECAD (Efficient DEsign and Control of Agglomeration in spray Drying machines). The main result of the EDECAD project will be a so-called "Design Tool", which will establish relations between the configuration of the drying installation (geometry, nozzle selection), process conditions, product composition and final powder properties. The Design Tool will be validated on pilot-plant scale and industrial scale. The project is expected to finish at the beginning of 2004. The EDECAD project will primarily focus on the food industry, because spray drying is by far their major drying process, but can also be applied in other industries.

The general structure of the Design Tool is depicted in Fig. 4. The central part represents the CFD model, which consists of the CFD core (flow solver and particle tracker) and sub-models for collision, drying and coalescence/agglomeration. The parts surrounding the central part in Fig. 4 represent the in- and output.

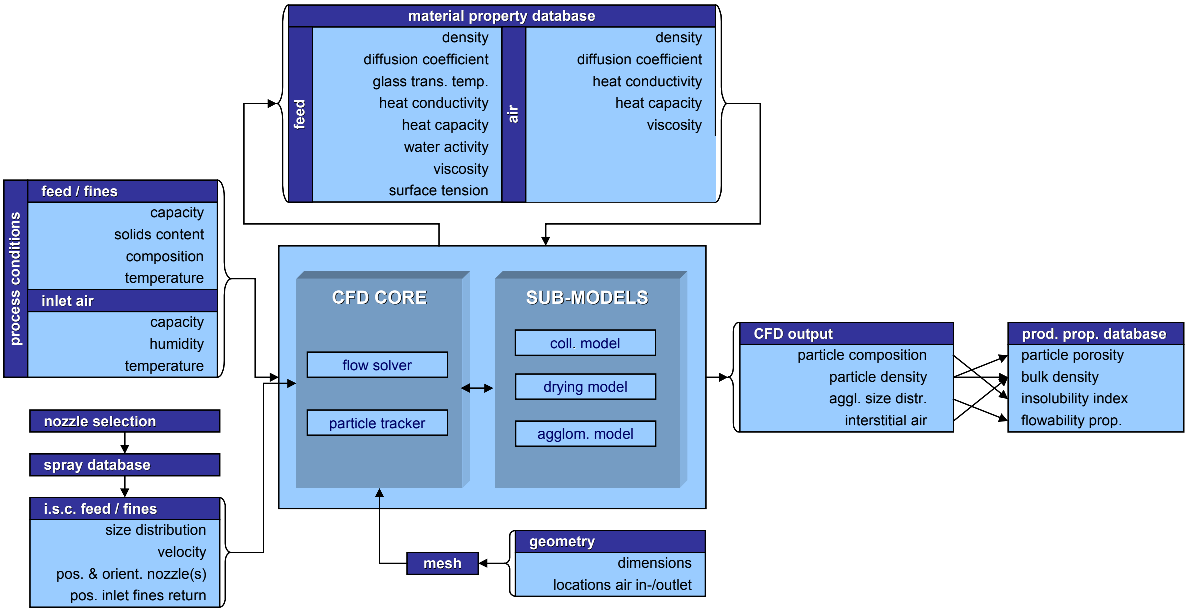

Fig. 4: General structure of the CFD model

The required input for the model consists of:

1. the geometry of the dryer (dimensions of the dryer and locations of the air in-/outlet(s));
2. the initial spray conditions for feed and fines return (particle size distribution, velocity, position and orientation of the nozzle(s), position inlet fines return);
3. the process conditions (capacity, solids content, composition and temperature of feed and fines return; capacity, humidity and temperature of the inlet air);
4. the material property database (database describing the relevant material properties as a function of the process variables).

The geometry of the dryer is required to be able to make the mesh for the CFD calculations. The process conditions and the initial spray conditions act as initial conditions for the calculations. During the calculations the CFD model interacts with the material property database.

The CFD model consists of two parts: The CFD core and the sub-models. The CFD core uses an Euler/Lagrange approach to calculate the flow field and the particle trajectories.
The *drying sub-model* predicts the evaporation rate and its effects on the particle diameter, temperature and the moisture distribution inside the particle. The drying model uses the results of the flow solver and the particle tracker and the relevant parameters from the material property database (diffusion coefficient, heat conductivity, etc.) [11].
The *collision sub-model*: predicts the collision probability and impact details using a collision model having a stochastic approach [12].
The *agglomeration sub-model* predicts whether agglomeration occurs during collisions, based on impact details and stickiness predicted.

The particle composition and the moisture content of the outer layer determine the glass transition temperature and thereby the stickiness of the particle, which influences the agglomeration process [13]. If agglomeration takes place the post-agglomeration properties are calculated using momentum and energy conservation. Post-collision properties are also computed when the particles do not agglomerate, but for instance coalesce or rebound.

4. Conclusions

During spray drying, agglomerates of powder particles are formed which determine the instant properties of the powder. Agglomeration during spray drying is considered to be a difficult process to control. As a consequence, agglomeration during spray drying is operated by trial-and-error. In 2001 an EC-sponsored project started with the aim of developing an industrially validated (computer) model, using CFD technology, to predict agglomeration processes in spray drying machines. It is the intention to combine an Euler-Lagrange approach with appropriate elementary models for drying, collision, coalescence and agglomeration of the dispersed phase. The project is expected to finish at the beginning of 2004. This paper introduced the background and approach of the project in general terms.

Acknowledgements

This work is sponsored by the European Commission in the frame of the EC Fifth Framework Programme within the research programme "Competitive and Sustainable Growth" (contract G1RD-CT-2000-00340, http://www.edecad.com).
The authors would like to thank the partners participating in this project: the industrial partners Armor Protéines (France), Numico (Netherlands) and Anhydro/Invensys Process Systems (Denmark) and the academic partners UMIST (UK, *collision model*), University of Bremen (Germany, *initial spray conditions*), Technical University of Darmstadt (Germany, *drying model*) and the Martin-Luther University of Halle-Wittenberg (Germany, *agglomeration model*).

References

[1] Pietsch W 1999 *Chemical Engineering Progress* **95** (8) 67-81
[2]. Retsina T 1988 *Food Technology International, Europe* 37-39
[3] Hansen P S 1980 *J. Soc.Dairy Technology* **33** (1) 9-23
[4] Graham B H 1997 *Food Australia* **49** (4)184-185
[5] Deis R C 1997 *Food Product Design* **7** (2) 97-113
[6] Písecký J 1997 *Handbook of Milk Powder Manufacture* (Copenhagen:Niro A/S)
[7] Shilton N C and Niranjan K 1993 *Food Structure* **12** (2)199-215
[8] Pisecky J. and Hansen S P 1990 *patent EP 0 378 498*
[9] Bergquist D H, Lorimor G D and Wildy T E 1992 *patent US 5130156*
[10] Katcher J H, *et al.*, 1989 patent *US 4 871 398*
[11] Straatsma J, van Houwelingen G, Steenbergen A E and de Jong P 1999 *J. Food Engineering* **42** 67-72
[12] Sommerfeld M 2001 *Int. J. Multiphase Flow* **27** 1829-1858
[13] Y.H. Roos Y H 2002 *Lait* **82** 475-484