

# **Powder Research to Promote Competitive Manufacture of Added-Value Food Ingredients**

## **Proceedings**



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# Project Overview

## Background

This project is the result of a project funded by the EU Commission through an Accompanying Measure. The focus of the project is to highlight industry problems, knowledge barriers and research and development opportunities in relation to food powders. It will highlight the priority research needs for development of new and improved powder products and processes. It is envisaged that this will act as a necessary step in **fostering the potential for future research ideas and collaborative research.**

## Objectives

The specific objectives to achieve were:

- to outline research and development needs and opportunities in terms of:
  - industrial problems with handling, processing and production of safe, high quality food powders that require further targeted research initiatives;
  - areas requiring further science and engineering knowledge so that this can be applied in the development of new and more efficient processes to produce added-value food powders that are safe and of high quality;
  - new and emerging food powder technologies requiring research and development.
- to promote the creation of a sustainable network of excellence in the area of food powders.

These objectives were achieved by:

- obtaining the views of many individuals actively working with powders.
- implementing a Workshop to create dialog on food powder production, handling and processing, whereby a number of people were invited to participate, who are actively involved in this area throughout the EU, from Industry, Research Centres and Universities;
- disseminating the findings among the scientific and industrial community.

## Organisation

### *Co-ordinators*

The principal partners who co-ordinated the implementation of the project were Dr. John Fitzpatrick from the Department of Process Engineering at University College Cork Ireland (UCC) and Dr. Lilia Ahrné from the Swedish Institute for Food and Biotechnology (SIK).

### *Management committee*

The management committee consisted of the two co-ordinators and the following members:

Professor Fernanda Oliveira, Head of the Department of Process Engineering, UCC, Ireland  
Professor Thomas Ohlsson, Head of Environmental and Process Engineering, SIK, Sweden

### *Scientific committee*

The activities of the project addressed six different areas, and each area had a leader selected on the basis of experience and competence in the subject. The scientific committee consisted of the two co-ordinators and the area leaders listed below:

Area	Leader
Quality and safety Powder production	Dr. Peter Lillford formely of Unilever Research, U.K.
Powder mixing and agglomeration	Professor Karl Sommer Technical University Muenchen, Germany
Other added-value technologies	Professor Koen Dewettinck Ghent University, Belgium
Powder storage and transport	Richard Farnish Wolfson Centre for Bulk Solids Handling Technology, U.K.
Powder characterisation	Dr. Sivert Ose Tel-Tek, Norway

## Implementation

The main steps in implementing the objectives of the project consisted of:

- Holding of a workshop on food powders
- Creation of strategic document for research on food powders
- Dissemination of the output from the project

### *Workshop*

The objectives of the workshop were:

- i) To assemble together a mix of individuals from industry, research centres and academia throughout Europe who were working with or had an interest in food powders. This gathering could act as a basis for a future network or for future collaborations.
- ii) To address the major industrial problems, knowledge barriers and R&D challenges and opportunities in the production, handling and processing of food powders

47 participants from throughout the EU attended a two-day workshop held in Brussels in November 2002. Day one consisted of presentations by a mix of participants from industry, research centres and academia on the issues that they believed to be important. Day 2 was led by the area leaders and consisted of five “brainstorming” sessions on each of the five areas mentioned above.

### *Strategic document*

The objectives of the strategic document were to outline the major industrial problems, knowledge barriers and R&D challenges and opportunities in the production, handling and processing of food powders. It is envisaged that this will act as a source of ideas for future projects and collaborations.

The creation of this document involved the development of a series of drafts. Draft 1 was developed from input by the project co-ordinators and area leaders. Draft 2 was developed from input from the workshop participants and many others, particularly those in the U.S. working with powders in general and food powders in particular. This draft acted as the starting point for the brainstorming sessions in day 2 of the workshop. Draft 3 was developed from the output from these brainstorming sessions. The final draft was developed from an appraisal of draft 3 by the participants and many others.

### *Dissemination*

The major outputs of the project to disseminate to a wider audience are the strategic document, the workshop proceedings and information on the participants in the project. The major vehicle for dissemination is by the implementation of the website ([www.foodpowders.net](http://www.foodpowders.net))

### **Workshop Proceedings**

This document is primarily a compilation of the papers presented on day 1 of the workshop and a list of those who participated at the workshop. The output from day 2 of the workshop is incorporated into the *Strategic Document*.

# Workshop Programme

## Day 1: Wed. 27<sup>th</sup> November

### *Morning Sessions*

- 9.00-9.15      **Introduction**  
Dr. John Fitzpatrick, University College, Cork, Ireland  
Dr. Lilia Ahrné, Swedish Institute for Food and Biotechnology, Sweden
- 9.15-10.00    Dr. Stephan Palzer, Nestlé, PTC Kempththal, Switzerland  
**Problems while handling and processing powdered convenience foods**  
*- What kind of further research activities are required to improve the manufacturing of culinary powders?*
- 10.00-10.45   Dr. Peter Lillford, U. of York, formerly of Unilever, UK  
**The functional properties of food powders and particulates**
- 10.45-11.00   Coffee/tea break
- 11.00-11.45   Dr. Gabriele Meesters, DSM Food Specialities, The Netherlands  
**Powder technology at DSM: Powders in applications**
- 11.45-12.05   Dr. Elisabeth Pallai, University of Kaposvar, Kaposvar, Hungary  
**Food powder research in Hungary. part I – Drying of heat sensitive materials –pulps and suspensions- to produce powderlike dried food products**
- 12.05-12.30   Professor Janos Gyenis, University of Kaposvar, Kaposvar, Hungary  
**Food powder research in Hungary. part II - Powder mixing, granulation and coating**
- 12.30-14.00   Lunch

### *Afternoon Sessions*

- 14.00-14.45   Professor Denis Poncelet, ENITIAA-Nantes, France  
**Microencapsulation of food ingredients**
- 14.45-15.10   Ruud Verdurmen, NIZO, The Netherlands  
**Spray drying and particle engineering: optimisation and innnovation**
- 15.10-15.35   Carl Hansen, Hamlet Protein, Denmark  
**An industrial perspective of bulk solids handling**
- 15.35-15.50   Coffee/tea break
- 15.50-16.15   Dr. Paru Sellappan, Nestlé Research Center, Lausanne, Switzerland  
**Use of inverse gas chromatography (IGC) in food powders**
- 16.15-16.40   Dr. Lilia Ahrné, SIK, Sweden  
**Work on food powders at SIK**  
Professor Thomas Ohlsson, SIK, Sweden  
**Application of microwaves for measuring food powder properties**  
Professor Anne-Marie Hermansson, SIK, Sweden  
**Particle shape**
- 16.40-16.45   **Concluding remarks day 1**

## **Day 2: Thurs 28<sup>th</sup> November**

### ***Presentation, Discussion and Brainstorming Sessions:***

*In each of these sessions, the session leader will start by giving a 30 – 35 minute presentation on the major issues highlighted so far in the project. The rest of the session will be opened up to discussion, comment and brainstorming by the all the participants.*

### ***Morning Sessions***

- 8.30-8.45      **Introduction**  
 Dr. John Fitzpatrick, University College, Cork, Ireland  
 Dr. Lilia Ahrné, Swedish Institute for Food and Biotechnology, Sweden
- 8.45-10.00    ***Session 1: Quality and Safety***  
 (leader: Dr. Peter Lillford, U. of York, formely of Unilever, UK)
- 10.00-10.15    Coffee/tea break
- 10.15-11.30   ***Session 2: Mixing and Agglomeration***  
 (leader: Prof. Karl Sommer, Technical University, Muenchen, Germany)
- 11.30-12.45   ***Session 3: Added-value Technologies***  
 (leader: Dr. Koen Dewettinck, University of Ghent, Belgium)
- 12.45-14.00    Lunch

### ***Afternoon Sessions***

- 14.00-15.15   ***Session 4: Storage and Transport***  
 (leader: Richard Farnish, Wolfson Centre for Bulk Solids Handling, UK)
- 15.15-15.30    Coffee/tea break
- 15.30-16.45   ***Session 5: Food Powder Properties and Characterisation***  
 (leader: Dr. Sivert Ose, POSTEC, Tel-Tek R&D Centre, Norway)
- 16.45-17.00    **Conclusion and close of workshop**

# **Presentations**

## Problems while handling and processing powdered convenience foods

- What kind of further research activities are required to improve the handling and processing of powder based foodstuff?

***Dr.-Ing. Stefan Palzer***  
*Nestlé PTC Kempthal/ Zürich Switzerland*

The aim of this key-note presentation was to point out where industry, and especially the food business is still requiring further basic research to understand processes or to solve apparent problems while handling powdered foodstuff. It was not intended to present solutions. Furthermore, the discussed topics should be understood as input for the various institutions active in the field of powder research. In this regard, there is a special emphasis on the handling and processing culinary powders. In the dehydrated culinary business the following different product groups can be distinguished:

### Powdered products:

- Soups (powder + garnishes, low in fat)
- Sauces and gravies (powder; sometimes garnishes; low in fat and often high in starch)
- Recipe mixes (low in fat, spices)
- Ready to serve dishes (cup products, pasta and rice preparations, big pieces)
- Powdered bouillon (high in salt)
- Seasonings (high in salt and Glutamate)

### Agglomerated and granulated products:

- Vending soups (agglomerated powder)
- Foodservice sauces and gravies (agglomerated powder; high in starch)
- Granulated or agglomerated seasonings
- Instant bouillon (agglomerated or granulated powder, high in salt)

### Tabletted and compacted powders:

- Bouillon tablets (Hard and Soft bouillon, high salt content, medium to high fat content)
- Sauces (tabletted sauces; high in salt, fat and starch)

The following problems can occur during powder handling and transport:

Mixes containing powder and coarse particles, which often have a different density and shape, tend to segregate. During transport and further handling the different components segregate and thus the homogeneity of the mix decreases. Due to this, expensive separate filling of the sachets or tins is required and selling bigger containers for foodservice clients is difficult because the product segregates before it has been used.

The reason for this segregation is the different mobility of the particles in the bulk. However, there is still a standardised and accepted method missing to simulate this segregation behaviour depending on the real movement of the powder during production and transportation. Furthermore, a clear rule on how to design the product to avoid this segregation is desired. How far can we compensate for differences in the particle mobility by changing of a single particle property? What is role being played by different particle density, particle size and particle shape in relation to segregation tendency? Is it feasible to give a quantitative rule concerning the impact of these features on the mobility of particles in the bulk? By solving these problems, it would be possible to systematically design non-segregating products.

Another problem, which occurs quite often during handling of culinary powders, is linked with the Glass-Transition-Temperature. The Glass-Transition-Temperature TG is the temperature above which the powder tends (at a certain water activity  $a_w$ ) to get rubbery. While getting rubbery it shows a time dependent caking.

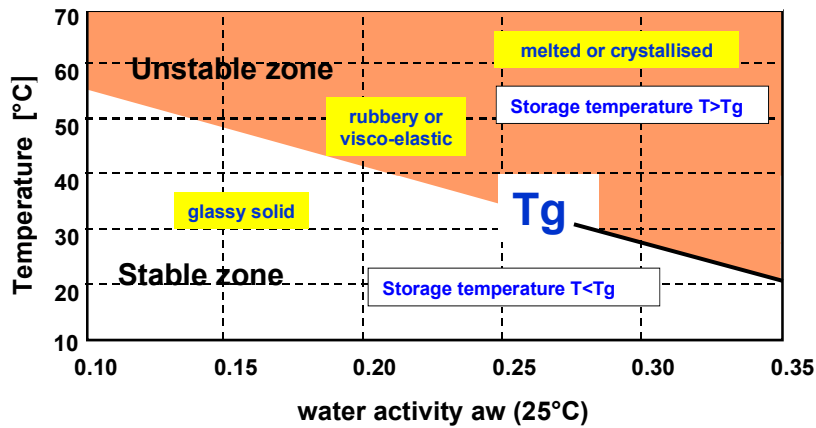


Fig. 1: Glass-Transition-Temperature in dependence of the water activity

Caking is well understood for single mixes with uniform particles. Storing these mixes at a lower temperature than TG prevents them from caking. Thus for single ingredients the TG concept is a very useful tool to avoid manufacturing problems due to caking and lumping. However, for powder mixtures containing particles with different properties it is much more difficult to apply this concept to predict the storage stability of the product. There exist different formulae for calculating the TG of a mixture using the TGs of the single components and their quantities in the mix. However these calculations neglect the structure of the powder bulk. Important properties like the particle size distributions, the shape of the particles and the distribution of the particles in the mix are not considered. Thus these calculations are not suitable to predict the stability of powder mixtures. A suitable method for calculating the stability of powder mixes taking all parameters into account is still missing.

Some of the moisture sensitive ingredients even tend to get liquid exceeding the TG significantly in a moist atmosphere. Especially yeast and meat extracts are very sensitive ingredients. To prevent these ingredients from liquefaction, vapour tight and cheap coatings are required. The current coating processes are by far too expensive for standard raw materials used in the culinary industry and the coating is often not really vapour tight.

Concerning the flowability and the caking of powders, an effective, food grade, water-soluble and non-E-number anti-caking agent is required. The commonly used effective silica acid powder is not water-soluble and it has to be labelled using an E-number, which is in general not well perceived by the consumer.

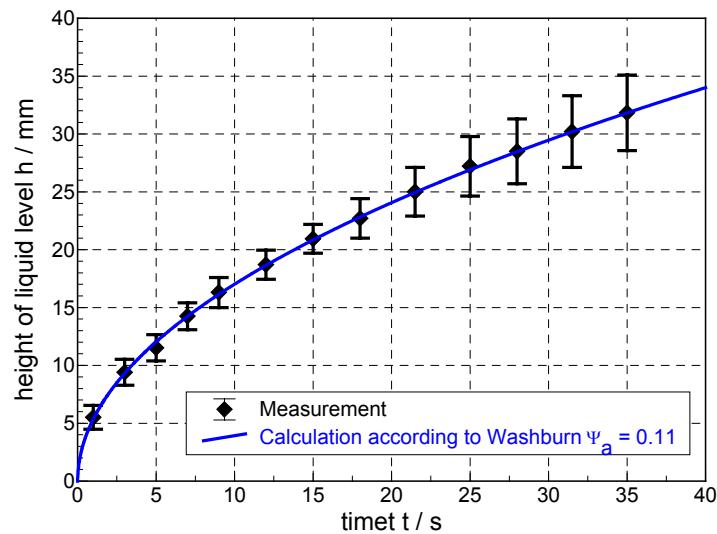
Beside these problems during storage and handling of powders several issues in the area of mixing and agglomeration are still not sufficiently investigated. Problems sounding simple and trivial are still causing huge costs. For example crust formation in mixers while adding liquids and especially aqueous solutions to dry culinary mixes seems often to be quite problematic. Due to the exceeding of the Glass-Transition-Temperature moisture sensitive ingredients are getting sticky and thus they are forming a more or less stable crust on the inner side of the mixer. Since the mixers are normally cleaned dry to avoid contamination with Salmonella it is difficult to scrape the crust away. Coating the inner side of the mixer with a suitable food-grade material, which is also resistant to abrasion, could be one solution. Another approach is to design the mixing process in a special way to avoid the formation of such a crust.

A similar problem is linked to the placement of atomisers in the different available mixers. Where has the atomiser to be positioned to avoid a crust on the mixer walls and lump formation in the processed powder while injecting liquids? Such problems sound simple and in fact running various trials with each mixer type can solve them. However, practice shows that often the manufacturers of the mixers do not know where the best place for the atomiser in their apparatus is located. For food manufacturers it is difficult to test several atomiser positions because it has to be carried out in an industrial scale mixer, which thus need to be modified by cutting and welding. In mixers, running for the daily production, this is of course not feasible. Although this topic is not a very scientific one there is still a huge potential for optimisation.

The influence of the wetting of powder particles with liquids on processes like agglomeration and coating of powders is still not sufficiently investigated. The wetting process consists of two components: The spreading of single droplets on the solid surface of the particles and the penetration of droplets in inter- and intra-particle voids. Both processes seem to influence properties of the final product like the particle size, the

strength of the agglomerates and the quality of a coating layer. For special material combinations a few quantitative results are published, but a general qualitative theory is still missing.

Another basic, complex and yet not solved problem is the measurement of the wetting properties of swelling and dissolving powders. Using the Washburn equation the wetting of inert particles can be described very well provided the particles are big enough.



**Fig. 2:** Time depending wetting of a silica acid powder with water

If the powder particles are tending to swell this effect can be considered by introducing a special swelling coefficient into the Washburn equation. Nevertheless, in most cases the powder particles are dissolving. This means the porosity of a porous particle package used for measuring the contact angle and thus the wettability of a powder is changing during the wetting process. In the mean time the composition of the liquid changes as well due to the dissolution of the powder material. Up to now there is no approach published to measure the wetting characteristics of such material systems.

The last topic linked to powder properties and their measurement is the assessment of the flow characteristics of powders under low normal stress. This product feature is one of the most relevant ones for the consumer. The flowability under low normal stress determines the dosing performed using the opened sachet, which contains the product. In addition, the optical appearance of the powder which is quite important for the consumer is influenced by its flowability. Furthermore, knowing the flow characteristics of the powder under low normal stress, suitable packaging solution, which would provide a satisfying dosing, could be developed. Up to now the majority of the research work has been focused on measuring the flow characteristics under high normal stress, which simulate the situation in silos or containers. First attempts to measure the flowability under low normal stress have been published recently. However, the link between these measurements and the calculation of a suitable container angle or the opening diameter of the packaging providing a proper dosing is still missing.

All these topics mentioned are certainly of interest for the food and especially the culinary industry. Finding low-cost solutions for the mentioned practical problems or delivering basic scientific knowledge concerning the measurement of powder characteristics would definitely lead to an improvement in the handling and processing of culinary powders.

# Functional properties of food powders and particulates

*Peter Lillford*  
University of York, UK

## Issues concerning the food industry and food supply chain

The quality of powders relates to handling in the factory and in the home, and is measured either in the dry state, by its ease of use and stability; or in the manner in which it handles on rehydration and mixing.

As more people eat out of home, catering is a rapidly growing business. Powdered ingredients are convenient for storage and stability, and since the consumer never sees the food assembly process, any prejudices concerning the lower quality associated with dried ingredients is removed. Caterers therefore like big packs of powder that they often leave open, and this can give rise to problems of caking, oxidation etc.

Foods prepared from powdered ingredients are usually considered as lower quality (and therefore lower value) than fresh or frozen ingredients and products. Thus there is great difficulty in adding cost to powders, which has a huge inhibiting effect on innovation and problem solving in food powder production. Technological improvement has been limited because of cost constraints and as a result, innovation is slow or non-existent. Many of the processes used today were designed for ingredients 10-20 years ago. There is a need for powder processors, ingredient people and marketing to identify routes to add more value to powders so as to overcome this resistance to innovation. Consumers may be willing to pay more for powders if they can perceive the high functionality and quality of a powder.

Food ingredient companies can tailor make their ingredients such that they can give a large variety of functionality, however these ingredients must be used exactly in the process for which they were designed and most applications have been developed purely empirically. This also tends to limit research and development since suppliers regard it as added cost, and their user customers are reluctant to change from established optimised processes even if they have only an empirical basis

Food ingredient powders can be broadly classified as follows:

- Simple powders (e.g. protein binders, polysaccharide thickeners)
- Encapsulated actives (e.g. flavours, acidulants)
- Particulates (e.g. dried carrot and mushroom pieces)

Most of them will eventually be utilised in some sort of wet formulation, thus their functionality will depend on the powder particle and component interaction with water. The following sections outline some of the functions of food ingredient powders. Note that air is the cheapest food ingredient followed by water, and many ingredients are applied to entrap more air and water by utilising their aeration and gelation properties.

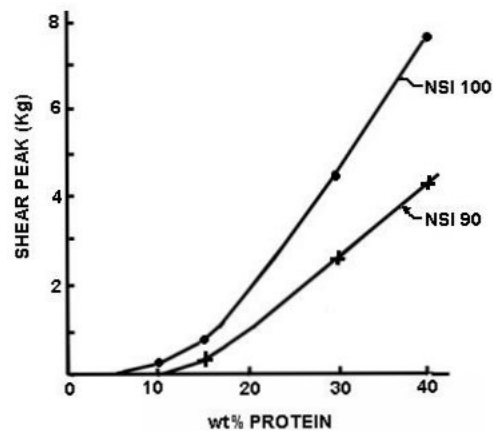
## Functional properties of simple powders

### *Technical functions*

- Product composition- to meet legal requirements of product description
- Taste and colour
- Thickening
- Water retention
- Gelation
- Fat replacement powders
- Emulsification and aeration

Considering the multitude of functionalities, it is important to firstly know what functionality you require and then to target appropriate cost effective ingredients that will give this functionality. It is also important to

make the right measurements of functionality and of factors that may affect functionality. For example, properties of simple protein powders, which are often measured are the solubility and dispersibility, standardised as the NSI and PDI values, respectively. Figure 1 shows the effect on gel strength of two powders with the same PDI, but a difference of only 10% in NSI. The result shows a very significant effect on gel strength reduction by the insoluble material.



**Figure 1.** Effects of insoluble protein on gel strength – soya, pH 4.7, 3% NaCl.

Component stability is a major influence on functionality in applications, for example, will egg-white powder have the same functionality as the native fresh material? A lot of dehydration research has focussed on process engineering and drying efficiency, whilst a lot more work needs to focus on material science aspects and how material properties created during drying affect component stability during drying, storage/transport and final application (usually as a wet formulation).

### ***Physicochemical function***

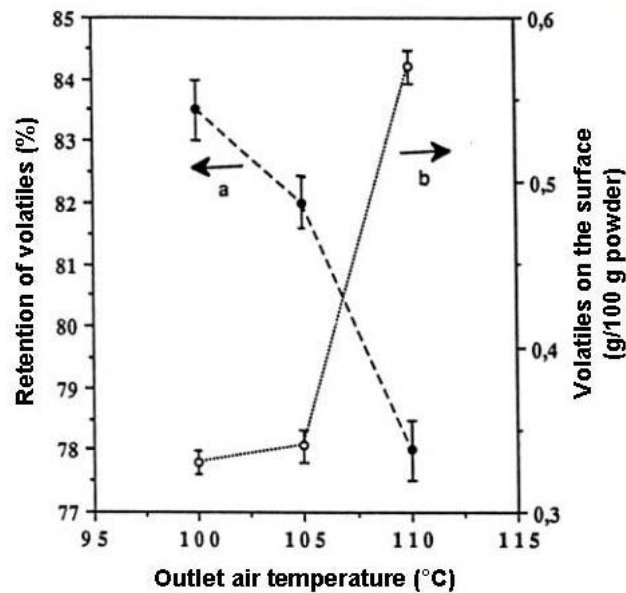
The factors which influence the final performance of simple powders are;

- Analytical Composition
- Rate of Dispersibility
- Rate of Solution
- Rate of Swelling
- Thermal Phase Behaviour
- Phase Separation
- Rate of Migration to Interface
- Residence Time at Interface

In particular, the ability of biopolymers to demix in solution means that subsequent microstructures cannot be predicted by inspection of the formulation

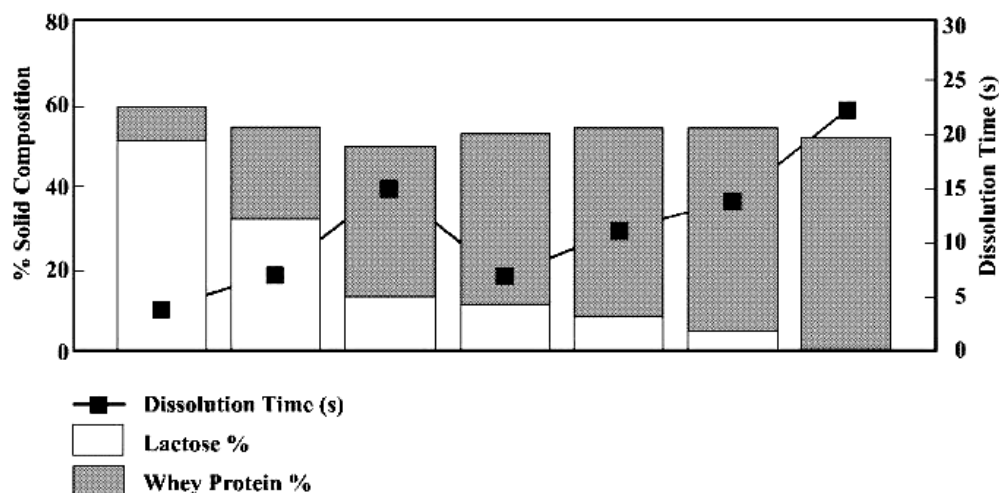
### **Functional properties of encapsulated actives**

Encapsulation allows the stabilisation of actives (colours, flavour volatiles, acidulants, enzymes etc) during storage and transfer in the dried state, whilst allowing triggered release when required (in product manufacture or consumption). We have some understanding of the process and structural requirements of encapsulation. For example, Figure 2 shows that even with rapid formation of a surface “skin” during spray drying, the barrier can crack if outlet temperatures are too high.



**Figure 2.** Retention of volatile products in powder vs outlet air temperature (inlet air temperature = 350°C): (a) total; (b) surface. (From: Bhandari, B.R., et al. *J. Food Sci.*, 57 (1), 212-221 (1992))

The chemical composition of the encapsulating layer determines efficiency of entrapment and also the dissolution and release rate when rehydration takes place (Figure 3.)



**Figure 3.** Effect of Surface Composition on Dissolution Rate of Spray-Dried Emulsions

So the phase behaviour of mixed solutes can either prove a problem for process control, or an opportunity for tailored release, if the microstructure of the surface layers are properly understood. The pharmaceutical industry also shares these interests and has developed sophisticated analytical techniques that the food industry could usefully “borrow”. We will have even more in common as nutraceutical powders, containing encapsulated micronutrients are produced. These will require release to be triggered not in the mouth but after and during digestion.

### Functional properties of particulates

The industry uses many dried components of sizes up to several millimetres. These are actually the highest added value components. Their functionality depends on visual appearance, texture, and flavour, which should be recognisable and represent the tissues from which they were derived (meat or vegetable pieces).

This is extremely dependent on the drying process which itself creates the dry structure and determines the ability of the material to rehydrate and swell to its original form. Air drying normally collapses particulates irreversibly, producing very poor resultant properties. Careful freeze drying is preferred since the dried piece maintains its original volume, and the porous structure permits rapid and complete rehydration by sequential uptake in open channels, followed by swelling of the hydrophilic matrix.

There is still scope to improve the properties of dried particulates. The microbiological stability that drying affords, can be combined with other ways of reducing water activity such as infiltration with small solutes. These combination drying processes offer considerable promise.

### **What next?-Learn from Nature**

Some plants and even animals can dehydrate during a dry season and then rehydrate themselves into the fresh living entity when more favourable living conditions return. Whilst they do this in a matter of hours rather than seconds, the advantage to the industry of stable storage and transport followed by complete recovery to the fresh state would be revolutionary. We do not yet know the “rules of the game” of anhydrobiosis, but selective gene expression is part of the key. Common phenomena in such organisms are

1. Membrane lipid composition
  - no hexagonal phases must form
2. Lots of intracellular polyols
  - plasticisers of H-bonds
3. Formation of expansins
  - cell walls must be flexible
4. LEA Dehydrin Proteins
  - unknown function, (stabilise other protein conformations?)

# Powder technology at DSM Food Specialties

## Powders in applications

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### Introduction

Over 70% of all the products made are in a solid state. These solids, particles, powders or granules are giving a lot of problems during handling, manufacturing and in application. At DSM-Life Sciences, particle technology is performed at several R&D-locations. Specialist groups are established within the company to try to solve particle related problems. For the Food Specialties the particle related research is performed in the Netherlands, in Delft.

Typical dry product produced at large scale by DSM Food Specialties are food and feed additives like, enzymes, yeast extracts, yeasts, bacteria for dairy and meat applications, preservatives, vitamins and nutraceuticals.

Typically these food and feed products are mixtures of several components that are hygroscopic, hydrophobic, and unstable under ambient conditions, have a biological activity (micro-organisms and enzymes), oxidise easily, are a potential health hazard, etc. Therefore, these products need to be formulated in such a way that these undesired properties are masked, and formulated such that in application they do not give rise to any problems of the above-described nature.

The important parameters of our products are:

- ❖ Flow properties
- ❖ Caking properties
- ❖ Instant character
- ❖ Drying behaviour
- ❖ Low cost production
- ❖ Product stability
- ❖ Excellent Performance in Application
- ❖ Safety during production and application

Some typical areas where research is needed are:

### Drying behaviour of food products

Many of the food powders are made from a liquid that is dried into a powder or agglomerate. Often salts, proteins, fats, nucleotides etc are present in these products. Due to these, drying behaviour is difficult to predict and often difficult to do in large dryers. Sticky behaviour during drying and hygroscopicity of these complex products are determined on a trial and error basis. Better understanding of the drying is needed.

Also the flow properties of these products cause many problems. Little is known about modelling and controlling these flow properties.

### Safety during production and handling

Several of the food products (but the same goes for many pharmaceutical products) are potentially harmful for humans. For example enzymes, which are used in many food additives can cause allergic reactions when dust is inhaled. Currently all the DSM products are granulated in a form such that dusting behaviour is low, guaranteeing safe handling. Possibly in the future stricter enzyme dust exposure limits may be imposed. This should need better analysis methods for determining enzyme dust formation of granules during handling, but

also development of tools that can determine the strength of agglomerates and strength of coated particles. Table 1 shows a typical result of the spread in a measuring device used in many food industries. In this area DSM is active to promote the development of these tools through governments, but also formed alliances with University groups who develop new measuring tools. Still this needs more effort and money to be developed.

**Table 1: dusting behaviour of a food powder**

	ppm
1	1243
2	738
3	1296
4	1049
5	1017
6	1379
xm	1120
sx	234
sx/xm [%]	21

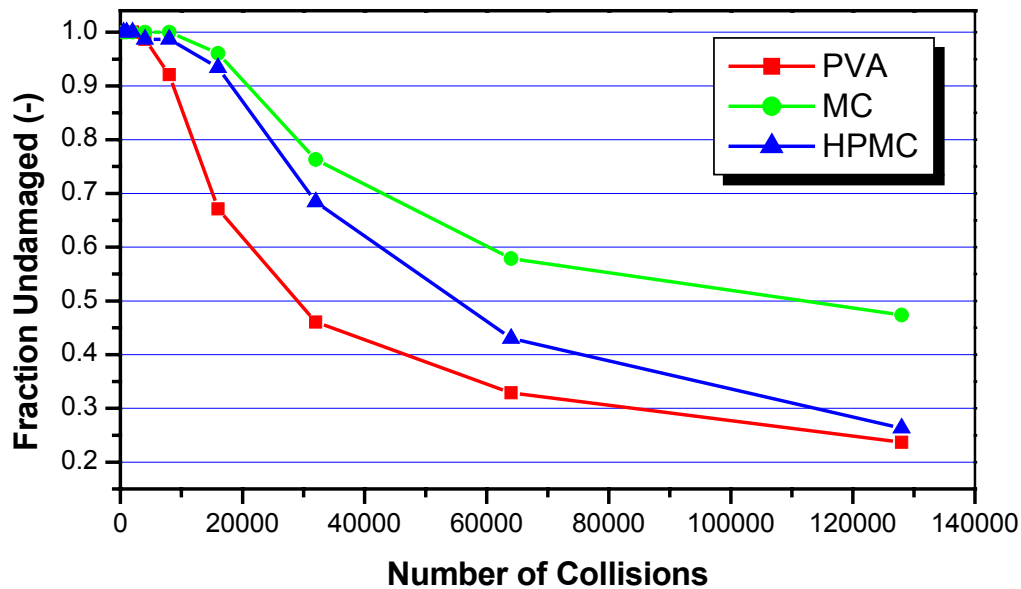
### Coating optimization

Many of the food granules produced have an outer coating to prevent the deterioration of the product due to ambient influences like moisture and oxygen. Also these coatings need to prevent the manufacturers and end-users from exposure to these products.

These coatings are similar to the coatings used in the pharmaceutical business, as long as these are food grade. Contrary to the pharmaceutical products these coatings are often applied at minimum thickness, still ensuring safe and stable products. What we lack at this moment are testing devices that can help formulation development especially in relation to coating processes. Also quality control will benefit from these developments, since these testing devices will help to establish constancy of coating of particles and will help to check and find the of-spec. batches.

From the polymer and materials development it is possible to determine many physical properties of coatings. This should be extended to the coated particles. What are the coating physical properties when they are coated around a granule? How to determine the resistance to attrition, abrasion, fracture etc. of coated particles in relation to the physical properties of the coatings? These questions still need to be answered.

Figure 1 shows results of a newly developed machine (Repeated Impact Tester) developed together with the University of Delft, showing that different coating give different strength to the particles [1,2].



**Figure 1:** Attrition and breakage of particles coated with different types of polymers

### Formulation of living organisms

Several of the food products contain living organisms, e.g. instant yeast (bread, wine and beer applications), lactic acid bacteria (yoghurt, cheese, meat and probiotic production). The organisms are dried in order to give them long stability during storage. The storage stability is important, since we cannot produce these cells all around the world close to the places of application. So we manufacture them at a few places dry them and transport them to many places around the world where they can be stored even longer (up to two years) before they are used.

Still a lot of research is needed in this area of drying of living microorganisms. The losses during drying, storage and hydration still need to be enhanced considerably. This will ask for still a lot of work.

### Control of processes

We currently have few sensors available to monitor on-line or in-line how food processes run. By developing these sensors it will help the engineers to better steer and control the processes, giving better product quality and less recycle of product. Since many food powders are granulated, granulation prediction and modeling should be pushed to a higher level. Currently only the particle size distribution can be measured accurately on-/in-line, but parameters like density, shape, coating thickness, dustiness, strength are at least as important, but are not controlled on line yet. This is mainly due to lack of sensors [3].

### Food Hygiene

In Europe the EU is sponsoring EHEDG (European Hygienic Engineering Design Group), a group developing procedures to develop equipment for use in the food area, which ensure hygienic production. Here the solids handling is taken as a special point of attention. Several food manufacturers, amongst others DSM, equipment producers and universities participate in this work. EHEDG publishes these documents produced by the groups [4].

## Conclusions

We need to combine the research on food powders with application in mind. Many restrictions are caused by the application. The use of complex mixtures of food products makes it difficult to establish optimal drying, flowability prediction, control of dust, strength etc of the final products

Food powders are not just powders. They have activity. This can be microbial, enzymatic, flavour, taste etc. This means that these aspects need to be maintained as much as possible during manufacturing, creating extra problems during product development.

Due to this the products may contain actives that are potentially harmful. So proper understanding of dustiness and prediction is needed, not only during product development, but also during manufacturing and during quality control. In this area we need to acquire much knowledge still.

To ensure better production we need to build sensors that can monitor our processes, giving the engineers the possibility to control their processes better.

Food Hygiene for dry powders is given much attention, and will need this even more in the future, especially for dry product handling.

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## Food powder research in Hungary - Part 1

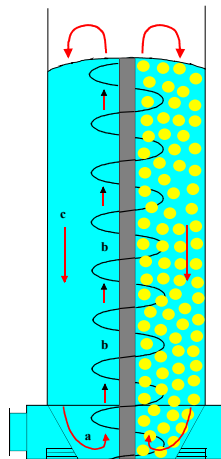
### Drying of heat sensitive materials – suspensions and pulps to produce powderlike dried food products

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In many food technologies, the final product must be recovered from solution or suspension. Consequently, in such cases the drying process is a substantial technological step to obtain dried powderlike products (e.g. vegetables, fruits, herbs or other biologically active materials) of long shelf-life and of high quality. The raw materials to be dried contain in many cases heat sensitive components, e.g. proteins, vitamins or special active ingredients. To preserve these, the drying process should be performed at suitable low temperature. Low temperature drying of heat sensitive materials of high moisture content with acceptable drying efficiency is rather difficult.

Intensive, well controlled heat and mass transfer can be carried out in the so called **Mechanically Spouted Bed (MSB) dryer**, developed in the Research Institute of Chemical and Process Engineering in Veszprém, in Hungary. In this type of dryer the characteristic circulating motion of the particulate material is ensured by an inner vertical, housless conveyor screw /1/ (see **Figure 1**).

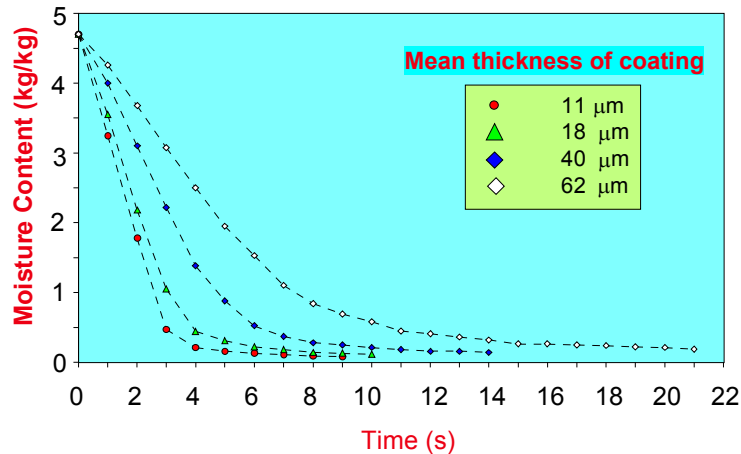


**Figure 1. Plot of the mechanically spouted bed dryer**

The air flowing in through slots in the bottom of the dryer in tangential direction at high velocity causes intensive gas-solid contact. Due to the mechanical particle movement the circulation of the particles is independent of the flow rate of the drying air, thus, this latter can be set to a value which is optimal from point of view of drying. By using inert charge, materials of high moisture content ( suspensions, sludges, etc.) can be advantageously dried in a single step process working continuously.

The wet material (suspension, pulps) is fed into the bed of inert particles, into the dense annular part sliding downward. The wet solid distributes on the large surface of inert particles, and forms an even, film-like layer (coating). The drying of the filmlike coating happens in the zone characterised by turbulent particle flow in the vicinity of the gas inlet, in the bed height of a few (6...8) centimetres. The dried coating wears off the surface as a consequence of the intensive friction in the rotation area of the inner screw, and leaves the dryer together with the air flow /2/. In the following, several drying tasks and results will be demonstrated. Experiments were carried out in a laboratory scale MSB-dryer /3/.

Tomato powder occupies a significant place among powdered vegetables. Its raw material is usually tomato concentrate. The drying of tomato concentrate is critical because of its **hygroscopic and thermoplastic characteristic**. Namely food products of thermoplastic properties (e.g. tomato and apple powder, etc.), becomes deliquescent and sticky in a definite critical temperature-moisture content range. The phenomenon of thermoplasticity of tomato is caused first of all as a consequence of its hygroscopic nature and of the „case hardening” process. At adequate drying conditions in MSB-dryer ( optimum drying rate set by adequate coat thickness) the thermoplasticity could be avoided. The drying curves at different coat thickness are shown in Figure 2.



**Figure 2. Drying curves at different coat thickness for tomato concentrate**

As it can be seen from the drying curves, that in case of film-like coating ( $\delta = 11-18\mu\text{m}$ ) the drying process takes place with nearly constant rate in very short time (5-6s), giving chance to jump over the critical moisture content- temperature range. In many cases **microwave energy can be used** successfully for well controlled drying of different food products, for example **to avoid case hardening**, and consequently the thermoplasticity phenomenon. In the Research Institute of Chemical and Process Engineering, a laboratory scale combined (spouted bed-microwave dryer) was developed. The picture of the dryer can be seen in Figure 3.



**Figure 3. Combined (spouted bed-microwave dryer)**

In this type of dryer heat sensitive food suspensions and pulps can be advantageously dried to produce powderlike products, working continuously. The heating process can be performed in different ways, that is by simultaneous convective and microwave heating, or successively.

On the basis of laboratory experiments **industrial scale MSB-dryers were realized**. For example **for drying of bewery yeast suspension** an MSB-dryer with a capacity of 100 kg water/h was put in operation. (Diameter of dryer was 1,0 m, bed height: 1,0 m, initial moisture content: 5,0 kg water/kg db, final moisture content: 0,05 kg water/ kg db, residence time of wet material in the drying zone was 8-10 s, specific drying rate: 120-030 kg water/m<sup>2</sup>h, specific energy consumption was 3000-3500 kJ/kg water). The inactive brewery yeast suspension as the by-product of the beer production contains vitamin B and trace elements in relatively high concentration, therefore, the dried powder after tableting can be used as roborant.

### **Improved construction of the MSB-dryer with inert particles**

To improve the wearing process, that is **to obtain finer grained powder-like dried product** the spouted bed height (the effectual length of the inner screw) should be increased. However, parallel to the increase of the bed height also the pressure drop increases across the spouted bed affecting adversely the ventilation energy. In order to increase the effectual length of the inner screw independently of the spouted bed height a modified construction was developed, that is a tube of changeable length was built in the dryer. This tube serves as a house for the elongated screw above the bed surface.

Applying this device the screw works above the bed surface as a closed conveyor improving the wearing, grinding effect. Furthermore, by the increase of the screw length above the bed surface parallel with the decrease of the spouted bed height, both improvement in wearing effect and decrease in pressure drop happen. It could be stated that as a result of increase in wearing time (in the length of the screw above the bed surface) a decrease in particle size follows, the particles became more uniform /4/.

To recover from solution or suspension solid products having desired particle size and narrow size distribution, a **fluidized-bed grinding dryer** was developed. In this continuously working equipment, particles of the final dried product are fluidized by preheated air and solution or suspension is sprayed directly onto their surfaces. Liquid evaporates, and the size of the fluidizing particles increases on effect of surface layering. To control the particle growth, roller grinders are placed at the bottom of the fluidized bed which perform selective desintegration. A controllable gap is formed between the rollers and the cylindrical wall (or air distributor). The rollers perform a circular motion and turn around their own shaft. Particles larger than the gap size break into several parts as an effect of compressing and shearing forces. Applying this dryer system, the minimum average particle size is about 200µm, but using special knife grinders, it is possible to produce less particle sizes too /5/.

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## Food powder research in Hungary - Part 2

### Powder mixing, granulation and coating

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#### Introduction

Mixing, granulation and coating are commonly used operations to produce, or to process food powders. These operations are also important for particulate solids other than foods, e.g. pharmaceuticals or chemical products. Their realization may be quite different, depending on the requirements and type of solids to be treated. Therefore, research and development in this field have crucial importance from respect of process improvement and quality enhancement. Hungary possesses very good conditions for agricultural and food production, and this was one of the main reasons that extensive research in this field was always in focal point at the Research Institute of Chemical & Process Engineering (RICHPE), Veszprem, Hungary.

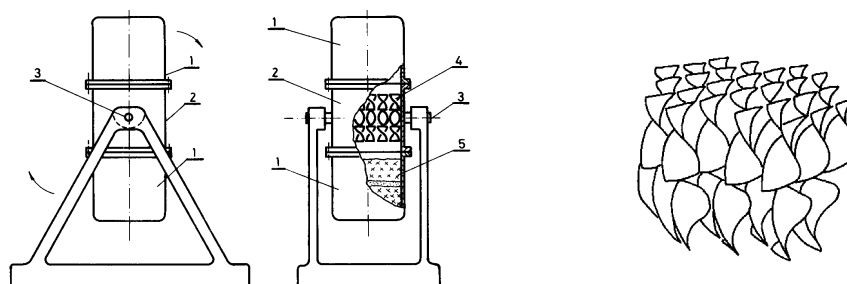
#### Mixing studies

Studies carried out on mixing of particulate solids have been an important part of the research activity of RICHPE during the last decades. The general aim of mixing is to achieve uniform distribution of constituents throughout the whole mass of the mix. The use of motionless or, in other words, static mixers had great potential to achieve this purpose.

Motionless mixers are widely known in other fields of material processing, especially to mix or agitate fluids, to improve direct and indirect heat and mass transfer, to enhance turbulence, dispersing or contacting materials in heterogeneous phase systems etc, but are not very often applied to mix solids. Essentially, these mixers are flow modifying devices inserted into a tube, duct or vessel, which do not move themselves. But, using pressure difference, the kinetic or potential energy of the treated materials, they can create predetermined flow patterns and/or random movements. Thus, velocity differences i.e. relative displacements of various parts of the moving material are generated, also in case of particulate solids. Splitting, shifting, shearing, rotating, accelerating, decelerating and recombining of different parts are common mechanisms in this process.

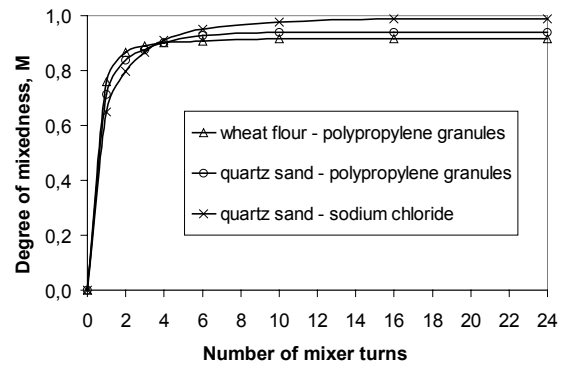
Research and development at RICHPE in this field took place in two direction: (i) Study of a special batch mixer, called Alternately Rotating Bulk Solids Mixer (ARBSM), and (ii) investigation of continuously operating gravity mixer tubes equipped with motionless mixer elements. The aims of studies were to clear up mixing mechanisms, kinetics, performance and other features of these mixers, as well as their utilization for practical tasks.

ARBM or „SysMix” Mixer shown in Figure 1 consists of two containers at both ends of a cylindrical mixer body and a mixing section in the middle, containing ordered motionless mixer grids. During operation, it is tumbling intermittently in alternating directions around a horizontal shaft, therefore food powders or other particulate materials flow down through the mixer grids with varying directions. Therefore, while mixing process is going on, segregation is hindered, due to the periodic variation of forces which otherwise might cause segregation. Operation principles and results are described in details elsewhere [1-3].



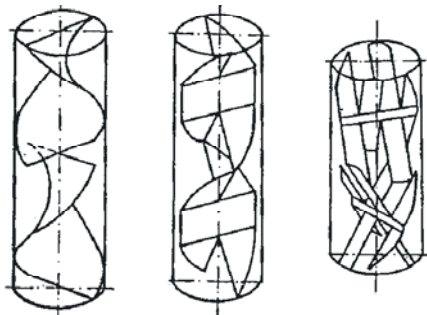
*Figure 1: ARBSM mixer with the enlarged view of the motionless mixer grids*

Figure 2 shows typical examples for the high performance of this type of mixer: homogeneity is increasing very steeply, achieving a high equilibrium degree of mixedness without any sign of segregation, even for mixes composed of particles with very different sizes and densities [4]. Theoretical studies gave firm explanation of this excellent behaviour. Experiments were also carried out in commercial scale (from 20-30 to 2-300 kg charge).

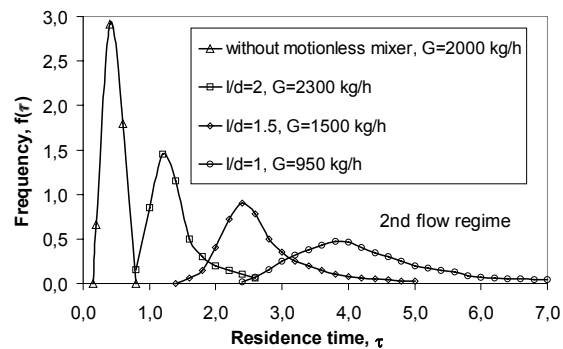


**Figure 2:** kinetic curves obtained in ARBM

Figure 3 shows gravity mixer tubes equipped with different types of motionless mixers. Investigations carried out in continuously operating mixer tubes with helical mixer elements gave evidence that, in the contrary to a general belief, these mixers have excellent mixing performance for solids not only in radial but in longitudinal direction, too. Figure 4 shows residence time distributions of tracer particles measured in gravity mixer tubes with different helical mixer elements [5]. Quasi-static mixers joined to each other through springs allow certain lateral and longitudinal movements during flow, preventing the solids from plugging. Such devices are well applicable for cohesive food powders, too. Capacity is changing from 0.5 to 60 tons per hour, depending on their diameter from 0.05 to 0.40 m I.D.



**Figure 3:** gravity mixer tubes with different types of motionless mixers



**Figure 4:** residence time distributions of tracer particles in continuously operating mixer tubes

Power consumption of these gravity mixers are very low, about 0.1 kWh/ton. It means that apart from feeding, no energy is required if the components are available at the tube inlet.

### Granulation and particle coating

Granulation is one of the most important research fields of RICHPE. Aims of studies cover process improvements and development of new products e.g. to achieve higher quality of food powders or granules. For this, needs of consumers have always guided our research activity, e.g. to produce non-perishable, free-flowing and easily soluble or dispersible instant granules with nice appearance.

#### *Fluidized bed granulation*

Food powders fluidized by hot gas (mostly air) exhibit very good heat and mass transfer between the gas and particles. It is important because this allows low temperature operation, avoiding any heat damage of food constituents. In batch granulators, very complex, highly intricate processes take place simultaneously and/or successively, often repeatedly. Homogenization, wetting of particles with binding solution sprayed onto their surfaces, agglomeration, fixation, drying (evaporation), maybe coating, and then cooling are the most important steps or processes. Material properties are generally very diverse, most of them highly influencing the whole operation. This complexness of the process needs sophisticated approach during research and designing equipment.

Characteristic mechanisms of fluidized bed granulation lead to produce loose agglomerates of primary particles with high porosity, which is favourable to accomplish instant feature.

Several new types of fluidized bed granulators have been developed at RICHPE during the last decades [6]. Special stirrers were constructed to improve particle bed motion and to diminish fluidization problems even for fine and cohesive food powders [7]. Two-phase spray nozzle (atomizer) ensures high efficiency in wetting particles uniformly with small droplets.

Experiments generally start in a compact laboratory scale device composed of a fluidized bed granulator chamber of 0.2 m I.D., electrically heated air supply, and filter bag to prevent dust entrainment with the exhaust gas. On the basis of results and experiences obtained by an extensive research program, pilot scale tests are also carried out with bigger quantity of material in a similar granulator but having 0.4 m I.D. Experiences and measured data achieved in pilot scale equipment are then generally sufficient for safe design of process, resulting in a commercial scale equipment for the given purpose, usually with 1.2 m I.D.

The most interesting experiences during production of instantly soluble food products in fluidized bed spray granulation were related to the following tasks:

- Instant coffee granulation starting from spray dried powder as raw material. Floating up behaviour of the original powder particles (mostly tiny hollow spheres like small ping-pong balls) could be easily changed by granulation.
- Instantly dispersible and coated red pepper ("paprika") granules were produced from fine ground powder by granulation and then coating. Thin coating film well preserved the original colour, tast, flavor, preventing quality loss during storage.

As binding material, usually pure water, solution of the material same as the primary particles, or various cellulose derivatives are mainly used.

#### *Spray granulation from liquid*

At RICHPE, special equipment has been developed and patented to produce granules directly from solution or suspension [9-10]. The most important features are: (i) seeds of the material identical with the solids to be extracted from the liquid are fluidized by hot gas, (ii) solution or suspension is sprayed onto the surface of particles, (iii) growth takes place by surface layering mechanism, (iv) granule size is controlled by orbiting and rotating crushing rolls, (v) good heat and mass transfer between gas and particles allows to maintain low temperature to avoid heat damage of food components.

#### *Roto-fluidized spray granulation and coating*

To produce very compact (dense), spherical granules with smooth surface and uniform size distribution, a highly effective roto-fluid equipment has been developed at RICHPE. Main features: primary particles or seeds are forced to a circular (toroidal) path by a conical rotating air distributor plate. Particles are loosened up or fluidized by hot gas introduced through several circular gaps in the conical rotating plate. Binding or coating solution (or suspension) is sprayed onto the surface of seeds which are covered or enlarged by layering mechanism.

By this way, not only high density granules, but uniform and defect-free coatings (film or thick layers) can be produced. Experiments start in this case directly in pilot scale with 0.4 m I.D. Several commercial scale equipment of 1.2 m I.D. is already in use by industry.

### Coating of particles (granulates) in fluidized bed equipment

Coating of particles with thin film layer or size enlargement by covering them with given quantity of various materials necessary for appropriate thickness is usual operation in particle technology. Shape and size of particles, porosity, permeability, solubility, or other properties of the coating layer can be arbitrarily changed in order e.g. to achieve controlled release of kernel material. Effective methods have been developed at RIChPE to produce coatings of tailor-made properties of particles, seeds or granules. One of them is a fluidized bed spray coating with conical insert [10] seen in Figure 5. In this equipment, perfect (defect-free) film coating or controlled size enlargement can be realized by ensuring intensive particle movements with regular flow pattern, and good gas and droplet distribution.

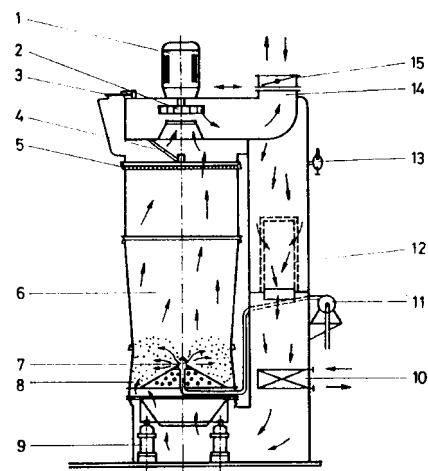


Figure 5: fluidized bed coating device

### A new research direction at RIChPE

Particles with nanostructured coating layer to create e.g. composite food powder components or ingredients will have increasing significance in food technologies too, similarly to certain pharmaceutical, cosmetic or fine-chemistry materials. From this consideration, research in this field has already started at RIChPE, cooperating with the National Institute of Resources and Environment, Tsukuba, Japan [11-12], and it seems to be a very promising new field of powder technology research at the Institute.

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## Bioencapsulation of nutraceuticals for food applications

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In western countries, feeding habits have changed a lot during the last half-century. We have switched from home made to industrially processed food. Very often processing destroys some fragile elements. The abundance leads to a consumption of too rich foods, however generally not well equilibrated. On other hand, people are now considering foods as a health vector. Additives have to be added to the food to provide additional nutritional values or to re-equilibrate the composition of the food. From this consideration, came the concept of nutraceuticals or functional foods. A given food can be regarded as "functional" if it is satisfactorily demonstrated to affect beneficially one or more target functions in the body, beyond adequate nutritional effects in a way, which is relevant to either an improved state of health and well-being, or reduction of risk of disease. Nutraceuticals include a large range of molecules types such as:

- inorganic and organic salts
- active molecules (vitamins, fatty acid ..)
- polymers (fibres, prebiotic, proteins)
- enzymes
- plants and yeast extracts
- biological cells (probiotics)

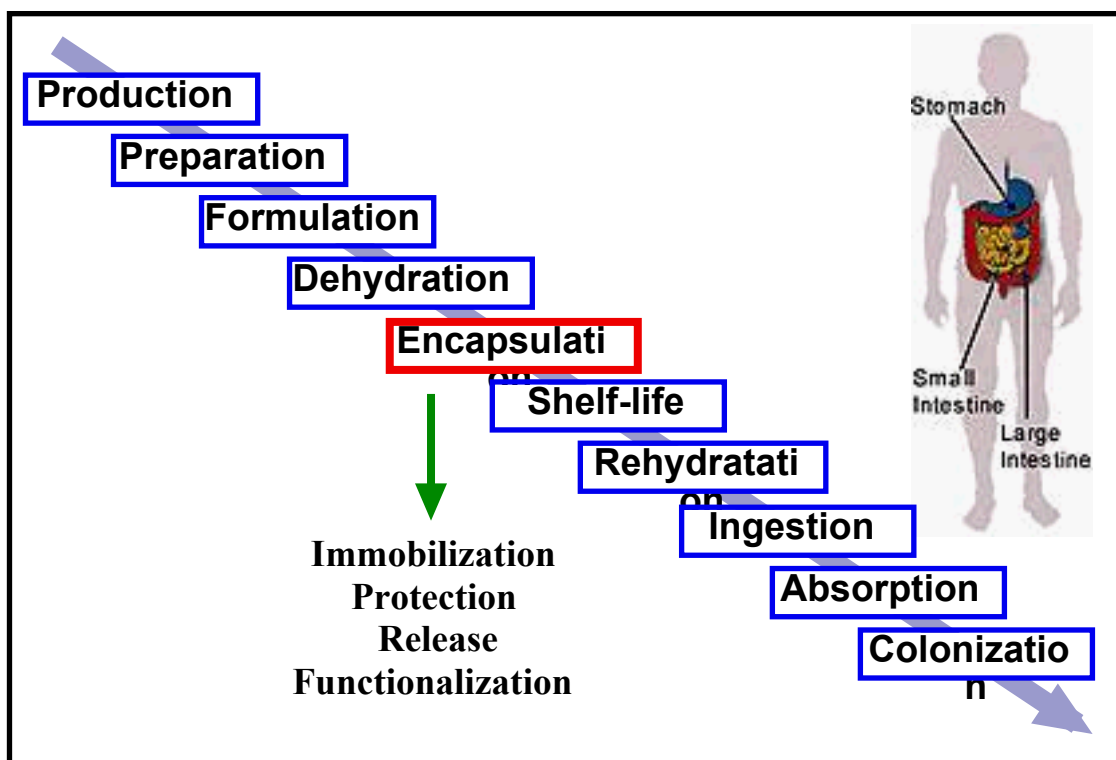
One could observe that it covers a very broad range of components. Their requirement varies as a function of the age, country, feeding and activity habits. They may interact with other food ingredients and need to be protected from them. This protection is also to avoid unwanted taste effects. In most cases, they are fragile and need protection during storage, processing and often during gastro-transit. They are added at very low concentration in food and required a form easily and reproducibly dispersible in a large system. They have to be release at the right place in body and even preformed to increase their absorption in the intestine.

One of the best solutions to these problems is microencapsulation. However, one must understand that encapsulation is one of the steps in the whole processing of a specific ingredient. All other steps will influence the microencapsulation efficiency and affect the integrity of the encapsulated materials but also the selection of the encapsulation method.

Let's take an example: the probiotics and even more specifically bifido bacteria which is recognized to have very important healthy effect such as cancer prevention, better food digestibility, protection against pathogens. To target such microorganism to the body, many steps are involved (Figure 1). The bifido species have to be selected not only for their nutritional quality but also for their good resistance to treatments and their capacity to be produced in large quantity at low cost. While produced, the bacteria may need to be placed in a suitable physiological stage to optimize their viability during drying, storage and regeneration. Futhermore to protect it and to provide adequate environment during reactivation of the cells, inoculum has to be formulated with different ingredients like cryo- or drying protectants, substrates or prebiotics (molecules that affect the capacity of colonization in the intestine). Then come a stage of drying either by spray drying or lyophilisation, and finally microencapsulation (these stages can sometimes be done in parallel). However, the story is not finished, even protected by encapsulation, the probiotics may be stored and processed in adequate conditions. One could not expect the encapsulated cells to be fully protected against high temperature or moisture. The stage of rehydration is also critical. Most scientists agree now that this stage is as much important as dehydration step for cell viability. The technology used for encapsulation will affect strongly the rehydration. Ingestion, gastro-transit, absorption and colonization are the final steps and are also strongly affected by the encapsulation procedure.

If you want to be successful in using an encapsulation process, you must take in consideration the whole "food chain". Even if looks simple for some ingredients (like salts), you may miss your objective if you dismiss this rule. On top, you will need to consider cost, technological and legal aspects. Despite all this

difficulties, the increasing interest for and market development of encapsulated food ingredients prove that this technology is successful both technologically and financially to provide higher quality of functional foods to customers.



**Figure 1 :** Probiotic processing

There exists a wide range of microencapsulation methods but very few are really suitable for functional foods in regards to their biocompatibility, cost or protective actions. As functional foods are at the interface between pharmacy and food industries, the most usual technologies are often from one of these fields or a combination. Table 1 gives a summary of different methods.

### Tabletting

Tabletting is a technology from the pharmaceutical field. It produces quite large capsules (a few mm) and, in many case, good protection. It is however difficult to figure out how to involve such technology in food applications. Sizes are obviously too large and this brings the question of the adequate microcapsule diameter for food applications. In fact, no real data exist about this and it may depend on the application stage. In dry food, the size must be related to powder grain size to avoid segregation. While suspended in liquid the size must be very small to avoid settling. However, density and particle surface tension play also an important role in reducing segregation and settling problem. Capsule detection in the mouth is obviously connected to their size but also probably to their surface roughness and “elasticity”. On other hand, the lower is the capsule diameter, the more difficult is the control of the size distribution, the lower is the productivity as well as the protective effect, and finally the higher is the cost. Engineers are then advised to define the largest size acceptable for their application and work with this size.

### Coacervation

Coacervation consists generally in dispersing an oil phase in a water polymer solution. The polymer is then demixed by addition of salt, acid or by changing the temperature. The resulting “coacervates” accumulate at the oil droplet interface and form a membrane. Capsules are then separated, cross-linked with glutaraldehyde and dried. Different types of polymers systems are proposed to form such capsules but the most usual is a

mixture of gelatin and arabic gum. This technology allows to form capsules containing a liquid hydrophobic core and it is quite unique in this way as potential food grade process. However, the cost of the process, the use of gelatin and cross-linker have strongly reduced the interest for such process, especially in Europe. Much research work is being undertaken to use different wall materials (such as vegetable proteins) to reduce the cost. Coacervation may come back in the future as a useful method of encapsulation for nutraceuticals.

**Table 1: Principle of different encapsulation methods.**

<b>Methods</b>	<b>Principle</b>
Tabletting	active ingredient is dispersed in a powder, and then tablets are formed by applying high pressure to the mixture in a mould
Coacervation	active ingredient is mixed with an hydrophobic liquid, emulsified in aqueous polymer solution. Capsules are then formed by precipitation of the polymer on the surface of the dispersed phase droplets by changing physicochemical conditions
Emulsion and double Emulsion	active ingredient could be solubilized in an oily phase and subsequently dispersed in water phase. Hydrophilic material could also be solubilised in water, the solution dispersed in oil and then the primary emulsion redispersed in water phase to reach to double emulsions.
Liposomes/ vesicles	molecules such as phospholipids are dispersed in water phase to lead to a multilayer structure where the active ingredients will tendency to absorb.
Spray drying or cooling	active ingredient is mixed with either a polymer solution or a melted material, spray in form a fine droplets which are solidify either by drying or cooling
Coating methods	Solid particles containing the active ingredients are covers by a coating material by spraying it as fine droplet in either a fluidised bed or an pan and solidify it either by drying or cooling.
Hydrogel bead Entrapment	Active ingredients are mixed with hydrogel sol, dropped in a gelification bath and resulting beads dry

### **Emulsions, double emulsions and multilamellar systems (liposomes)**

While dispersing a hydrophobic material in food matrices (generally hydrophilic), one could consider emulsion as an encapsulation method if it is stable enough. By using double emulsions, even hydrophilic material could be entrapped in oily phase. If amphiphilic material is used, diverse configuration of multilamellar system could be realized where hydrophobic material is encapsulated in bilayer lamellas and the hydrophilic material in the intermediate layer. These technologies could be conducted in very soft conditions allowing very gentle encapsulation. However, most of these systems are not stable as true microcapsules and must be often considered as a vector for molecules than as a true encapsulation. To stabilize such system, emulsions and multilamellar systems could be included in hydrogel matrices for example. They will contribute to the controlled release of the active ingredient but also in many cases to its absorption. They could also contribute to maintain the integrity of enzymes and even enhance the activity of hydrophobic ones.

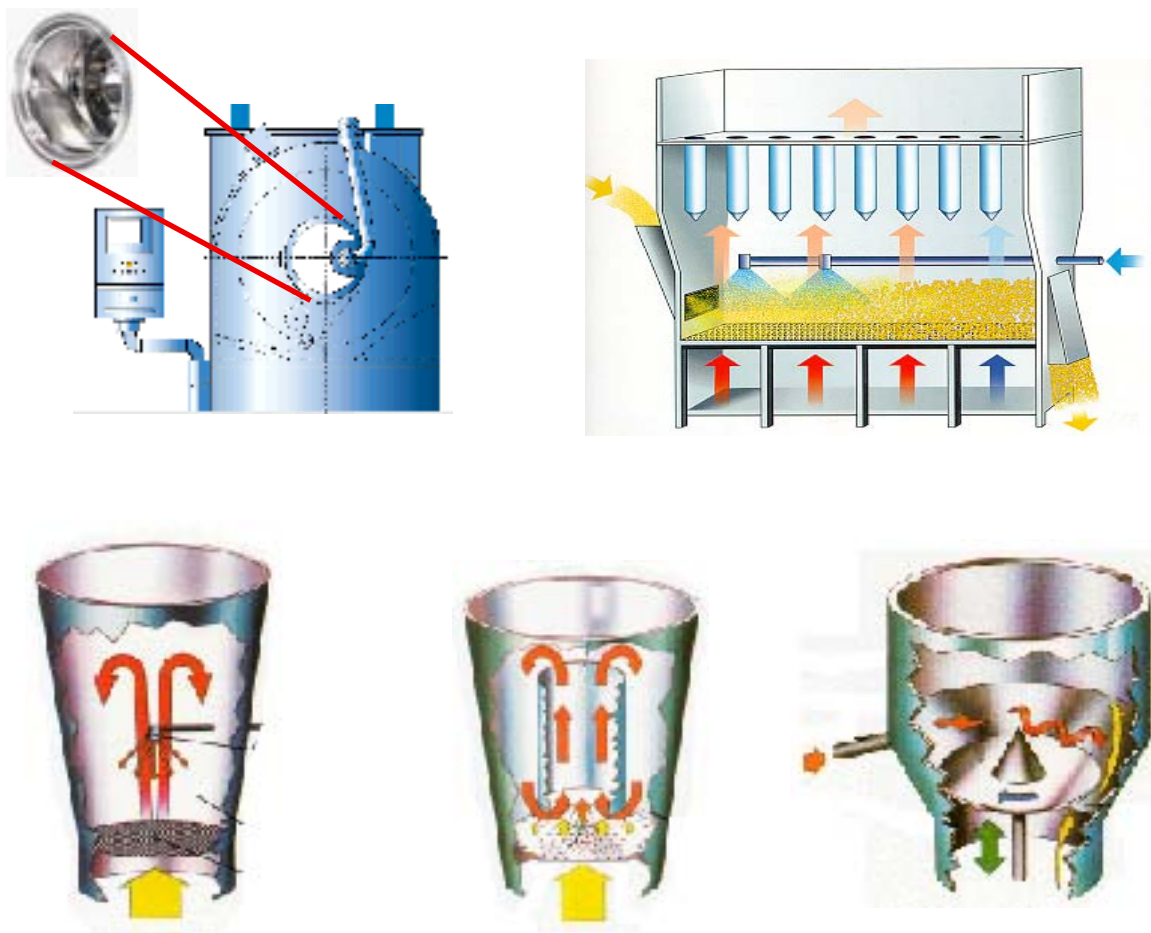
### **Spray cooling**

An alternative to encapsulation by spray drying is to work by spraying a melted material and solidifying the droplets by cooling. The range of matrices available for such processes is more limited and consists often in hydrophobic material (such as fatty acid). Dry hydrophilic material offers generally a better protection to oxygen and is more compatible with many food powders (flour). Its protecting property against moisture may be a function of the relative humidity. At low moisture, hydrophilic material may be a good barrier but obviously at high moisture, hydrophobic barrier is needed. One great advantage of the encapsulation by spray cooling is the high productivity. One hundred percent of the sprayed solution form the particles, while with drying process it may represent from a few percents to maximum 40 %. Cooling process is then a lot

faster than drying. Cooling reduces slightly the process cost as it requires limited amount of energy in regard to evaporation associated to higher volumetric productivity.

### Film coating

While having a fine dry form (either the nutraceuticals is initially solid, or has been previously encapsulated), it may be of interest to coat its surface. This coating could provide new surface properties, protection and controlled release. The coating could be realized in two main reactors: In pan coating, material is placed in a rotating drum ( or pan) and a coating solution is sprayed on the particles. To avoid agglomeration, the particle kinetic energy provided by the drum must be higher than the interparticle sticky energy. Such condition is easily performed only with large particles (larger than 1 mm). For small particles, fluidised bed could be used. Particles are placed in an upward air-flow reactor and then suspended in front of the spray nozzle. The most simple arrangement is a reactor with the spray nozzle placed on top of the reactor (top spray). It allows large particle loading but the coating is often not perfect and it exists some risk of agglomeration. To reduce these problems, a cylinder is placed at the center of the reactor, the air flow rate is higher in this zone promoting circulation of the particle (moving up in the central zone and downward in the outer zone). Spray nozzle is then introduced in the bottom of the reactor. This process is the so called Wurster process. The circulation of the particles ensures a better coating. Finally, a combination of the fluidisation and the rotating effects could be obtained by introducing a rotating disk at the bottom of the reactor, fluidising air is only provided at the periphery. Such system leads to a good circulation of the particles and to final spherical particles ( “spheronisation”). The spray is provided directly in the bed and promotes a very good coating properties. However, this process is incompatible with fragile particles.



**Figure 2** : Film coating process (courtesy of Glatt Pharmatech, Germany)

### **Hydrogel bead entrapment**

While looking simply for an immobilization method for cells or large molecules, hydrogel beads could constitute a cheap and gentle method. This could even be extended to hydrophobic molecules after its emulsification in the pre-gel solution. There exists a large range of polysaccharides or proteins, which can form a gel in the presence of ions (alginate), by decreasing (K-carrageenane) or increasing the temperature (konjac). The release could be obtained by sequestration (using some ions), or changing the temperature. Obviously, such encapsulation will not offer high potential of protection but could fit with some specific applications. To increase the retention and protection capacity, one could produce high dry matter beads by adding to pre-gel solution some filler such as inert powder or low viscous polymer (such as arabic gum). The resulting beads could even be dried at moderate temperature. This approach is not really developed today but could figure as a very gentle technique for encapsulation of very fragile material.

### **Conclusion and perspectives.**

The present overview does not try to cover all the technologies available to encapsulate nutraceuticals. There exists many variants to the presented ones. While selecting a method, the researcher or the engineer will have to take in account many aspects as reported in the beginning of this text.

To provide more information to the reader, you can visit the web site <http://BRG.enitiaa-nantes.fr> where you can find the slides associated to this presentation which are is available at:

(<http://BRG.enitiaa-nantes.fr/Documents/neutraceuticals>) or contact the authors [poncelet@enitiaa-nantes.fr](mailto:poncelet@enitiaa-nantes.fr)

This work includes many links to web site related to the different technologies described here.

# Spray drying and particle engineering: optimisation and innovation

*Ruud Verdurmen*

*NIZO food research, Ede, The Netherlands*

## **NIZO food research**

NIZO food research is an independent industrial research and knowledge organisation that carries out innovative contract research for companies active in the food and biotechnology industries. The aim is to develop applications in the fields of texture, flavour and health and to optimise and innovate production processes focussing on quality, safety and processing technology. To achieve this, NIZO food research is organised in multidisciplinary teams of highly educated and application driven professionals.

NIZO food research supplies solutions for companies based on a thorough knowledge of:

- Microbial systems
- Biopolymer systems
- Process systems

NIZO food research is part of various national and international research networks and participates in the Wageningen Centre for Food Sciences.

## **Main challenges in the production of powders**

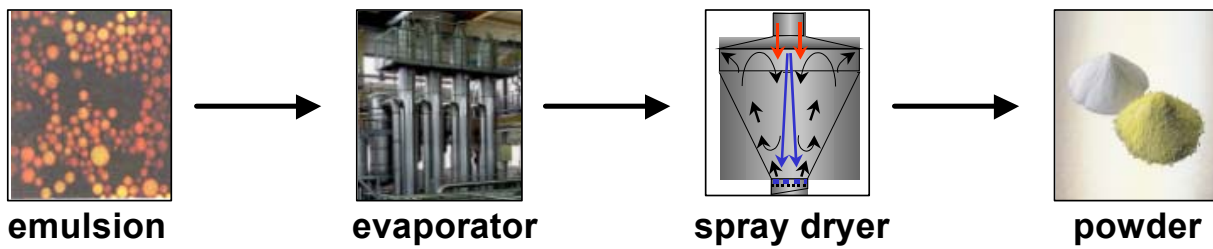
The following main challenges can be identified when looking to the production processes of food powders:

- The development of food powders with a higher added value, e.g. powders with a specific functionality (e.g. purity, nutritional value) or improved rehydration properties;
- Reduced time-to-market: in general the development time of new products/processes (the trajectory from idea to application) is urged to be shorter and shorter in order to be competitive. As a result the knowledge intensity of such trajectories needs to be higher and higher. Also having multi-product installations with a short change-over time can reduce the time-to-market;
- Reduction of processing costs. There usually still is adequate room for further optimisation of existing drying processes, for example by:
  - Maximising the capacity of existing installations
  - Reduction of fouling and thereby reducing the costs of product losses
  - Reduction of energy consumption
  - Using on-line product quality control systems.

It is the experience of NIZO food research that predictive computer models are very effective tools to reduce time-to-market and to reduce processing costs.

## **General production process of powders by spray drying**

A large portion of the food powders is produced by spray drying processes. The removal of water usually takes place in two stages, see Figure 1.



**Figure 1:** Schematic presentation of the production process of food powders

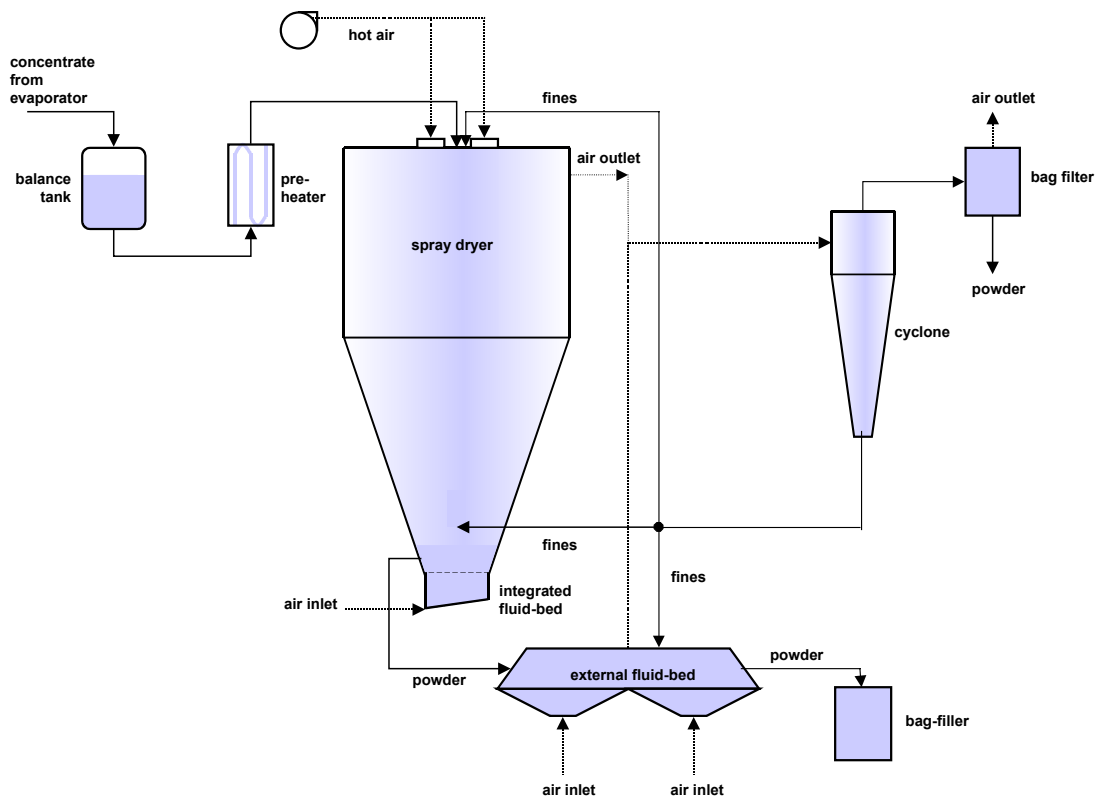
The first stage is concentration by vacuum evaporation and the second stage is drying; 90 % of the water is removed in the evaporator and only 9-10 % in the spray dryer when calculating the amount of water removal per dry mass. However, the energy required per kg water evaporated in the dryer is about 15 times the energy required per kg water removed in the evaporator, see also Table 1.

**Table 1:** Typical figures for the conversion from milk to milk powder.

Product	Milk		Concentrated milk		Milk powder
Total solids [%]	10		50		96
Kg water per kg total solids [-]	11.1		1		0.04
Specific energy use for conversion [MJ/kg water evaporation]		0.3		4.4	

Spray drying is a relatively gentle drying process that has replaced the cheaper but also the more product-denaturing drum dryers. Moreover spray drying makes it possible to manufacture powder qualities for different applications and quality standards.

In Figure 2 the scheme of a multi-stage-dryer is shown. In practice a spray dryer can consist of one, two or three stages. Multi-stage drying increases the thermal efficiency of the drying process, produces agglomerated powder with good rehydration properties and prevents overheating of powder particles. In the first stage, the preheated product ( $< 100\text{ }^{\circ}\text{C}$ ) is sprayed by atomisation into a chamber filled with circulating hot air. The inlet temperature of the air is normally  $150\text{-}250\text{ }^{\circ}\text{C}$ . By atomisation the concentrate is converted into droplets of  $10\text{-}200\text{ }\mu\text{m}$ . In the industry two atomisation systems are used: stationary pressure nozzle and rotating atomisers. The droplets are flowing in the tower and adsorb heat necessary for evaporating of the moisture. The moisture is removed by the hot air. Depending on the dimensions of the tower the residence time of the powder particles is in the order of 5-30 seconds. The dried powder falls to the bottom of the dryer and is transported to the next drying stage or to a packaging system. The exhaust air is removed through an outlet duct and passes through cyclones and filters where small powder particles (fines) are removed. The fines can be recycled to the top of the dryer or to other drying stages. The result is an agglomerated powder.



**Figure 2:** Schematic representation of industrial configurations of spray-driers (single-, two- and three-stage)

To obtain a high-quality powder, a constant dry matter content in the concentrate produced in the evaporator preceding the drying process is necessary. The occurrence of changes in dry matter content in the feed to the dryer is one of the major sources of disturbance in the drying process. It is also advantageous to remove as much water as possible at the evaporation stage from an energy-saving point of view. In practice however, due to variations that occur in dry matter content of the concentrate as a consequence of variations in feed and process variables, the set-point for this dry matter content is often lower than theoretically possible. This in order to reduce the risk too high a viscosity of the concentrate. Less variation in dry matter content of the concentrate enables a higher set-point and thus also improves the energy efficiency of the powder production process. When using conventional control technology, such as single-loop proportional-integral-derivative (PID) controllers, the long time delay from input (e.g. flow or dry matter content of milk fed to the evaporator) to output (e.g. total solids content of concentrate by controlling the steam supply) will result in a relatively long period of off-spec concentrate. Modern design methods for multivariable control make it possible to design compensators that reduce or eliminate the off-spec period. For the design of such a multivariable control system one should determine the dynamic behaviour of the evaporator involved. This can be done either by using a physical model simulating the dynamic behaviour or by carrying out step-response measurements on the actual evaporator and using system identification techniques to draw up a black-box model. The first approach is more flexible and robust for handling changes in the design and process operation. The advantage of the latter approach is that it requires less detailed knowledge about the design of the evaporator. Also in drying processes there is a trend to use more and more predictive models in the control strategy. The main issue for the automatic control of spray dryers is to achieve a reduced variation in the moisture content of the powder, enabling a higher setpoint for the moisture content, which strongly reduces the operating costs.

An industrial case is the design and implementation of a feed-forward control system for a four-stage falling-film evaporator with thermal vapour recompression. This control system contains a feed-forward compensation for dry matter content of the feed to the evaporator (e.g. by measuring the density of milk using an in-line sensor), a feed-forward compensation for flow to the evaporator and a feed-back control system using the measured density (in-line sensor) of the concentrate. The dry matter content of the concentrate is controlled by adjusting the steam supply to the evaporator. Based on step-response

measurement the specific control algorithm is designed and implemented in the existing programmable logic controller (PLC) of the evaporator.

This new feed-forward control system has decreased the standard deviation in dry matter content of the concentrate from 0.31 % to 0.19 % (w/w%). Compared to a simple control system it is now possible to increase the set-point of the dry matter content of the concentrate by at least 0.7 %, resulting in an annual energy saving of Euro 10 000 based on a nominal capacity of 30 m<sup>3</sup> milk per hour. The capacity of the evaporator can now easily be adjusted to the capacity of the spray dryer without large variations in dry matter content. It is estimated that as a result of this, the set-point for the moisture content of powder can also be increased by about 0.07 %, which will result in an annual energy saving of Euro 50 000.

### **Predictive models for spray drying**

Two different predictive models for spray drying of dairy products have been developed, implemented and industrially validated by NIZO food research. These two models, DrySPEC2 and DrySim, will be described below. The development of predictive models is an ongoing process; at this moment a consortium of universities and companies (with NIZO food research as the co-ordinator) is developing a model to predict the agglomeration in spray drying installations.

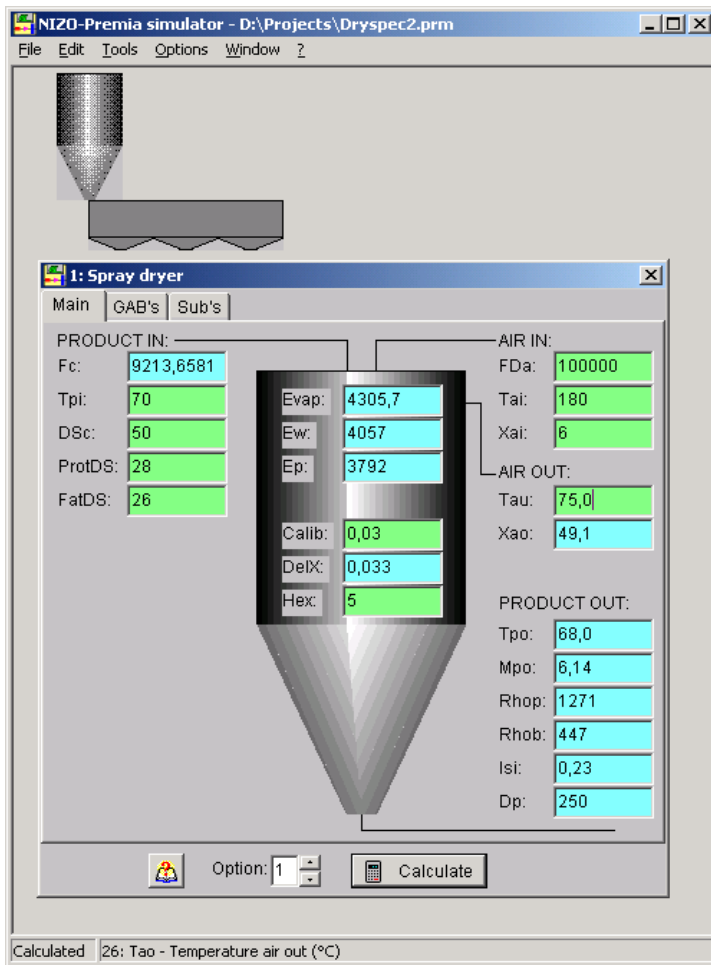
#### ***DrySPEC2***

The first drying model that was developed by NIZO food research is DrySPEC2 (DRYer System for Property and Energy Control). This computer model describes the relation between the processing conditions of the drying process, energy consumption and the properties of the powder produced for a two-stage dryer. The purpose of this model is to establish the process conditions that ensure optimal exploitation of the capabilities of existing drying installations with regard to energy consumption and the powder properties. This model assumes a near-equilibrium state of water vapour pressure between powder and outlet air, which eliminates the need for a detailed description of heat and mass transfer phenomena during the drying process. In Figure 3 a screenshot of DrySPEC2 is shown. The model is integrated in a user-friendly interface in which other software modules can also be accessed. The standard set-up of this model is for a two-stage dryer (spray chamber and fluid bed dryer), but it has also been adapted other types of dryers, e.g. containing an internal fluid bed.

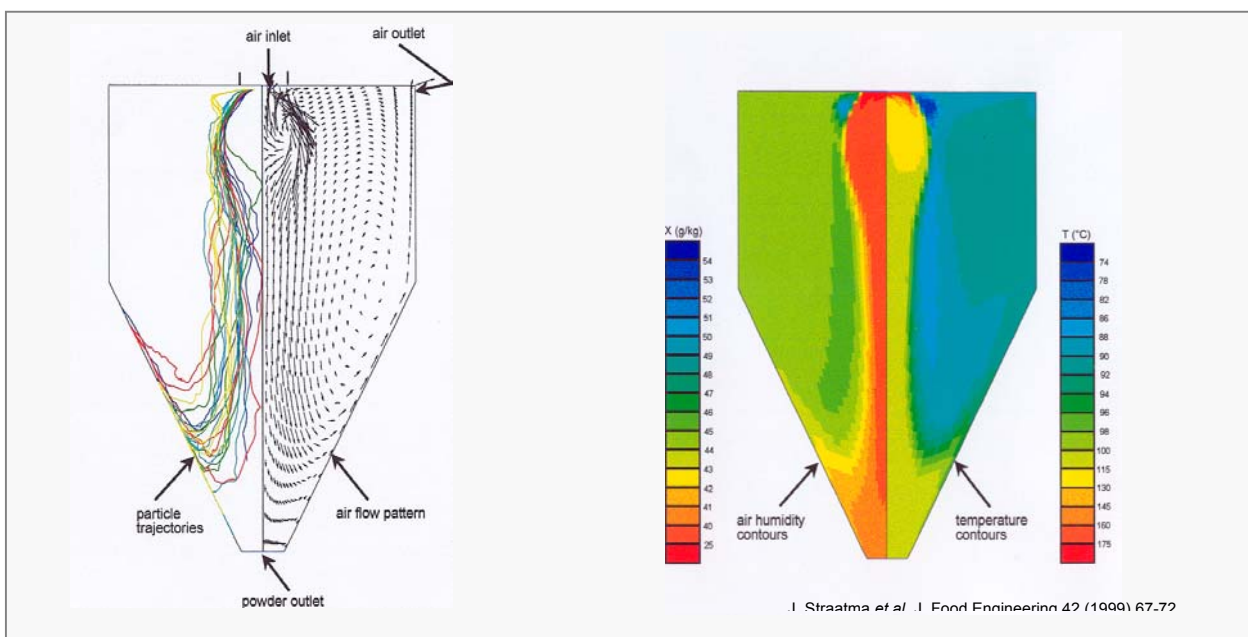
DrySPEC2 has successfully been implemented for the production of dairy products such as skim milk, whole milk and whey permeate. The results obtained in increasing the earning capacity of industrial spray dryers are: up to 20 % increase of capacity, limiting the deviation in moisture content to lower than 0.05 % (for example by adjusting the process to variations in total solids content of the feed or moisture content of inlet air) and an annual energy reduction potential of about 250 000 m<sup>3</sup> natural gas per installation.

#### ***DrySim***

In order to simulate the drying process in more detail, it is necessary to gain insight into the flow pattern, local temperature and local moisture content of the air and the temperature-time history of drying particles. The flow pattern of air depends on the geometry of the dryer and the location and design of the air inlet and air outlet channels. The trajectories followed by the (drying) particles depend not only on the air-flow pattern but also on the position and method of atomisation. At NIZO food research the drying model DrySim was developed as a tailor-made simulation program for spray dryers, making use of computational fluid dynamics (CFD) techniques. DrySim is a two-dimensional simulation model of a spray dryer. It calculates the flow pattern, temperature and moisture content of air, the trajectories of the atomised particles and the drying behaviour of individual particles, see also Figure 4. Sub-models for the formation of insoluble material or for describing the stickiness of particles have been added to DrySim. DrySim has proven to be an effective tool in giving indications of how to adapt industrial dryers, for example to obtain a better product quality, a higher capacity or to reduce fouling.



**Figure 3:** Screenshot of NIZO DrySPEC 2 with user-friendly interface.



**Figure 4:** Computational simulation (NIZO Dry-Sim) of an industrial spray dryer.

### **Product and process innovation**

The process optimisations as described above are mainly targeted at the supply-chain and the production of commodities. In contrast, innovation programmes focus at the development of new products and/or dedicated processes for:

- Food/feed specialities (products with high added value)
- Ingredient industry
- Biotech/pharmaceutical industry.

It turns out that product and process innovations:

- Are mainly driven by functionality
- Require a multidisciplinary approach (e.g. material science, food science, process technology)
- Require a wide variety of analysis equipment, process equipment and application tests

For these reasons it is needed to co-operate (pooling of knowledge, know-how and tools, partnership) between universities, technology centres and producers to achieve real break-throughs.

Some examples of the type of work carried out by NIZO food research in this area are:

- Micro-encapsulation of flavours using food grade materials
- Mild spray drying of micro-organisms (e.g. probiotics)
- Fluid bed coating using food grade polymers to provide a tight barrier

The encountered knowledge barrier is the lack of fundamental knowledge on the:

- Behaviour of biopolymers during encapsulation and coating processes
- Behaviour of food grade materials for controlled release purposes
- Behaviour of micro-organisms during drying

### **Summarising remarks**

**Optimisation** focuses mainly on the production of commodities. Main customers are production managers and technologists. There is still a long way to go for full implementation, although many solutions are already developed. Knowledge transfer and budget are the main barriers.

**Innovation** is mainly initiated by marketing and R&D. For real break-throughs co-operation between disciplines and parties (universities, technology centres and producers) is essential to reduce investments in equipment and personnel.

**Process intensification** has not been mentioned in the presentation, but is also an interesting and promising development. It comprises a smart combination of processes, also for the production of food powder. Examples are co-spray drying, total filters, steam-cooking nozzles and straight-through agglomeration.

# An industrial perspective of bulk solids handling

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This presentation is based upon experiences from daily work and incidents in a factory. The production of this factory is characterized by:

1. Production of special soya protein,
2. Hygienic production,
3. The finished goods are two fine powders,
4. One product is a little cohesive,
5. The product can self-ignite,
6. Process industry with continuous production 24 hours a day all year round.

An important objective in a production facility is to optimise processes and get control over them, and some issues connected with that will be mentioned in the following.

## **Comminution**

Comminution is a very common unit operation in many powder handling productions. The operation is an intense contact between product and comminution tool, and the result will eventually cause wear. There is a real need for materials for the comminution tool, which can resist both erosive and abrasive wear. There already exist materials, which resist wear for an extensive period of time, but they are expensive.

The comminution process is not just breaking the particles into smaller particles, but it also creates functionality, which is connected with particle size, shape and surface.

Comminution is a process using much energy, and a lot of it is used to warm up the product instead of breaking it.

## **Sampling**

The importance of sampling cannot be overestimated. Poor sampling is a major reason for poor analysis. In order to meet its purpose the sample must first of all be representative, but before the sample can be analysed it must be divided correctly so that a very small sample will represent the whole lot. Such a lot can be as much as a shipload.

Especially in pneumatic conveying systems, the sampling is very difficult, but even in free falling systems it can be difficult.

Sampling is also important in the way that it can be decisive for price and even as evidence in a lawsuit.

## **On line measurement**

The objective of measurements is to monitor and give an overview of the process and quality parameters. In order to achieve this the measurement must be:

- Real time
- Continuous
- Operating automatically

The measurement must be performed under production conditions and the instruments operated by production operators. This requires robust equipment, which can resist dust, higher temperatures, vibrations and water splashes.

An automatic control system consists of units such as a measuring device, a regulator and a regulating device. In many cases the most difficult part is the measuring. If it is not possible to determine the parameters, which describe the product or the process it is not possible to control the process.

The advantages are not unique for bulk solids handling, but they are:

- Control over process,
- Control over quality,
- Consistent quality,
- Better yield, due to the possibility of operating closer to limits.

### **Other measurements**

There is a big need for different measurements to describe the properties of the bulk solids. These measurements are necessary in order to design process equipment properly.

It is possible to get information about these properties, but normally only from specialised laboratories. If these properties could be determined without too much effort in the factories, they would be used much more in daily design and production e.g. in design of silos and chutes.

Another type of measurement is relating to safety, which is especially concerned with dust explosions and self-ignition. The important part is to determine the conditions, which can cause dust explosion or self-ignition. It may seem quite easy to determine such conditions, but it is difficult to determine the behaviour under various production conditions, and especially to predict the unusual conditions, which often cause the accidents.

It would really help if such measurements were available in factories.

### **Storage**

Storage may seem to be just an intermediate period between production and delivery, but often there is more in it. The stored products may not be just chemical inactive, but they may undergo chemical changes e.g. due to oxygen from air, products moisture or fat content.

It is important that quality is preserved during storage. That means no chemical changes and no segregation.

Another important topic related to storage is the control of flow out of bins, which means feeding. There is nothing new in that, but it should be considered more carefully than it often is.

### **Conveying**

Conveying is an essential part of production, because it ties the different unit operations together. Often conveying works without any problems, but absolutely not always and there still are issues, which must be taken special care of.

Such issues are:

- Dust from conveying
- Conveying of sticky or fatty products
- Blockage in the conveying line
- Cleaning of the conveying line/avoiding carry over between different products
- No chemical changes composition e.g. oxidation
- No particle change, e.g. degradation or clumping

### **Drying**

Drying is part of many processes within the bulk handling industry. Drying is removing a solvent, most often water, but the process also has an influence on the product and its functionality e.g. colour and nutritive value.

Drying can be performed in various ways, but almost all of them require a lot of energy. There is a big need for new drying processes, which have lower energy consumption and give the wanted quality. Moreover, the processes must also have high capacities, preferably work continuously and with a full control system to control both processes and quality.

Drying will most often take place by the use of big quantities of air, which may spread an unpleasant odour in the surroundings. Therefore there is a need for drying processes, which will not cause environmental problems.

### **Safety**

Safety includes more issues like dust explosion, self-ignition, health risk for both staff and consumers.

The possible risks are specific for each different product, and they can behave very differently. This means that one has to look closely into the characteristics of each different powder, and that means not just different regarding chemical composition but also regarding particle size, surface etc.

The EC directive 94/9/EC requires that all companies must make a risk analysis before July 2003. The result of the risk analysis is a division of the plant into zones with varying risk of dust explosion.

A big number of powder handling companies have had self-ignition, where the temperature in the products under certain circumstances slowly rises until the product suddenly ignites. A fire is nasty, but it can even become worse because it can start a dust explosion. Not all products can self ignite but moisture content and particle size and surface are parameters of importance. If a product can self ignite, there will normally be three conditions, which have to be fulfilled in order to start the fire.

These are:

1. A high or higher temperature,
2. A thick layer of product, which functions as insulation and stores the heat in the product,
3. Sufficient time for the exothermal reaction in the product to start and produce sufficient heat for the product to reach the ignition temperature.

This also means that the self-ignition can be avoided by removing one or preferably two of those conditions, being either of them.

If there is a risk of self-ignition one wants to detect it before it actually ignites. This can be difficult, because the temperature may increase to ignition in a small spot in the middle of the product layer. Temperature and smoke detection does not work very well, because the temperature increase will only be small a short distance away from the place of the exothermal reaction, and there may not be any smoke before the fire really starts. Carbon monoxide detectors have in some cases been used successfully.

Fine dust can threaten the health of production staff, which is well known. Anyhow it is still an important issue and should be seriously taken care of.

During recent years the demand for safe food and feed has increased. More countries already require a certification for both food and feed in order to protect the consumers, who can be people or animals. This certification could be ISO 9000, but properly a system like HACCP would be more convenient because this is intended for revelation of critical control points in the production, which can threaten the food or feed safety. Until now a HACCP-system can only be certified according to the Danish standard DS 3027, but in a couple of years an international standard under the name ISO 22000 should exist.

### **Summary**

Some experiences from the daily work shows that there is a lack of knowledge and the existing knowledge is not used very much. Many chemical, mechanical or process engineers are not taught much bulk solids handling if any.

It is also disappointing to see how little some suppliers know of basic bulk solids handling, and unfortunately not all consultants have sufficient knowledge.

Many analyses are complicated, which may be the reason why engineering is too often done by general rules. When a solution worked in one case it will often be used in other case, whether it is the right one or not.

A wish from industry is more development and bringing the knowledge into more general use.

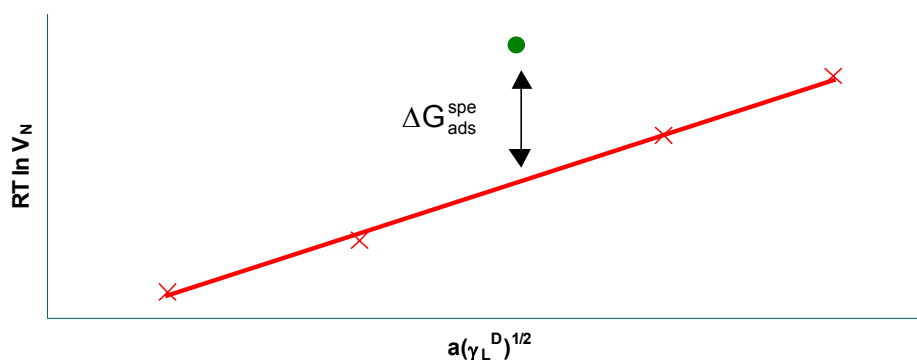
## Use of inverse gas chromatography in food powders

*Paru Sellappan and Ph. Rousset*

*Nestlé Research Center, Vers-chez-les-Blanc, CH-1000 Lausanne 26, Switzerland*

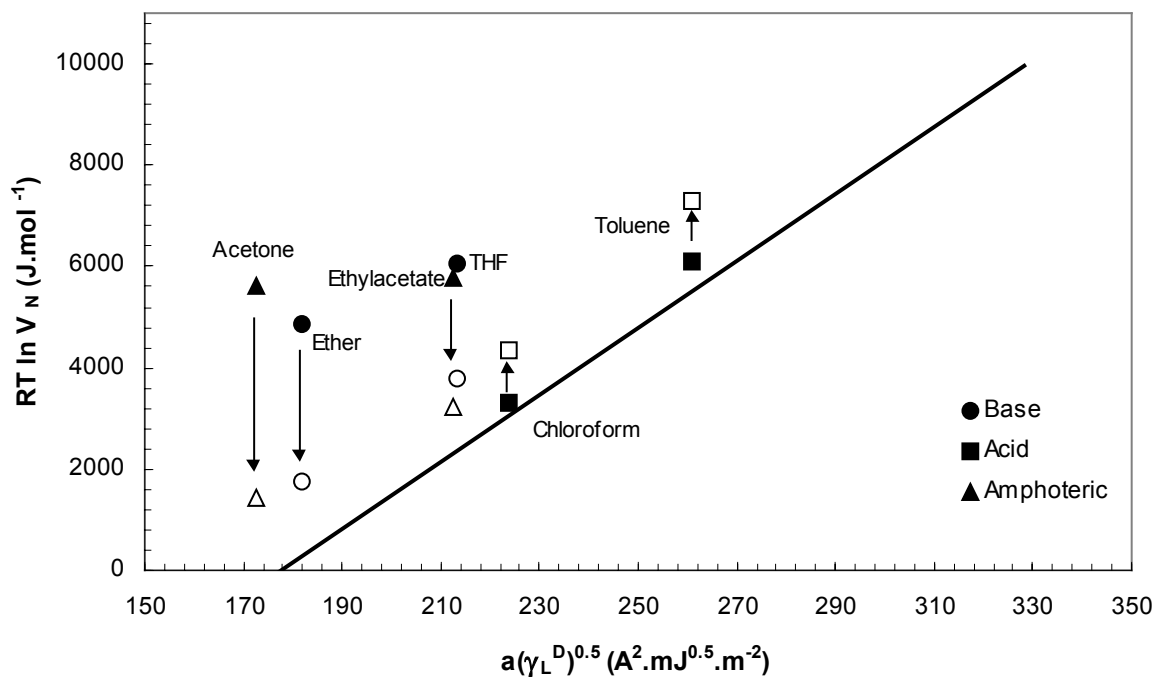
Food powders are complex non-homogeneous systems for which characterisation of surface energy is very challenging. Currently used techniques to determine surface energetics such as contact angle and calorimetric methods have their advantages and disadvantages in terms of methodology and complexity which may affect the usefulness of their measurement (Buckton, 1990). Inverse gas chromatography (IGC) is a useful complementary tool for gathering information on the chemical and thermodynamic state of powder surfaces. A large amount of literature already exists in the use of IGC (Nardin et al., 1990; Lavielle and Schultz, 1991) in characterising inorganic particulate systems, however there are only a handful of studies in pharmaceutical and food powder surfaces (Smith et al., 1981; Demertzis et al., 1989; Ticehurst et al., 1994). Unlike conventional gas adsorption techniques, IGC measures adsorption down to extremely low gas or vapour concentrations, corresponding to nearly zero surface coverage (Panzer and Schreiber, 1992). This is likely to be important as the first adsorbing layer controls processes such as surface wetting, with further multilayer coverage being controlled by condensation interactions (Brunauer et al., 1938).

The IGC principal is based on the dependence of a retention volume of a volatile substance on its interaction energy with the stationary phase. In IGC, the stationary phase is the solid adsorbent to be characterised while probe molecules of known physico-chemical properties are used as volatiles. The probes influence the nature of the studied interactions; dispersion and specific interactions. Dispersion interactions are studied using *n*-alkanes (or non-polar adsorbates). Due to their structure, the *n*-alkanes have no dipole moment and no component which undergoes specific interaction. Therefore these specifically determine the physical forces. In the case of polar adsorbates, a separation of dispersion and non-dispersion forces is necessary from the total interaction between the solid and the probe molecule if the size of the specific interaction is to be evaluated. These interactions can be evaluated in a variety of ways (Papirer, 1983; Sawyer et al., 1968; Fowkes, 1964). A frequently used method is through the thermodynamic consideration defined by Fowkes (1964), which leads to a relationship between  $RT \ln V_N$  vs  $a(\gamma_L^D)^{1/2}$ .  $R$  is the gas constant;  $T$ , the temperature;  $a$ , the area of the adsorbed molecule on the powder surface and  $\gamma_L^D$ , the dispersion component of the liquid surface energy. For a series of apolar probes, this plot yields a straight line, from the slope of which the dispersion component of the solid surface energy,  $\gamma_s^D$  can be calculated (shown in Figure 1). The surface free energy of adsorption,  $\Delta G_{\text{ads}}^{\text{spe}}$  is represented by the vertical distance between the alkane reference line and the polar probe of interest. The difficulty of the last method is that the area,  $a$ , occupied by the adsorbed molecules may raise problems, given the possibility of different configurations at the adsorbate-adsorbent contact (Panzer and Schreiber, 1992).



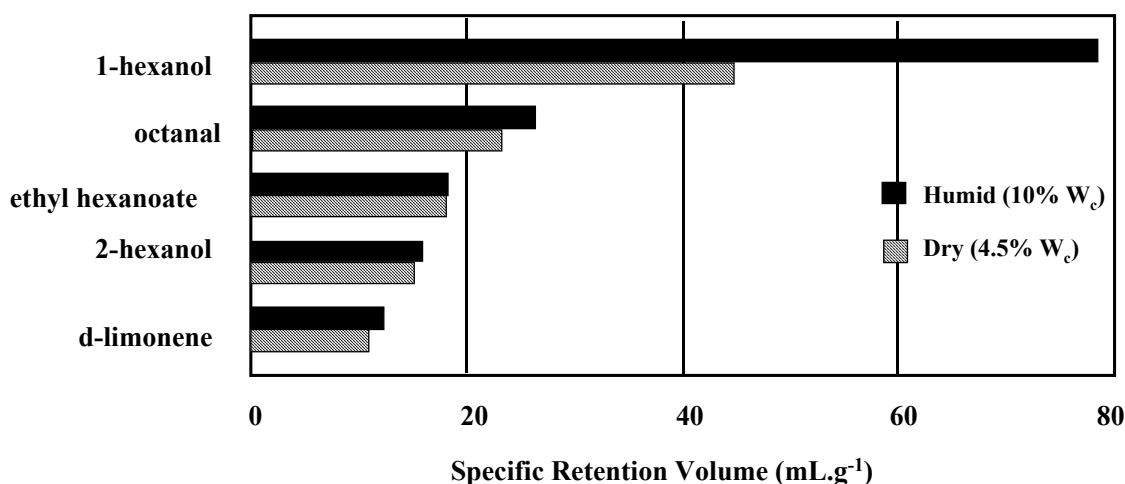
**Figure 1:** Determination of dispersion and specific interactions

The surface energetics of a solid plays a major role in influencing the interaction between another solid or a liquid/vapour. There are many examples of such processes, including powder mixing and flow, tableting, wettability and aroma interaction. It can also be used to detect changes in manufacturing conditions of these solids. In Rousset et al. (2002), the influence of lecithin on surface properties of sucrose was studied using IGC (Figure 2). The figure indicates that lecithin greatly decreased the acidic (acceptor) character of sucrose originating from the hydroxyl groups of the molecule. It also slightly changed its basic characteristics. The decrease in the acidic character may be explained by the apolar chain of the phospholipids in lecithin. The increase in the basic character may be due to some phospholipids like phosphatidylethanolamine. Overall, adsorbed lecithin increases the lipophilicity of sugar particles, thus inducing an increase in the fluidity of fat based suspensions like chocolate.



**Figure 2:** Effect of adsorbed lecithin on sucrose surface (Rousset et al., 2002)

IGC was used to compare the retention of aroma compounds on corn starch under dry and humid conditions (4.5% and 10% water content respectively in starch) in Boutboul et al. (2000). The results, highlighted in Figure 3, indicate that the specific retention volume is higher under humid conditions especially for 1-hexanol and octanal. These compounds adsorb strongly onto starch through the formation of hydrogen bonds. The authors discussed that under IGC humid conditions, all the water molecules of the carrier gas were not fixed to the matrix. Thus, free water could partially dissolve the hydrophilic molecules which could then penetrate the matrix. They also proposed several binding mechanisms: the adsorption of volatiles on the free -OH sites of starch, the diffusion of the molecules through the matrix facilitated by the free water and also water may separate amylose chains through plasticising effect and liberate new fixation sites of amylose for molecules containing polar functions. In this case, the authors concluded, the adsorption phenomenon is increased by the presence of water.



**Figure 3:** Specific interaction of aroma compounds on starch (adapted from Boutboul et al. 2000).

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# Swedish Network in Powder Technology

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## Background

The market for food powders is increasing in the food industry due to the increasing use of special ingredients but also due to the increasing consumption of powder mixtures, such as spice mixtures and coffee mixtures. Industrial production of powders involves either a drying process or blending of different powder ingredients.

The Swedish food industry has identified a need for increasing their knowledge about:

- Methods for characterising powder properties and behaviour
- Production, handling and storage of powders
- Agglomeration of powders
- Dissolution and dispersion of powders in liquids
- Sterilisation of powders
- Caking and clump formation

As a result of a request from the Swedish food industry, SIK started a powder network in 1999 to locate existing competences and on-going research projects in food powders. The network is currently up and running, having participants also from companies supplying equipment and from the non-food sector.

## Objectives and organization of the network

The objective of the network is to:

- *promote a forum aiming to increase knowledge in the area of food powders*
- *exchange knowledge and practical experience between participants*
- *identify areas that require further research & development*
- *discuss, outline and start research projects*

The network is driven in such a way that allows the participants to decide the main subject to be discussed in the meetings. Four meetings are planned per year and they take place in each of the participant companies, giving the opportunity to the other participants to visit and become familiar with new processes and measurement systems.

## Participating companies

The following Swedish and Danish companies are or have been involved in powder network:

<b>Food Companies</b>	<b>Type of product</b>
Arla I&M	Dairy powders
Santa Maria AB	Spice mixtures
Danisco Sugar AB	Sugar products
Källbergs Industri AB	Powder egg powders
Campbell Soup Sweden AB	Powder soups
<b>Equipment suppliers</b>	
APV systems	Drying and agglomeration equipment
ABB Research	Control, sensors
VEBE Teknik AB	Powder handling equipment
Moberg Processkontroll AB	Process control
<b>Non-food companies</b>	
Höganäs AB	Iron powder
Swedish Match	Tobacco powder

## Activities

The following external invited lecturers have participated in the powder network:

<b>Area</b>	<b>Lecturer</b>	<b>Institution</b>
Storage of powders	Prof. Yrjö Roos	UCC Cork, Ireland
Characterisation of Powders	Dr. Sivert Ose	Postec, Norway
Sampling of powders	Prof. Svarovsky	UK
Acoustic chemometry	Prof. Kim Esbensen	Teltec, Norway
Surface Chemistry	Dr. Anna Fureby	YTH, Sweden
Agglomeration	Dr. Stefan Hoge Kamp	Karlsruhe, Germany
Spray Drying	Dr. Fabrice Ducept	ENSIA, France

## Day 2 Presentations

These presentations by the area leaders and the output from the subsequent brainstorming has been incorporated into the **strategic document** for research on food powders

# List of Participants

## Project Co-ordinators

1. John Fitzpatrick, Department of Process Engineering, University College, Cork, Ireland
2. Lilia Ahrné, SIK - The Swedish Institute for Food and Biotechnology, Gothenburg, Sweden

## Area Leaders

3. Peter Lillford (formely of Unilever), York, England
4. Prof. Karl Sommer, Technical University Munich, Weinstephan, Germany
5. Prof. Koen Dewettinck, University of Ghent, Ghent, Belgium
6. Richard Farnish, Wolfson Centre for Bulk Solids Handling, London, England
7. Sivert Ose, POSTEC, Porsgrunn, Norway

## Workshop Presenters

8. Stephan Palzer, Nestlé, Switzerland
9. Gabriele Meesters, DSM Food Specialities, The Netherlands
10. Elisabeth Pallai, University of Kaposvar, Kaposvar, Hungary
11. Prof. Janos Gyenis, University of Kaposvar, Kaposvar, Hungary
12. Prof. Denis Poncelet, ENITIAA de Nantes, Nantes, France
13. Ruud E.M. Verdurmen, Senior Project Manager Powder Technology, NIZO, Ede, The Netherlands
14. Carl Hansen, Hamlet Protein, Horsens, Denmark
15. Paru Sellappan, Nestlé Research Center, Switzerland
16. Prof. Anne -Marie Hermansson, SIK, Gothenburg, Sweden
17. Prof. Thomas Ohlsson, SIK, Sweden

## Workshop Participants

18. Joel Abecassis, Cereals research lab of INRA, Montpellier, France.
19. Håkan Ahlmen, Ahrla Foods, Stockholm, Sweden
20. Prof. Zeki Berk, Technion, Haifa, Israel

21. Henri Berthiaux , ENSTIMAC, Ecole Des Mines, Albi, France
22. Amparo Chiralt, University of Valencia, Valencia, Spain
23. M. Demeersman, Dera Food Technology NV, Belgium
24. Frédéric Depypere, Ghent University, Belgium
25. F. Devos, Belgomilk, Belgium
26. Prof. Elisabeth Dumoulin, ENSIA, Massy, France
27. Klaus Eichler, Glatt International, Germany
28. Laurence Galet, ENSTIMAC, Ecole Des Mines, Albi, France
29. P. Goossens, Beldem S.A., Belgium
30. Prof. Pierre Guigon, Universite de Technologie, Compiègne, France.
31. Nick Hedges, Unilever, UK
32. Stephan Hogeckamp, University of Karlsruhe, Karlsruhe, Germany
33. Øystein Høstmark, SSF, Norway
34. Prof. Ilari, ENITIAA de Nantes, Nantes, France
35. Volker Kehlenbeck, Technical University Munich, Weinstephan, Germany
36. Prof. Andrzej Kmiec, Wroclaw Univ. of Technology, Wroclaw, Poland.
37. John Kougoulis, Technical University of Crete, Crete, Greece
38. Mr. Kristof, Alfoldi Gabonaipari Co. Ltd., Hungary
39. Prof. Harris Lazarides, Aristotle University of Thessaloniki, Thessaloniki, Greece
40. G. Maesmans, Tate & Lyle, Amylum Belgium NV, Belgium
41. A. Nezzal, Tate & Lyle, Amylum Belgium NV, Belgium
42. Prof. Jan Pieters, Ghent University, Belgium
43. Massimo Poletto, University of Salerno, Italy
44. Frederik Ronsse, Ghent University, Belgium
45. Ernest Teunou, ENITIAA de Nantes, Nantes, France
46. Prof. Jean Vasseur, ENSIA, Massy, France
47. N. Vekemans, Beldem S.A., Belgium