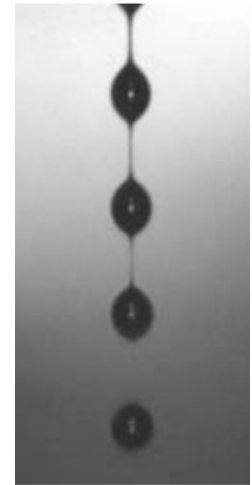
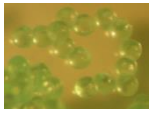


Print-drying: mild processing conditions & high quality powders

Joris Salari, Nicole Papen-Botterhuis, Robin Koldeweij, Pieter Debrauwer

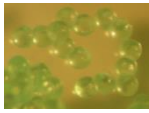




Overview

- › Spray-drying
- › Print-drying concept
- › High viscosity inkjet (HVJ) printing:
 - Rayleigh breakup
 - HVJ printing technology
 - Multi-nozzle printing
- › Drying:
 1. Retrofit in existing spray-dryers
 2. Novel drying concept
- › Examples:
 - › Dairy (Enthalpy, EU/FP7)
 - › Coffee
 - › Egg
 - › Calcium citrate
 - › PPS





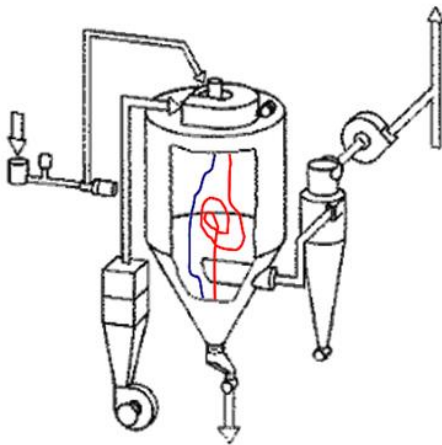
slide 2

Spray-drying

Spray-drying is one of the most commonly used industrial processes for:

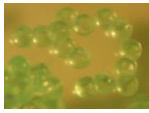
- 1) Drying liquid process streams &
- 2) Micro-encapsulation

Applications: food, feed, household & cleaning products, pharmaceutical-
and chemical industry.



Spray-drying; turbulent drying.



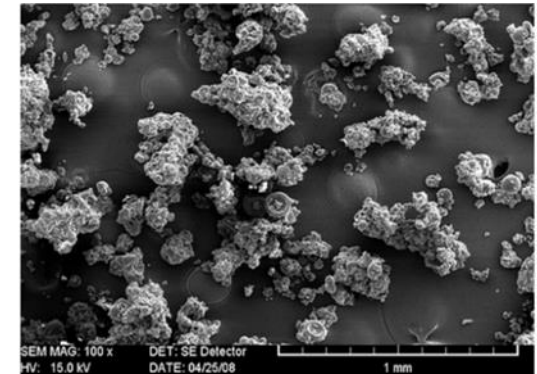
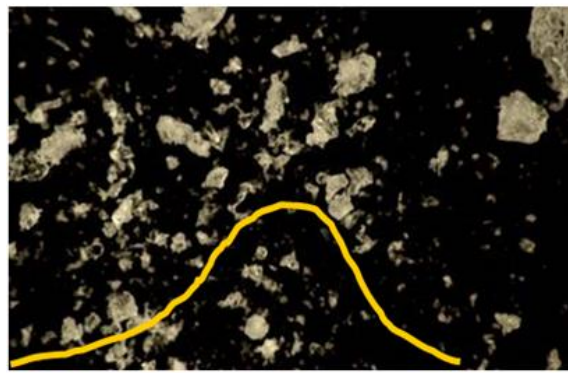
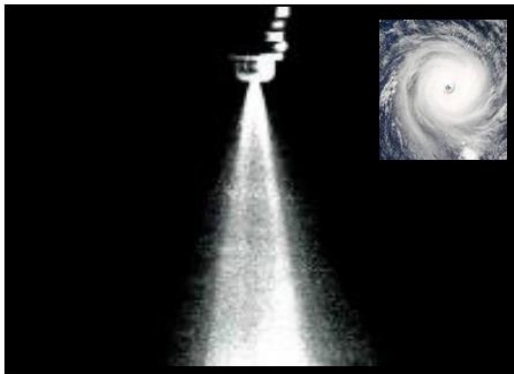


slide 3

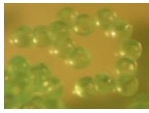
Spray-drying

Disadvantages spray-drying:

- › Broad size distribution of resulting particles.
- › “Fines” are produced, resulting in product loss, downtime, risk of dust explosions and health risk for consumer and production workers.
- › Drying protocol often based on the largest particles.
- › Generally, spray drying is *energy intensive & inefficient*.



→ Need for improved atomization/drying process



Print-drying concept: uniformity

Uniform *powder* properties:

- Narrow particle size distribution,
- or at least the absence of fines.

→ Energy-efficient processing (≈ 50 wt% w.r.t. spray-drying):

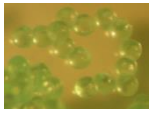
- Possibility to use residual heat,
- Matching thermal load to droplet size,

→ Resource-efficient processing:

- No fines and therefore less product loss,
- Matching thermal load reduces degradation/evaporation of active.

→ High quality/added value products:

- Improved powder handling,
- Enhanced stability & controlled release properties.



slide 5

Print-drying concept

High viscosity
printing head
(inkjet type)



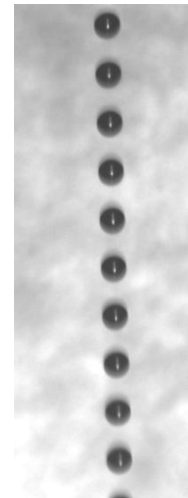
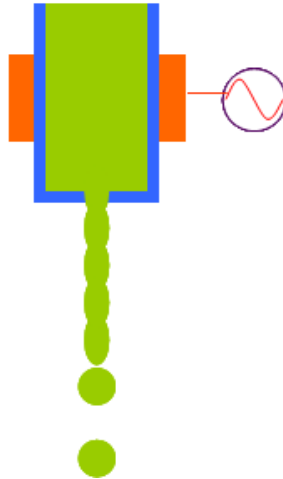
Stimulated
Rayleigh
breakup



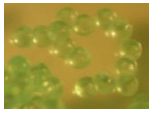
Generate
monodisperse
droplets



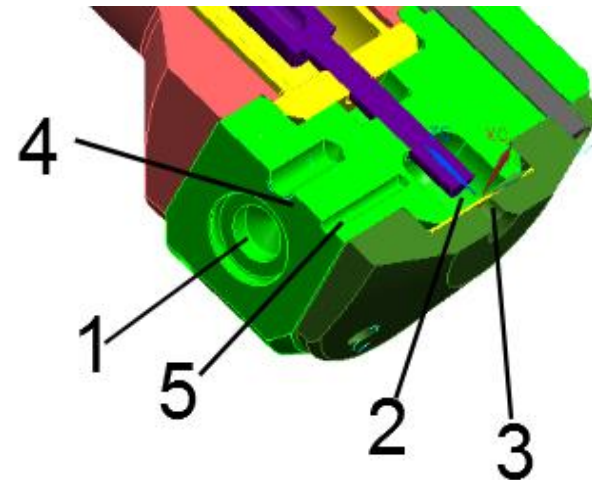
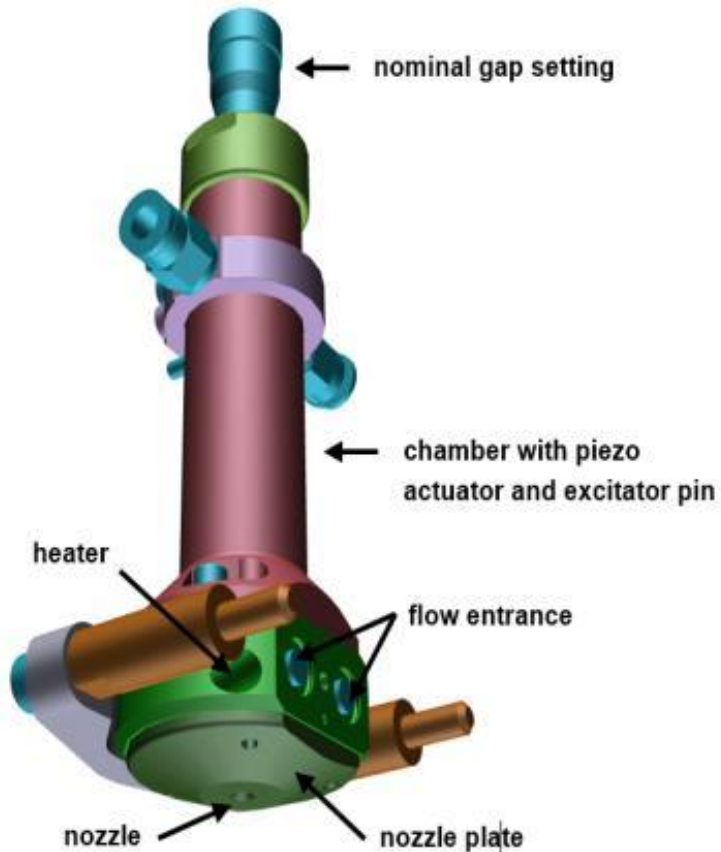
Droplets
are dried in
a tower



- › Monodisperse droplet processing & particle formation allows resource- and energy efficient processing & yields high quality products.

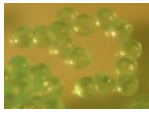


'High viscosity inkjet' printing:



Print-nozzle:

1. Liquid inlet
2. Liquid chamber
3. Nozzle
4. Insert for heating element
5. Positioning element



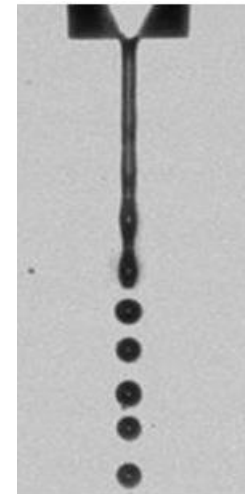
'High viscosity inkjet' printing:

Rayleigh breakup: Breakup of a liquid jet due to Rayleigh instability.

Driven by minimization of surface area.

Parameters influencing breakup:

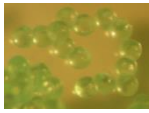
- surface tension, γ
- viscosity, η
- density, ρ
- actuation.



Applications:

- Inkjet printing
- 3D/additive manufacturing



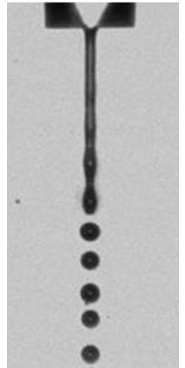


'High viscosity inkjet' printing:

Droplet velocity:

The velocity of the droplet (v_d) is the flow rate divided by the nozzle area. Due to surface tension (σ), the jet gets thinner after being fed through the nozzle. This leads to a change in velocity and can be calculated with the following equation:

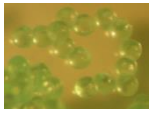
$$v_d^2 = 2v_{nozzle}^2 - 2 \frac{\sigma}{\rho D_{nozzle}} \sqrt{\frac{v_d}{v_{nozzle}}}$$



Droplet diameter:

The volume of printed drops (V_d) is determined by the total flow (Φ) and the piezo frequency (f) and can be calculated as follows:

$$V_d = \frac{\phi}{f} \quad d_d = \left(\frac{6V_d}{\pi} \right)^{1/3}$$



'High viscosity inkjet' printing:

Multi-nozzle printing: upscaling strategy

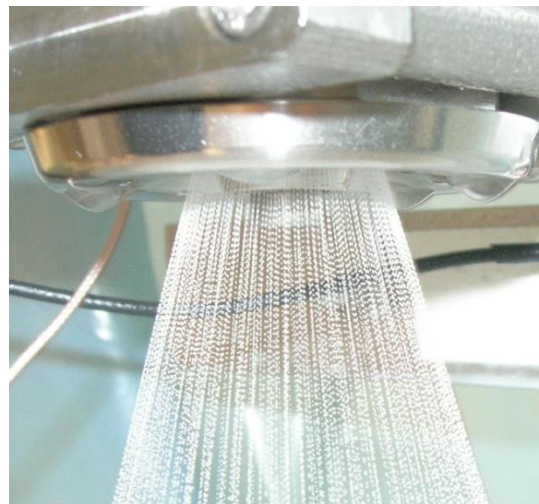
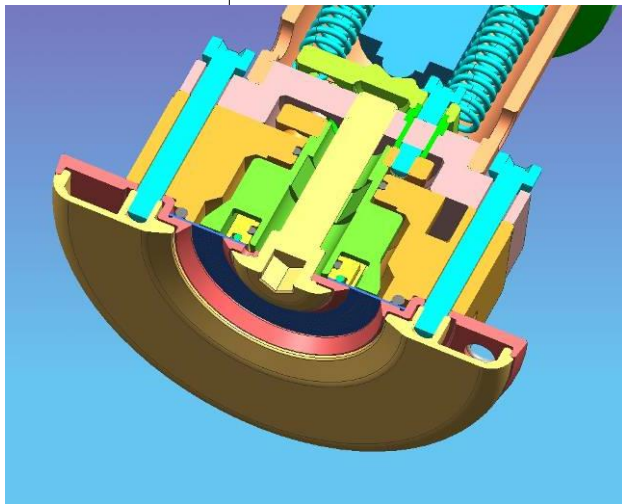
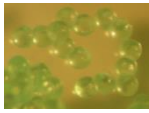


Table 1. Specifications of spray-atomization and single- & multi-nozzle printing

Characteristics	Atomization	Single nozzle	Multi-nozzle
Uniformity:	Non-uniform	Uniform	Uniform
Max. viscosity:	300 mPas	500 mPas	500 mPas
Particle size:	50 – 250 μm	25 – 1250 μm	25 – 250 μm
Nozzles:	1	1	500
Scale:	Max. 100 000 kg/h	~ 0.2 L/h	~100 L/h



Drying:

Conventional spray-drying

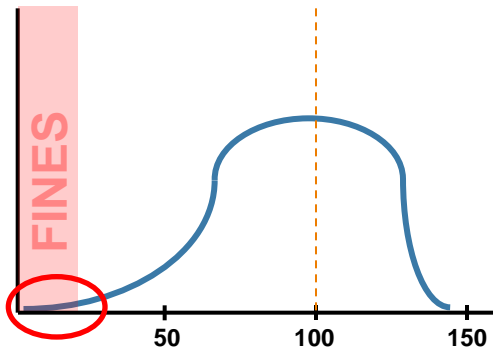
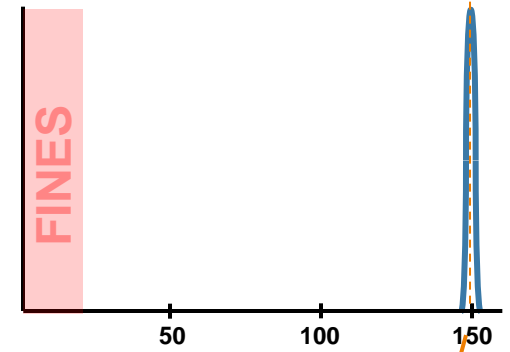
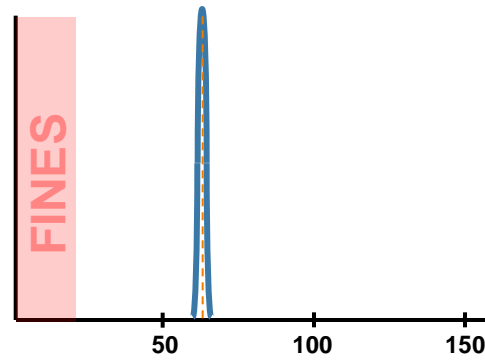
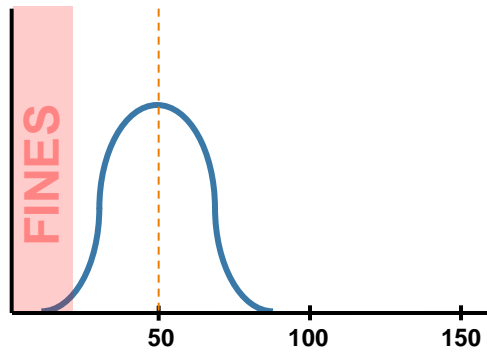
1) *Retrofit* printing in existing spray dryers.

2) *Print-drying*: controlled printing & drying conditions.

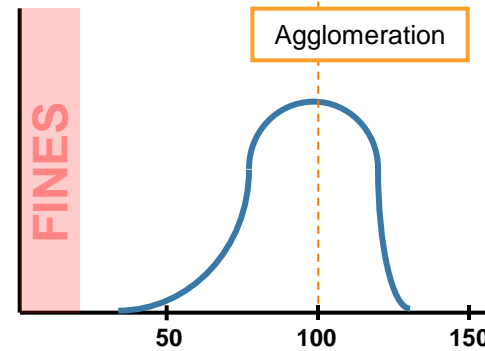
Droplets:

Drying

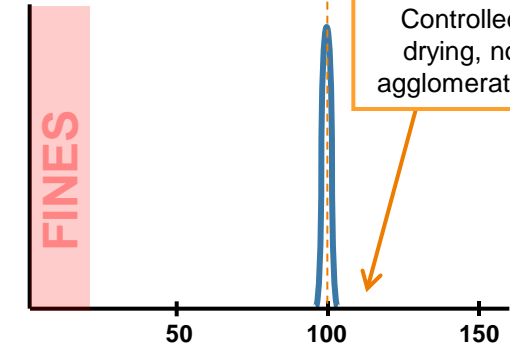
Powders:



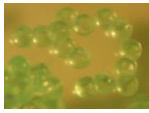
Span: 1,3



Span: 0,8 & No fines



Span: 0,3 & No fines

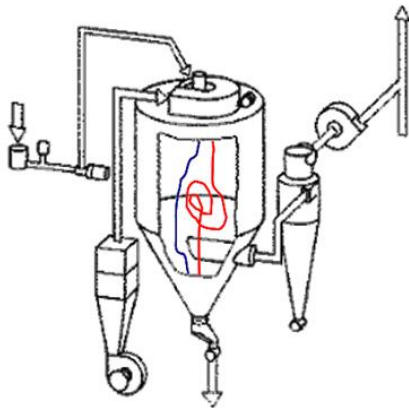


slide 11

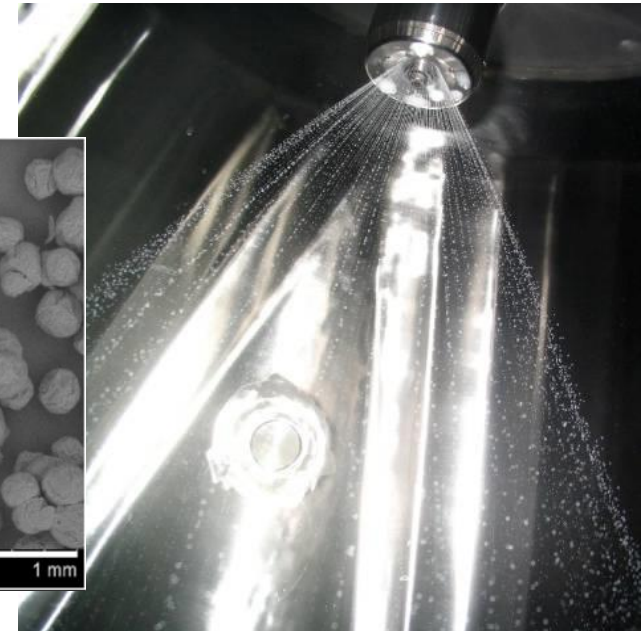
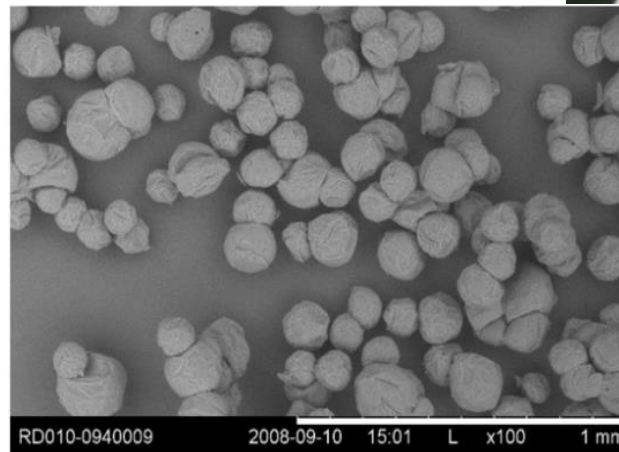
Retrofit drying

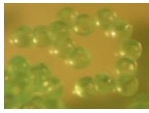
1) Retrofit printing technology in existing spray-dryers

- Uniform droplet printing
- Turbulent drying (coalescence & agglomeration can occur),
→ absence of fines



Spray-drying; turbulent drying.



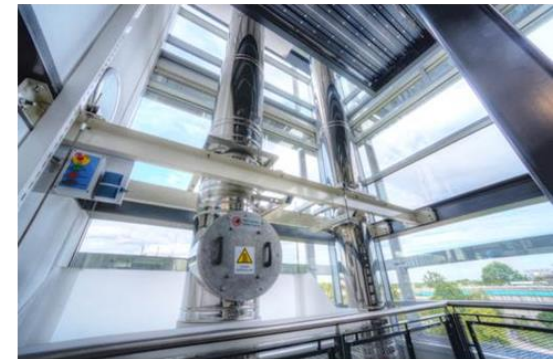
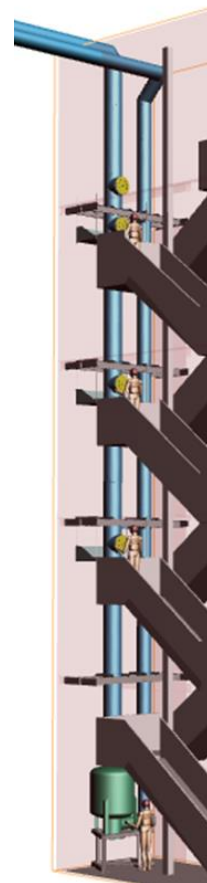
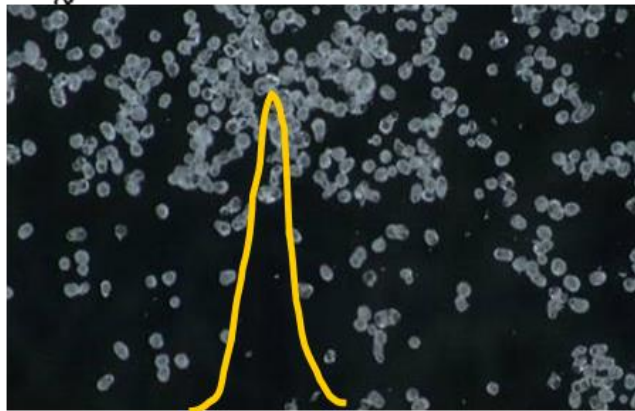
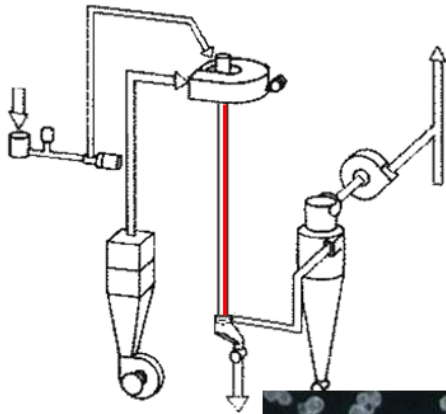


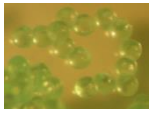
slide 12

Innovative drying

2) Novel drying concept: laminar flow drying tower

- Uniform droplet printing
- Laminar drying



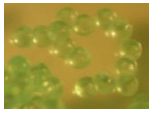


Examples/experimental results

(Food) materials:

- Dairy/milk formulae (EU/FP7)
- Maltodextrin
- Protein formulations
- Whole egg & egg white
- Coffee
- Calcium citrate suspensions
- Enzymes (NL/TKI Afrofood)
- Flavour & fragrances (NL/TKI Afrofood)





EU/FP7 project: ENTHALPY

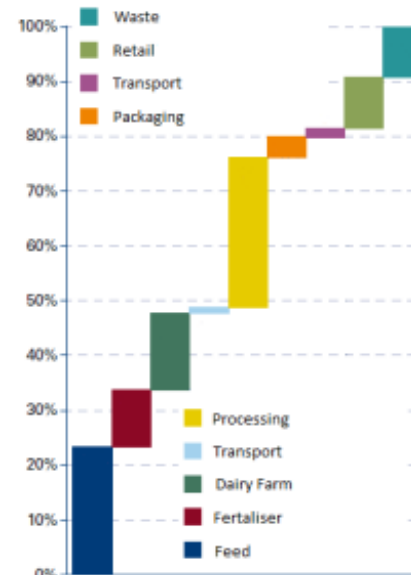
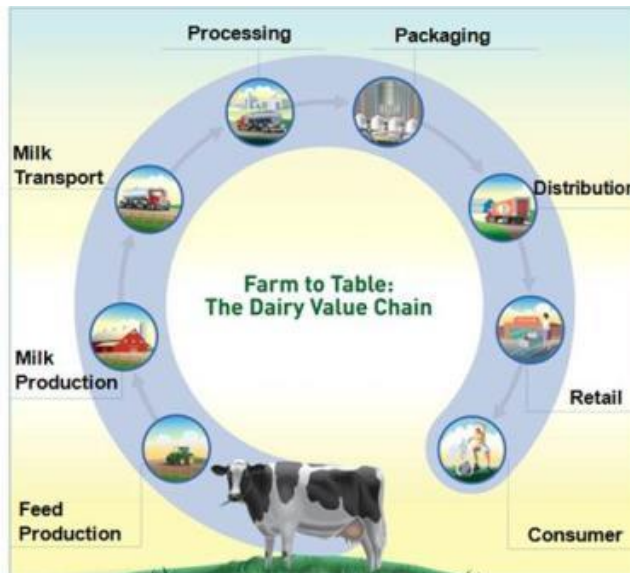


Energizing the drying process to save energy and water, realising process efficiency in the dairy chain

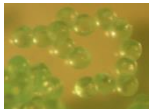
Dairy industry is responsible for **8%** of total energy use in EU.

Processing is the main contributor in the dairy chain.

Within “ENTHALPY” energy savings of 63% and water savings of 18% are expected



Source: Environmental improvements potentials of meat and dairy products, EUR 23491 EN, 2008

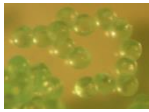


ENTHALPY Consortium



Advisory board:

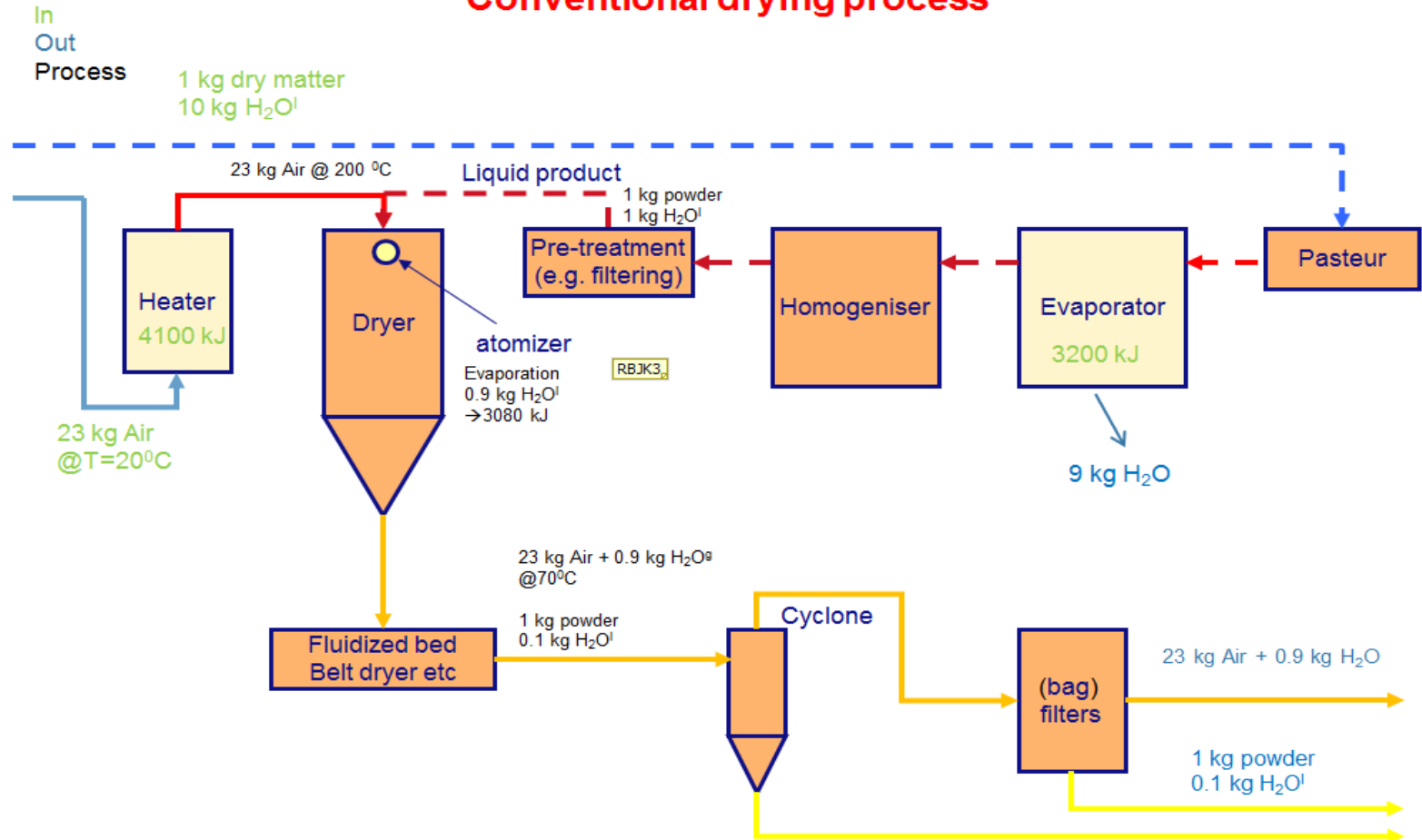


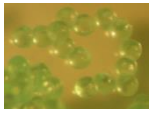


ENTHALPY Processing



Conventional drying process





ENTHALPY Key technologies



- **Homogenous droplet sizes**
- **Identical residence time**
- **Elimination of fines**

- **Reduction of water use**
- **Reduction of chemicals**

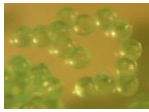
- **Homogenous heating**
- **Less protein denaturation**
- **Solar thermal energy**

- **Water recovery**
- **Heat recovery**

- **Process & product control**
- **Cleaning when needed**

- Mono disperse atomising
- Enzymatic cleaning
- Pre-treatment
- Membrane technology
- Inline monitoring

- Process system engineering
- Modelling
- Life Cycle Analysis
- Food quality

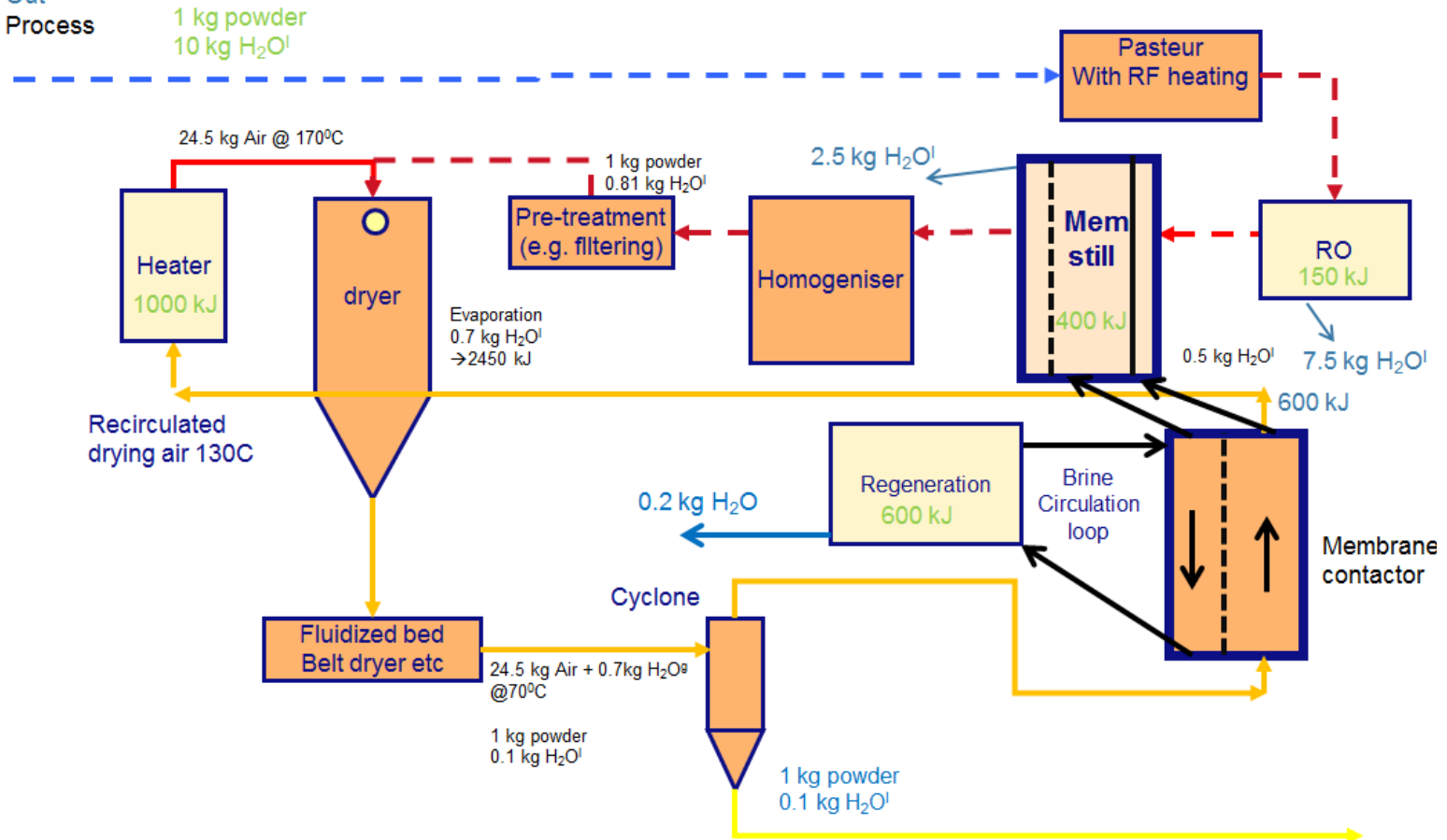


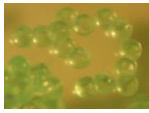
ENTHALPY Processing



Novel drying process

In
Out
Process





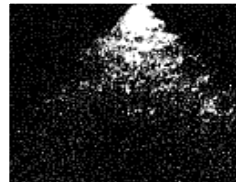
slide 19

ENTHALPY Results

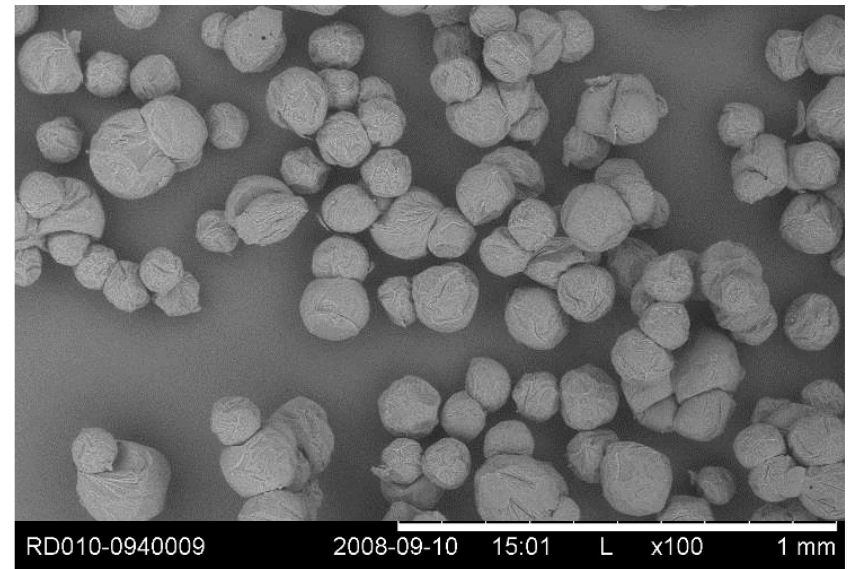
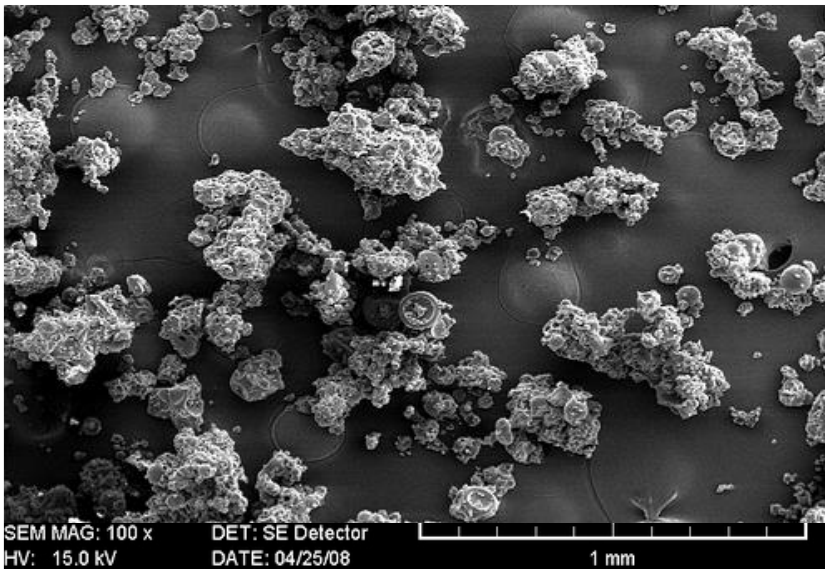


Retrofit multi-nozzle print-drying of dairy.

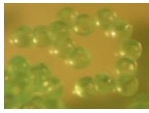
Conventional
spraying



Droplet printing



Uniform powder properties, higher bulk density & excellent flowability.

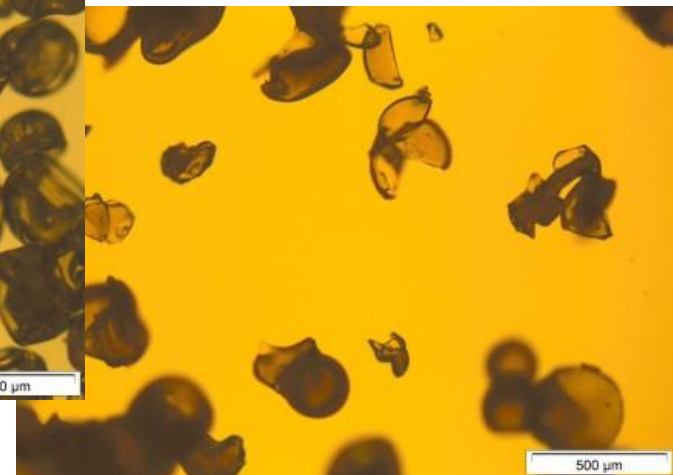
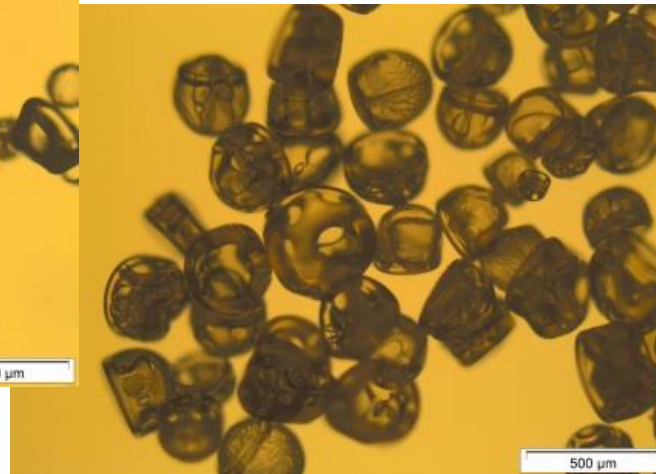
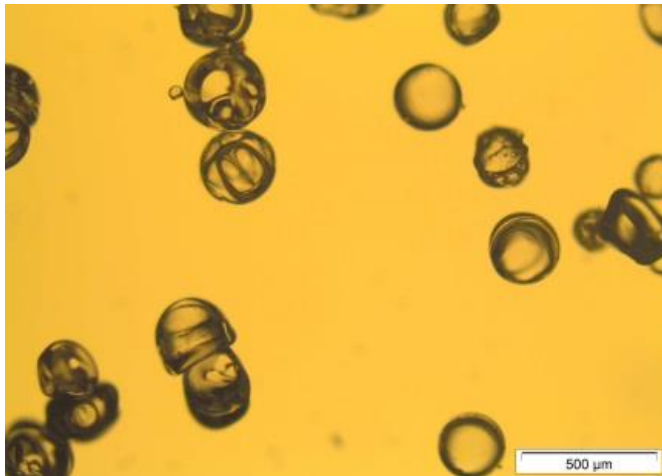
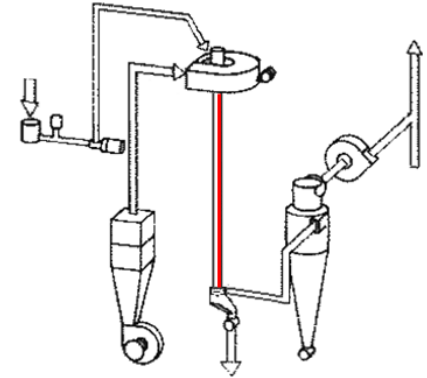


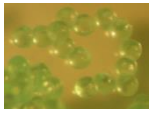
slide 20

Experimental results

Innovative drying concept: drying tower

- Maltodextrin
- Milk formulae



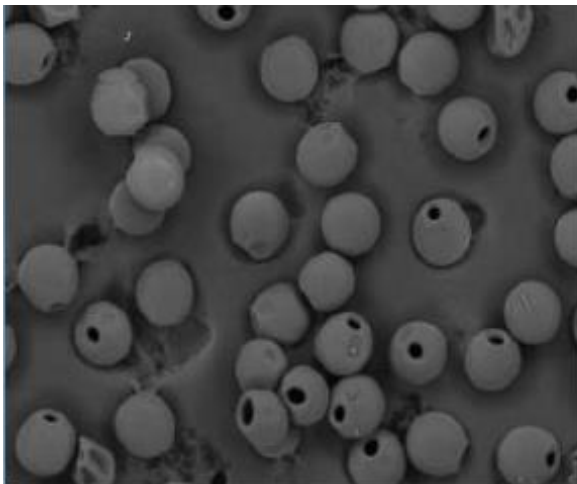
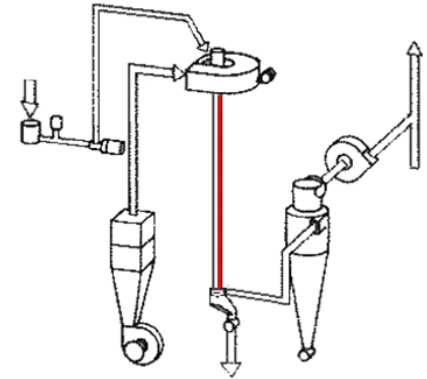


slide 21

Experimental results

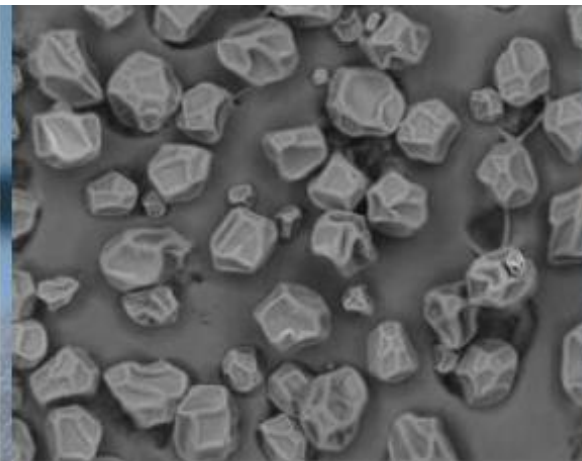
Innovative drying concept: drying tower

- Milk protein formulations



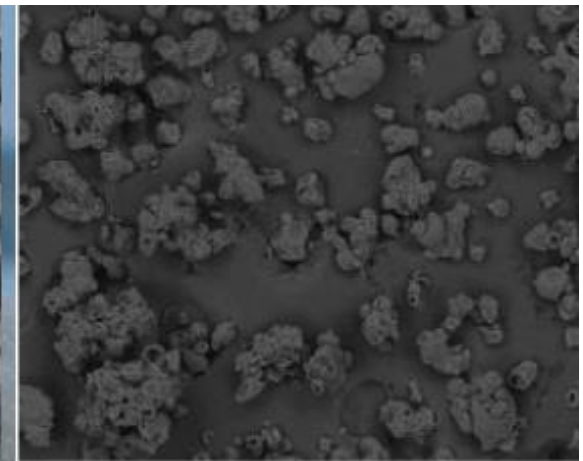
600µm

Milk protein concentrate
produced at 77°C



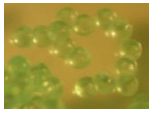
600µm

Milk protein concentrate
produced at 178°C



600µm

Commercial milk protein
concentrate

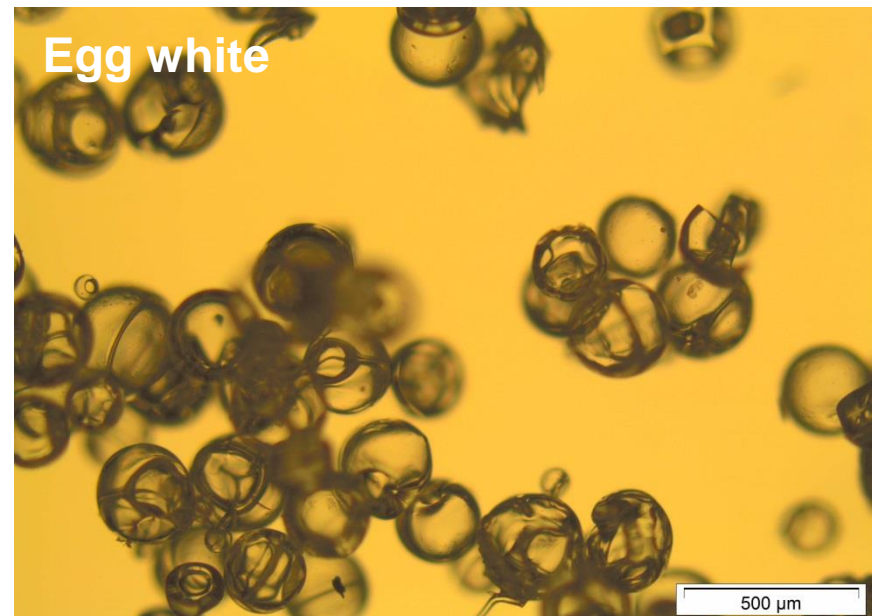
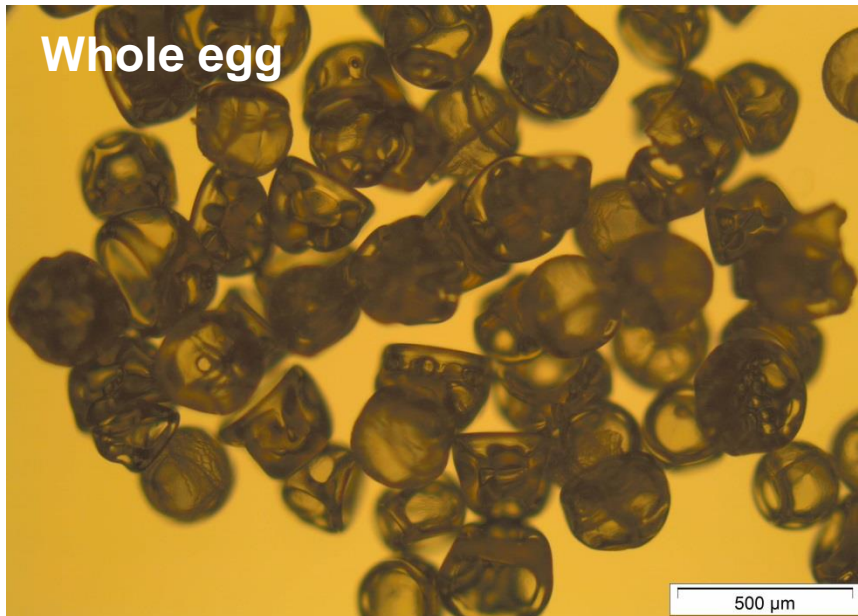
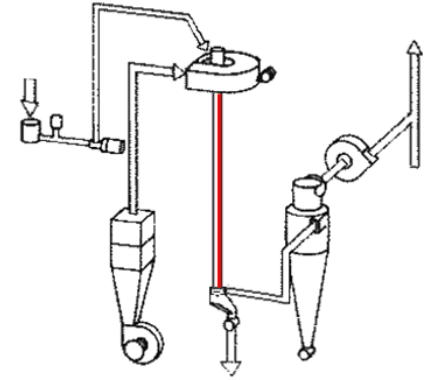


slide 22

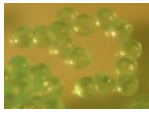
Experimental results

Innovative drying concept: drying tower

- Whole egg &
- Egg white.



Good size & shape uniformity.

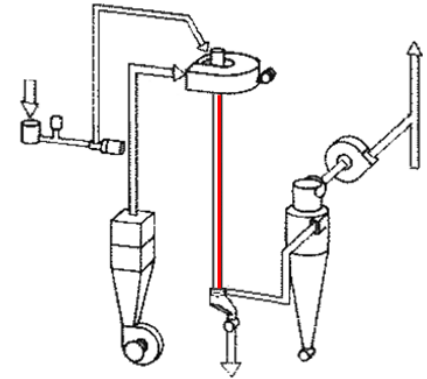


slide 23

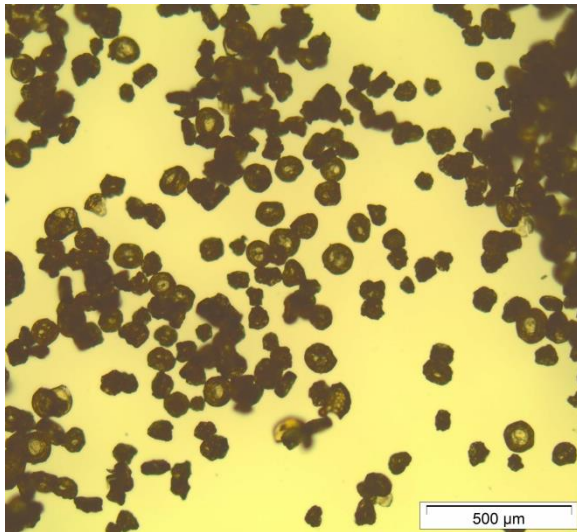
Experimental results

Innovative drying concept: drying tower

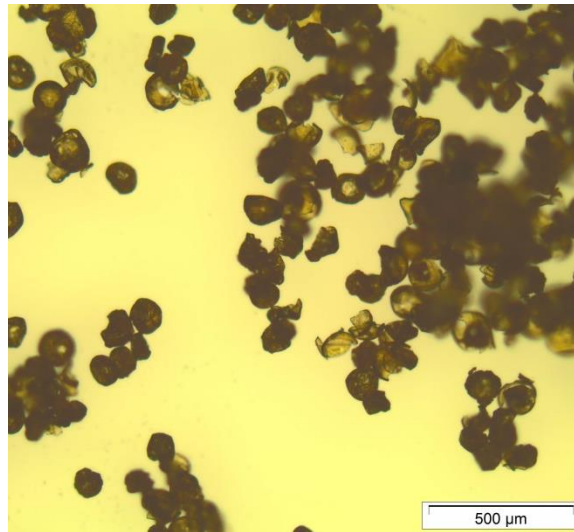
- Instant coffee



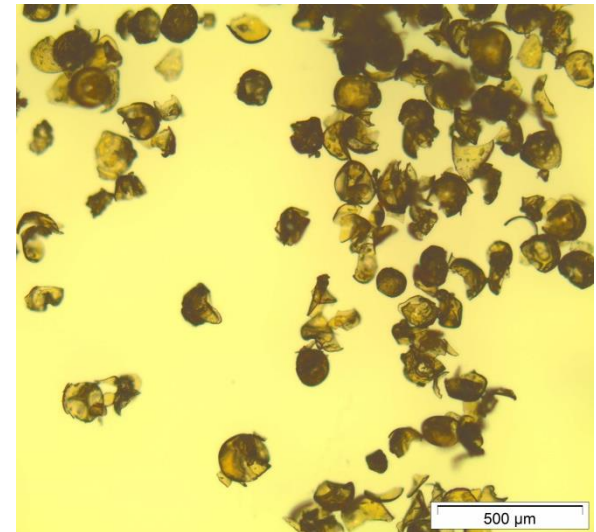
$T_{\text{outlet}} = 95 \text{ } ^\circ\text{C}$



$T_{\text{outlet}} = 110 \text{ } ^\circ\text{C}$

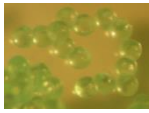


$T_{\text{outlet}} = 130 \text{ } ^\circ\text{C}$



Good size and shape
monodispersity

increasing fragmentation

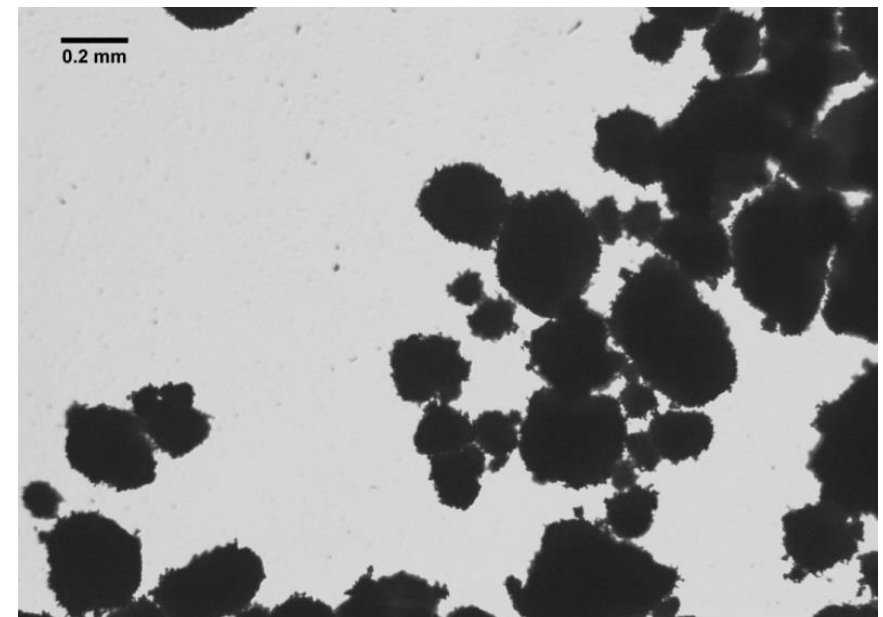
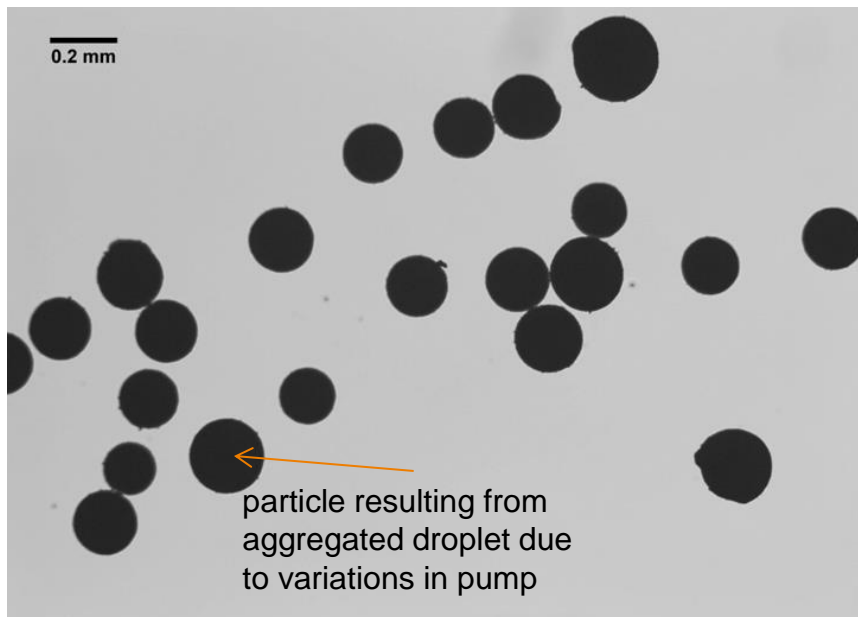
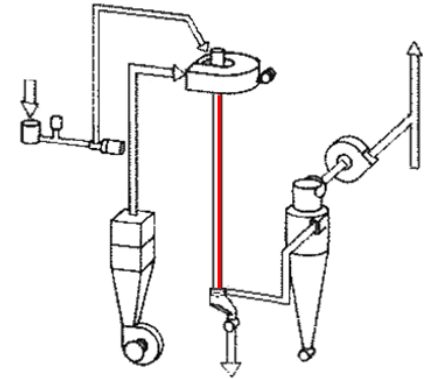


slide 24

Experimental results

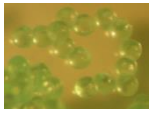
Innovative drying concept: drying tower

- Calcium citrate particle suspensions



Sample printed from 35 w% suspension.

Commercially available sample



Experimental results

Retrofit multi-nozzle print-drying

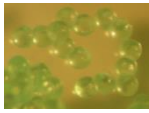
- Enzymes (DuPont)
- Flavour & fragrances (Givaudan)

Aim: Efficient production of high quality powders.



Within the project there is still the possibility to participate.

Let me know if you are interested!



Conclusions

High viscosity inkjet printing is an efficient way for producing monodisperse droplets (max. scale is currently 100 L/hr).

Integration with spray-drying yields powders with highly uniform properties (size, shape, density etc.) & the absence of fines.

Particle formation depends on the drying conditions.

Future work is concerned with demonstration of the energy- & resource efficiency and further scale-up of the print-drying process.

OPEN FOR COLLABORATION



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- New processes & materials

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