



**inlactis**

inate 10  UTEC 



# Part I: Dairy Ingredients Interactions process / product

## Effect on dairy powder quality



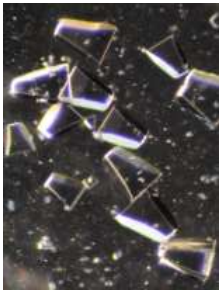
# Dairy Powder Processing

Liquid



Heat treatment  
“Cracking” (MF, UF, NF, RO, IE, ED)  
Vacuum concentration

Dairy concentrate



Lactose crystallization  
Homogenization  
Spray drying

Dairy powder



Storage



Rehydration

# Introduction to Innovation

Process/Product Interactions

- Dairy and Food Process

**PROCESS**

**PRODUIT**

- Dairy and Food Science

**INNOVATION**

- New Products



# Research questions

How the processes change the water transfers and therefore the qualities of the powder ?

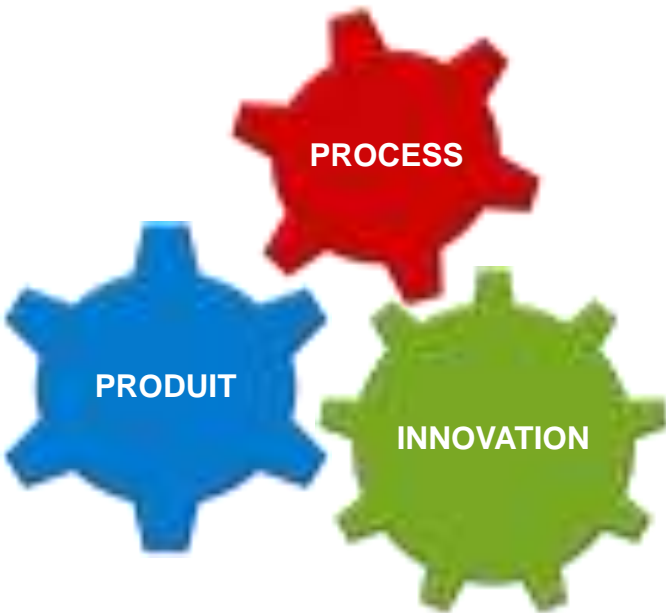
How the physico-chemical compositions change the water transfers and therefore the qualities of the powder ?



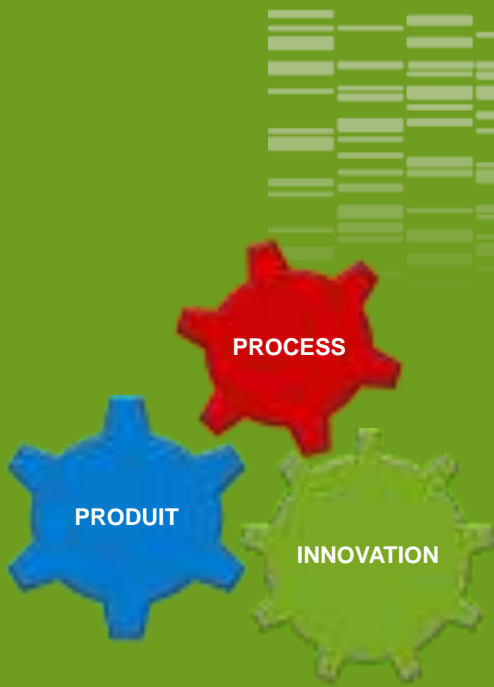
Understand the water transfer in relation to the process and the physico-chemical composition of the concentrate *before, during* and *after* spray-drying to improve the quality of powders



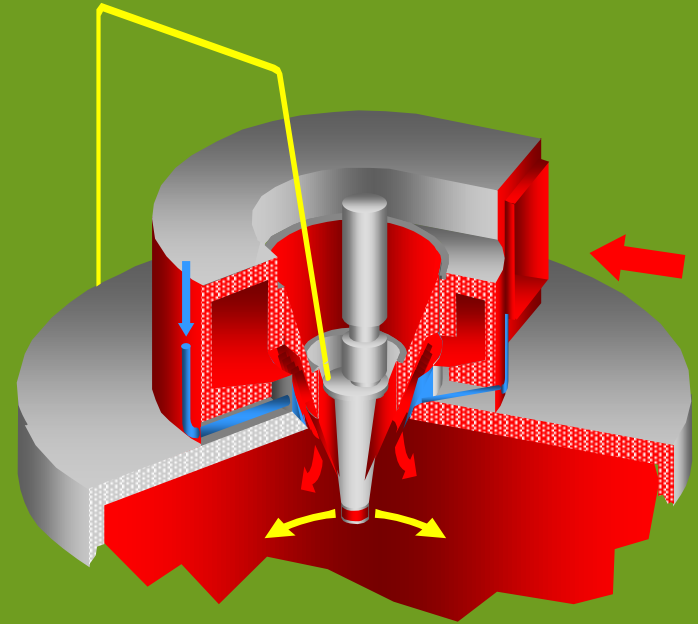
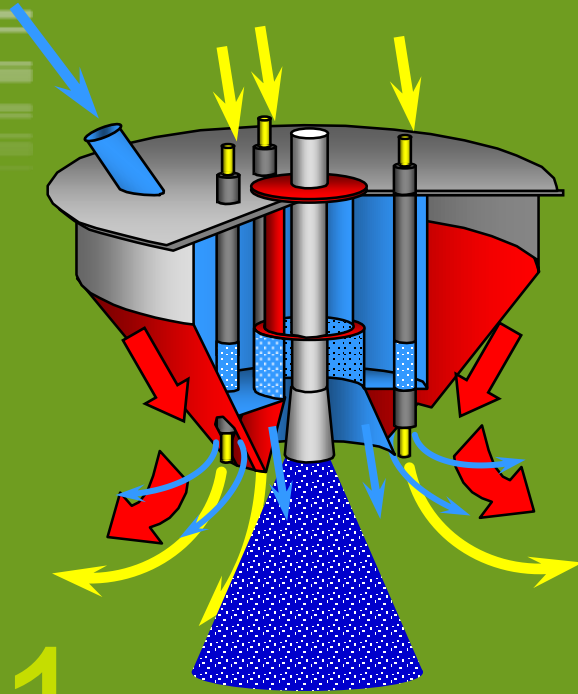
# Research questions: Part I



How the processes change the water transfers and therefore the qualities of the powder ?



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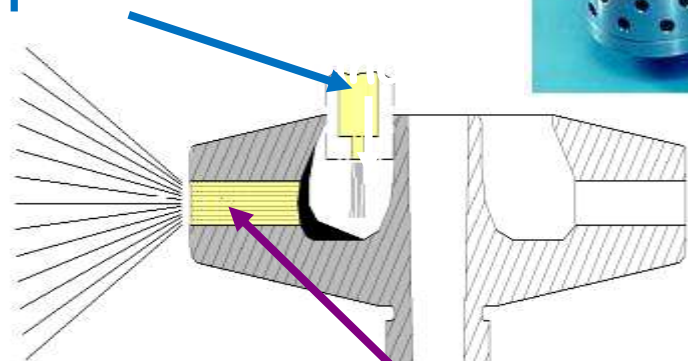


# SPRAYING

# Wheel / Rotary Atomizer



Liquid distribution



Accelerating chamber



2 m

# Nozzles



Model SK-MFP  
SprayDry Nozzle  
(with maximum free passage)



SKH-MFP SprayDry Nozzle  
(with maximum free passage  
and hand tight features)





# Advantages & Disadvantage

## EFFECTS

**Wheel**

**Large span:**

- High Density, Low Flowability, High Floodability, High Hygroscopicity, High Cakinability

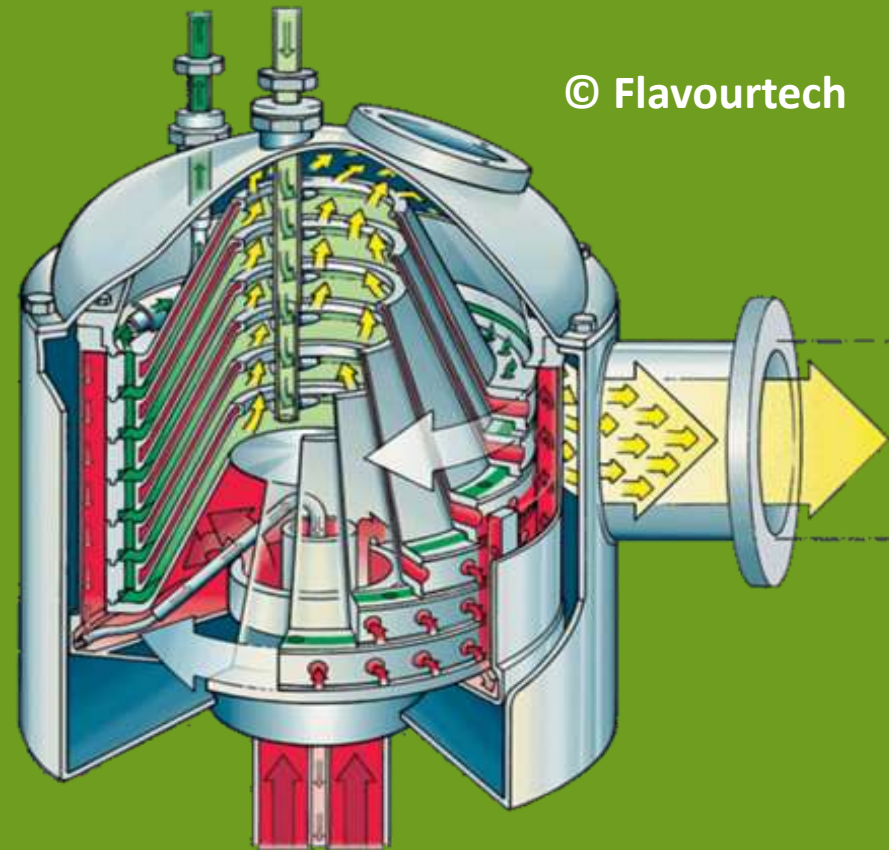
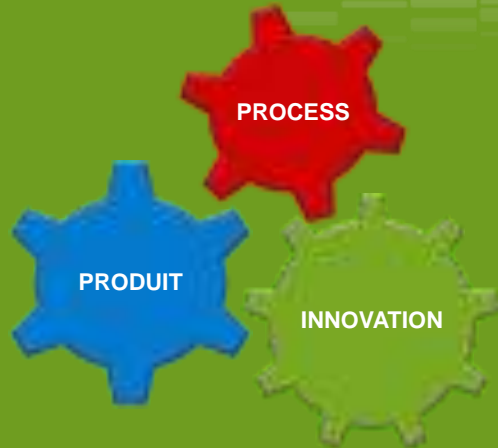
**Pressure nozzle**

**Narrow span:**

- Low Density, High Flowability, Low Floodability, Low Hygroscopicity, Low Cakinability

**Two-fluid nozzle**

- Low density, High Air Incorporation



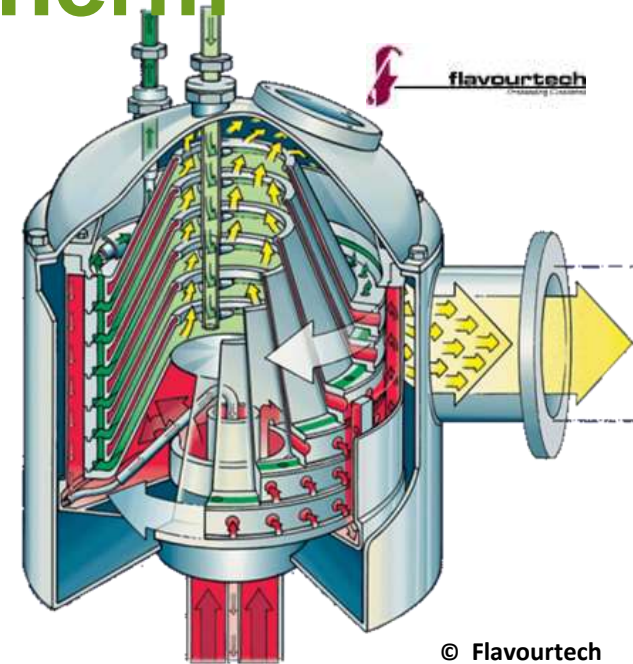
**\_01.2**

# Thin film spinning cone evaporator: Centritherm

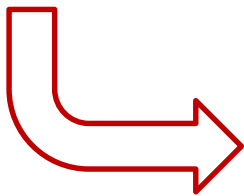
# Thin film spinning cone evaporator: Centritherm

- ✓ Evaporator composed of multiple cones that form a cone stack;
- ✓ Centrifugal force of the rotating cones creates a thin turbulent layer and allows efficient wettability of heat exchange surface;
- ✓ Indirect heat transfer between steam and a liquid to be concentrated;

- ✓ Extremely short evaporation time ( $\approx 1$  s) and low evaporation temperature ( $\approx 50$  °C)
- ✓ Ability to process viscous products



- ✓ High concentrations achievable while maintaining protein functionality:
  - Increase spray dryer maximum capacity
  - Reduce the energy consumption of drying step
    - Increase dairy powder density
    - Low thermal impact on the product



# Results

Concentration of 4 dairy products on CT evaporator at an evaporation temperature of about 50 °C for 2h:

✓ **WPC 80**

- Concentration up to 42.5 % DM without protein denaturation,
- Increased powder bulk density and particle size without modifications of rehydration properties,
- Reduction of energy costs with CT evaporation.

➤ **Skim milk**

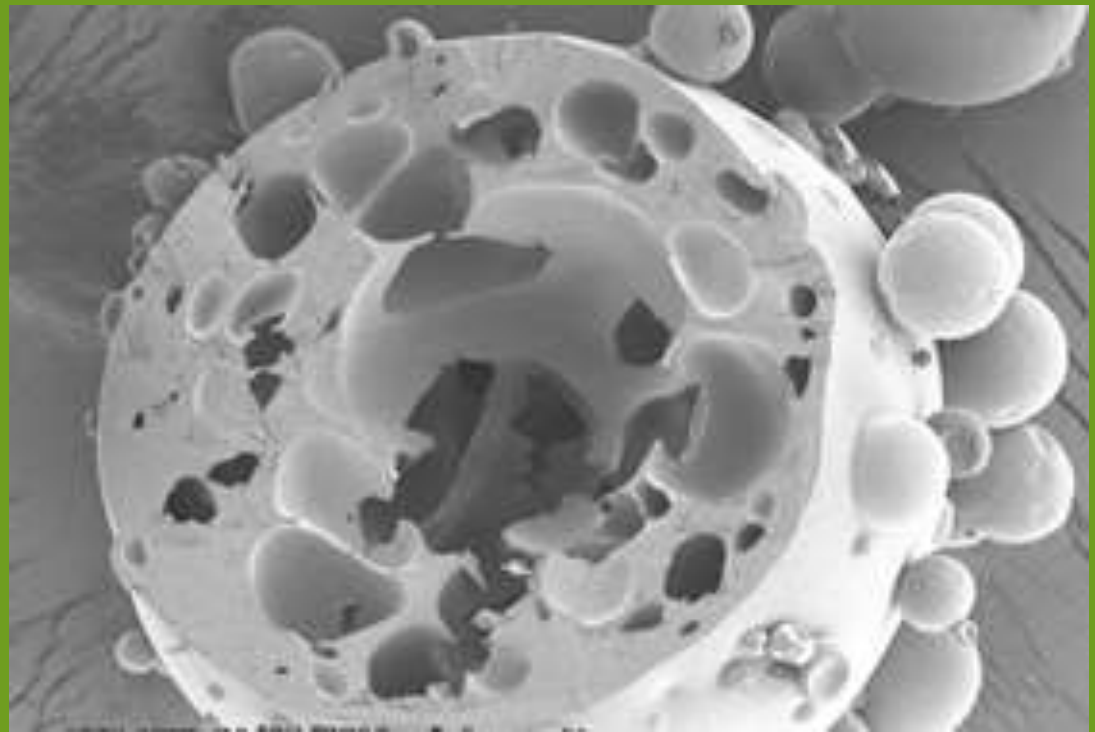
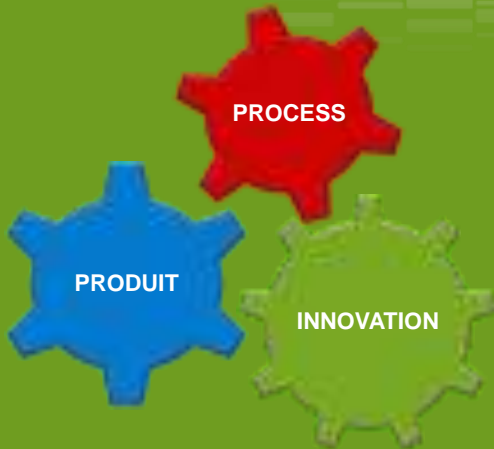
- Concentration up to 57 % DM without protein denaturation,
- Increased particle size but similar density and rehydratation properties,
- Reduction of energy costs with CT evaporator particle size.

➤ **Sweet whey and MPC**

- Concentration on CT is possible up to 63.4 % and 25.0 % for SW and MPC respectively but falling-film evaporation possible too on both products up to the same concentrations.
- Trials at higher evaporation temperatures to get higher DM.



Tanguy, G. et al., Journal of Food Engineering 166 (2015) 356–363

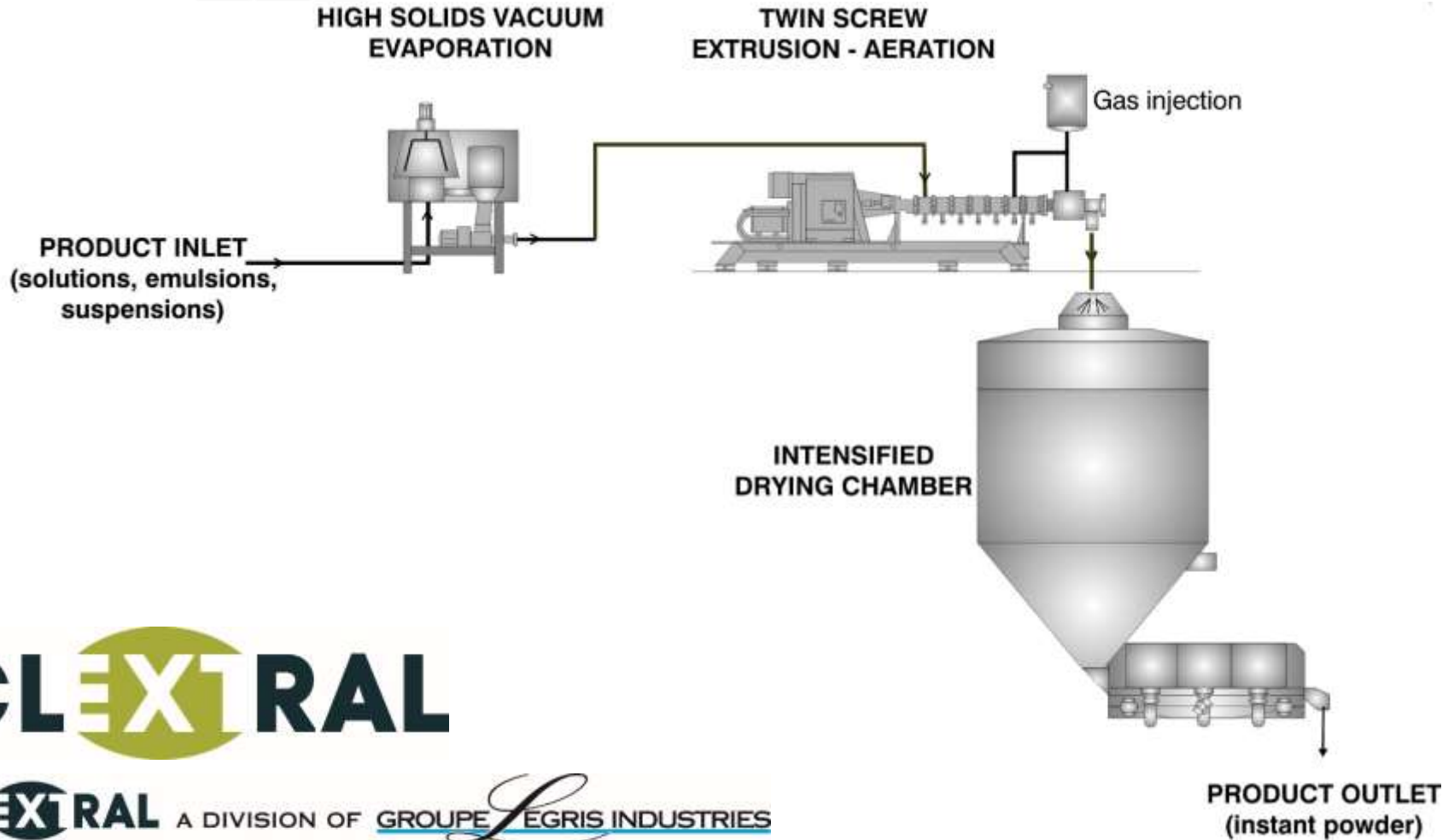


**\_01.3**

**CLEXTRAL**

# Extrusion-Porosification Technology (EPT®)

# Extrusion-Porosification Technology (EPT®)



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# Rehydration characteristics

- ✓ Rehydration characteristics (as determined by INRA – France):

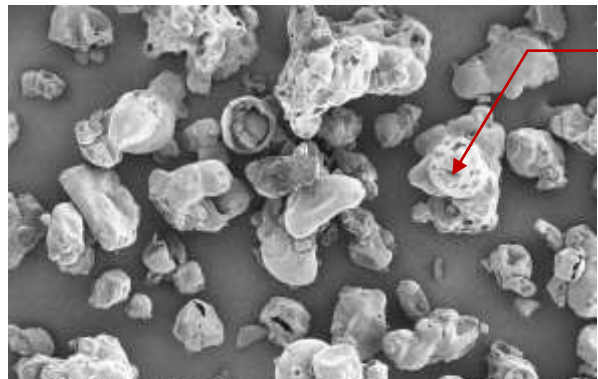
Sample	Wettability (s)	Dispersibility (%)	Solubility (%)
SD-MPC	> 120 s	38	99
EPT-MPC	> 120 s	95	98

*Extrusion-Porosified MPC shows significant improvement of rehydration characteristics (dispersibility in particular)*

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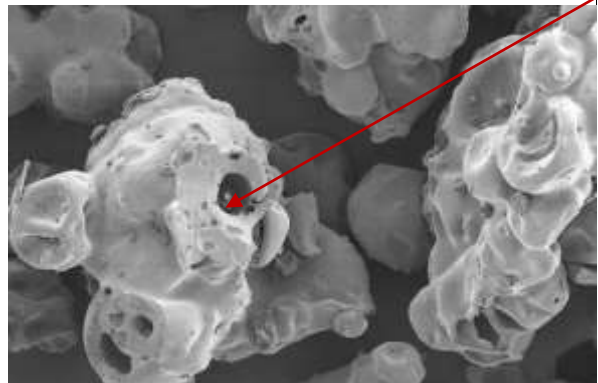
# Texture of MPC powder particles

## ✓ Spray-dried MPC



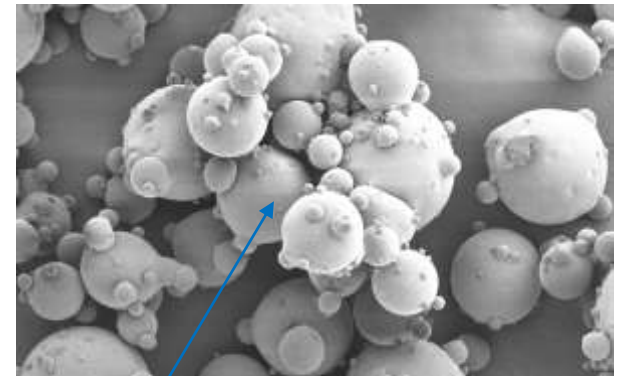
200  $\mu\text{m}$

SD-MPC shows irregular shapes, smooth surface, rather dense shell and few large internal vacuoles



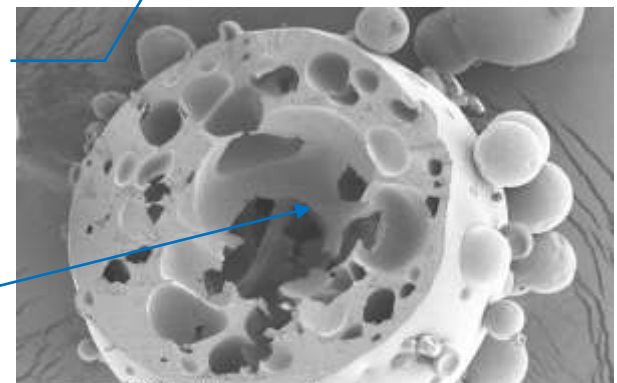
100  $\mu\text{m}$

## ✓ Extrusion-porosified MPC



200  $\mu\text{m}$

EP-MPC shows spherical shapes, smooth surface, highly porous texture with numerous capillaries



100  $\mu\text{m}$

Specific surface area = 95  $\text{m}^2/\text{g}$

Porosity = 47 %

Specific surface area = 140-145  $\text{m}^2/\text{g}$

Porosity = 70-72 %

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# Conclusions

✓ **Extrusion-porosification processing of milk protein concentrates allows:**

- instant powders to be texturized extensively (particle size, intra- and extra-particle texture), thanks to the flexibility of process variables
- rehydration characteristics of instant powders (dispersibility and solubility, in particular) to be drastically improved

→ No protein denaturation on MPC

✓ **Extrusion-porosification processing** is particularly well adapted to dry and texturize instant powders from complex mixes and formulations (applied development in progress)

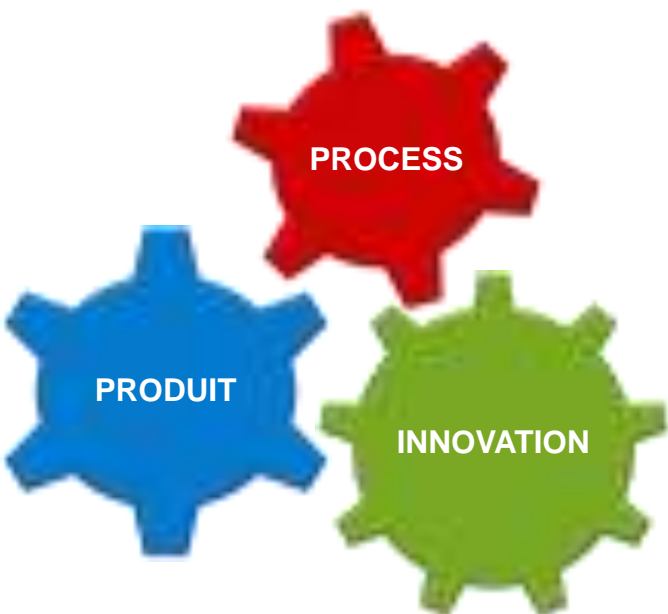
 Bouvier, J.-M., et al. Dairy Science and Technology, 93 (2013) 387-399.

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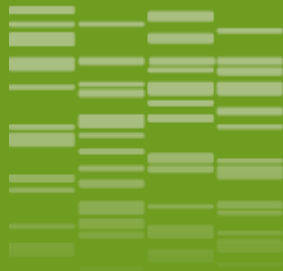
**CLEXTRAL**



# Research questions: Part II



**How the physico-chemical compositions change the water transfers and therefore the qualities of the powder ?**

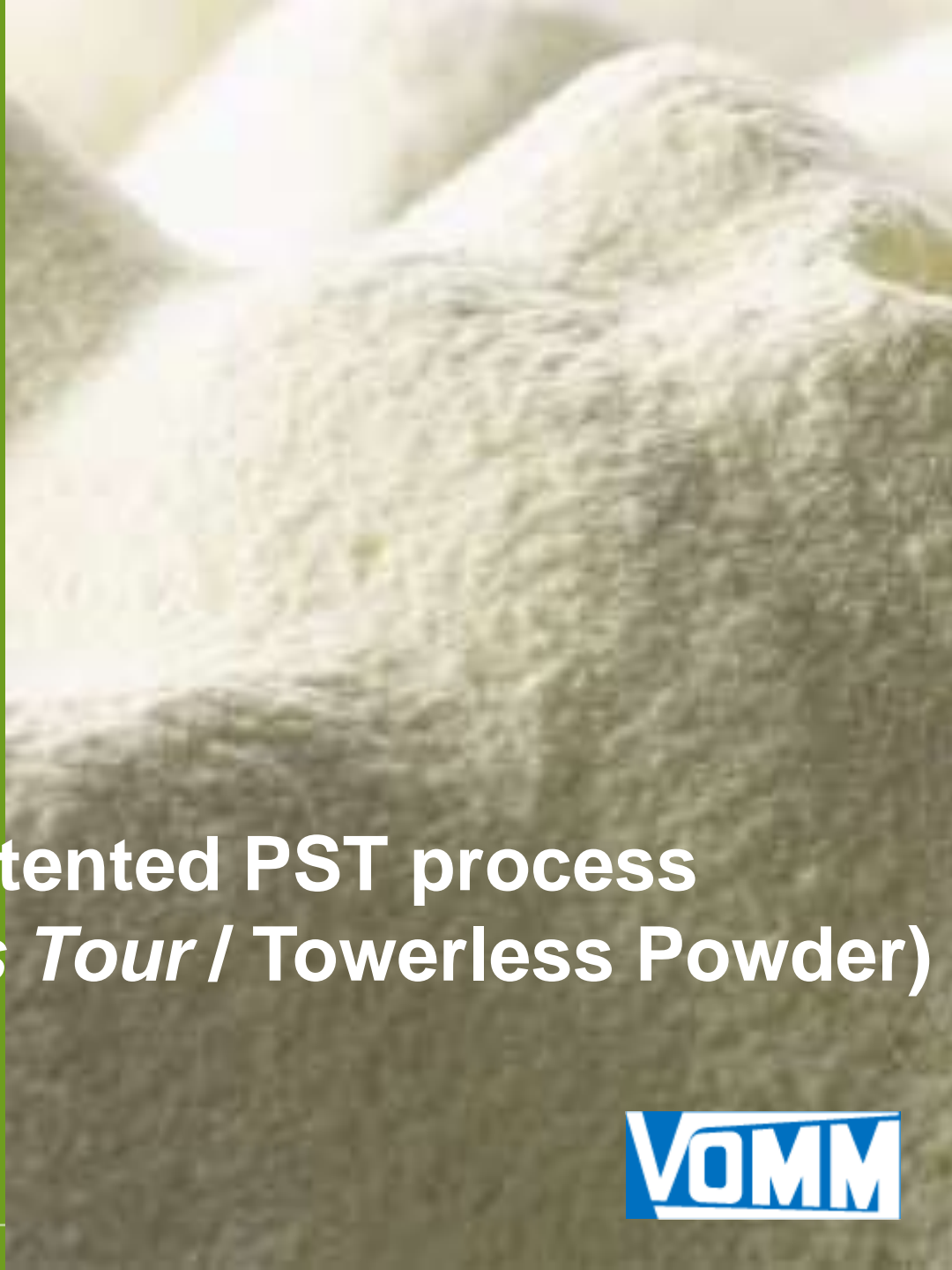


**Patent PST** (Poudre Sans  
Tour/Towerless Powder) :  
"Poudres laitières" n°1457413  
submitted the 31/07/2015.

Inventors: Schuck P, Tanguy G,  
Dolivet A, Méjean S, Jeantet R,  
Garreau D, Vezzani C.

**\_01.4**

# The patented PST process (*Poudre Sans Tour* / Towerless Powder)



# Energetical Consumption

(kJ.kg<sup>-1</sup> water)

**Energy cost in France** 3 TWh to remove water to produce dairy powder on a total of 12 TWh for dairy companies.



**Vacuum Evaporation**



**Spray Drying**

< 360 kJ.kg<sup>-1</sup>

> 3,600 kJ.kg<sup>-1</sup>

Min: X 10

Energy cost for spray drying represents **31, 36 and 57%**, (on the total cost including vacuum evaporation) only to remove **3.3, 4.3 et 9.5%** of the total water to produce **permeate, whey and skim milk powder** respectively



Schuck et al., *Drying Technology*, 33 (2015) 176–184

**3 options:**

- ✓ Increase the total solid content during [C°] by VE before SD
- ✓ Optimize the SD parameters
- ✓ Remove the spray dryer !

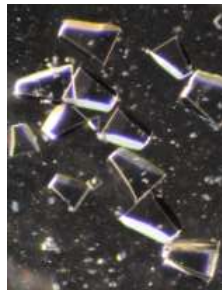
# Process to produce Whey/P<sup>te</sup> powder

## Whey/Permeate



- Heat Treatment
- Separation (MF, UF, NF, RO, IE, ED)
- Concentration by Vacuum Evaporation up to 60%

## Whey/Permeate Concentrate



- Lactose Crystallization
- ~~Spray Drying~~
- Post crystallization* (option)
- Fluid bed drying



## Whey/Permeate Powder

# New process to produce Whey/P<sup>te</sup> powder



## Whey/Permeate

- ❑ Concentration by vacuum evaporation up to 60% DM
- ❑ Lactose crystallization

## Whey/Permeate Concentrate

- ❑ Surconcentration up to 80% DM
- ❑ Granulation up to 90% DM

## Whey/Permeate Powder $a_w$ 0.4 - 0.6

- ❑ *Post crystallization (option)*
- ❑ Fluid bed / Turbo drying up to 97% DM

Whey Powder  $a_w$  0.2

50%



# Powder properties (Permeate)

	d(0.5) ( $\mu\text{m}$ )	Span (-)	True $\rho$ ( $\text{kg}\cdot\text{m}^{-3}$ )	Bulk $\rho$ ( $\text{kg}\cdot\text{m}^{-3}$ )	Tapped $\rho$ ( $\text{kg}\cdot\text{m}^{-3}$ )	Flow-ability (-)	Flood-ability (-)
<b>STD</b>	<b>125</b>	<b>1.5</b>	<b>1513</b>	<b>528</b>	<b>637</b>	<b>70</b>	<b>53</b>
<b>PST</b>	<b>200</b>	<b>1.5</b>	<b>1554</b>	<b>527</b>	<b>616</b>	<b>78</b>	<b>50</b>
	<b>Hygroscopicity (%)</b>		<b>Solubility (%)</b>	<b>Dispersibility (%)</b>	<b>Wettability (s)</b>		
	43% RH	86% RH					
<b>STD</b>	<b>1.0</b>	<b>13</b>	<b>&gt; 99.5</b>	<b>97</b>	<b>14</b>		
<b>PST</b>	<b>0.9</b>	<b>16</b>	<b>&gt; 99.5</b>	<b>96</b>	<b>2</b>		



# Energy cost (Permeate)

**Global Process:  
PST/STD: -11%**

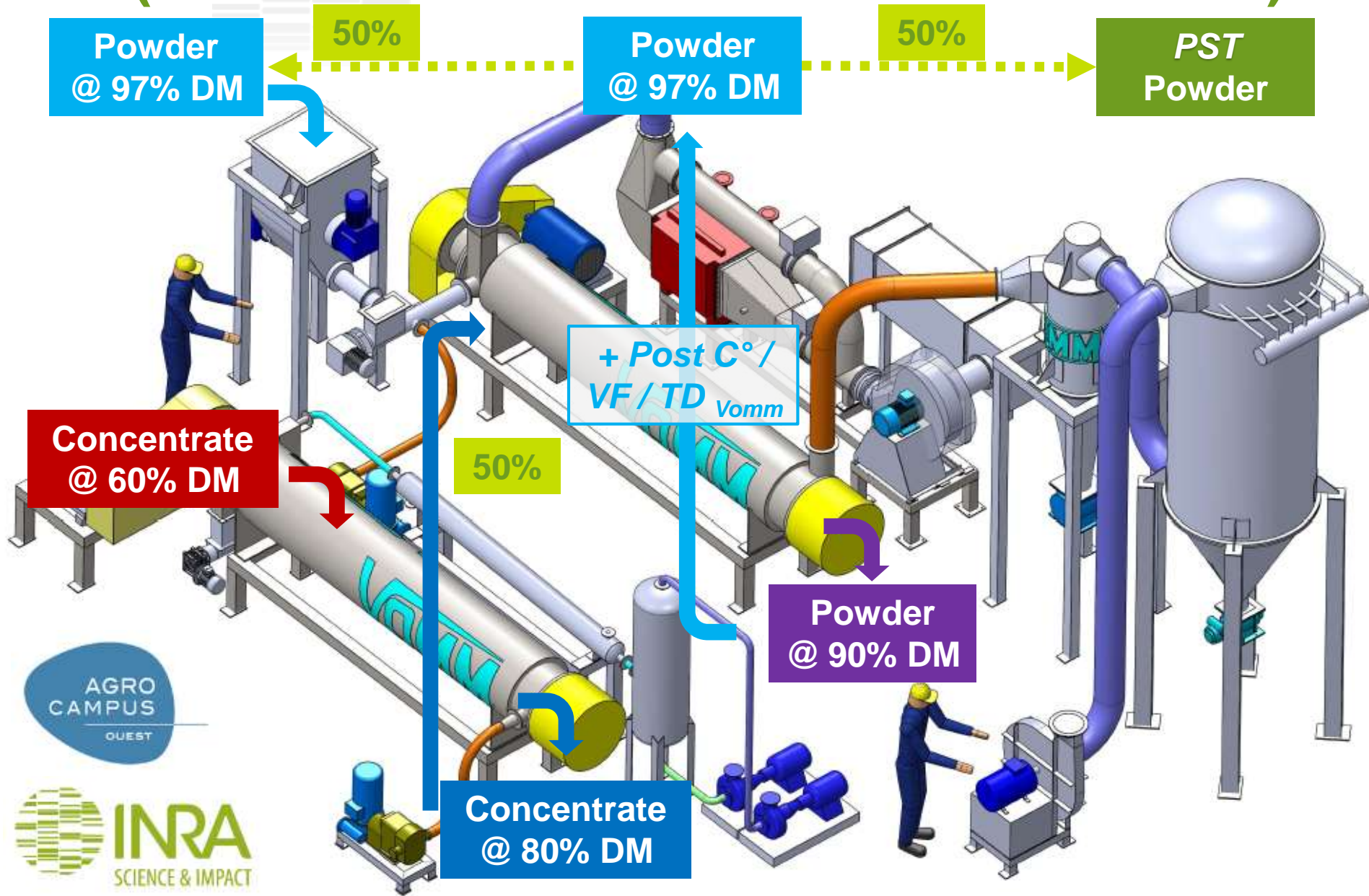
**Process 60-97%DM:  
PST/STD: -32%**

		Inlet		Outlet		Energy	
		Dry Matter	Flow rate	Dry Matter	Flow rate	Steam	Cost
		% w/w	kg.h <sup>-1</sup>	% w/w	kg.h <sup>-1</sup>	kg.h <sup>-1</sup>	kJ.kg <sup>-1</sup> of powder
<b>STD</b>	Vacuum [C°]	5.5	30,000	60	2,750	4,542	<b>10,067</b>
	Spray-drying	60	2,750	97	1,701	2,308	
<b>PST</b>	Vacuum [C°]	5.5	30,000	60	2750	4,542	<b>8,987</b>
	Over [C°]	60	2,750	80	2,063	791	
	Turbo drying	88.5	4,126	97	3,764	782	

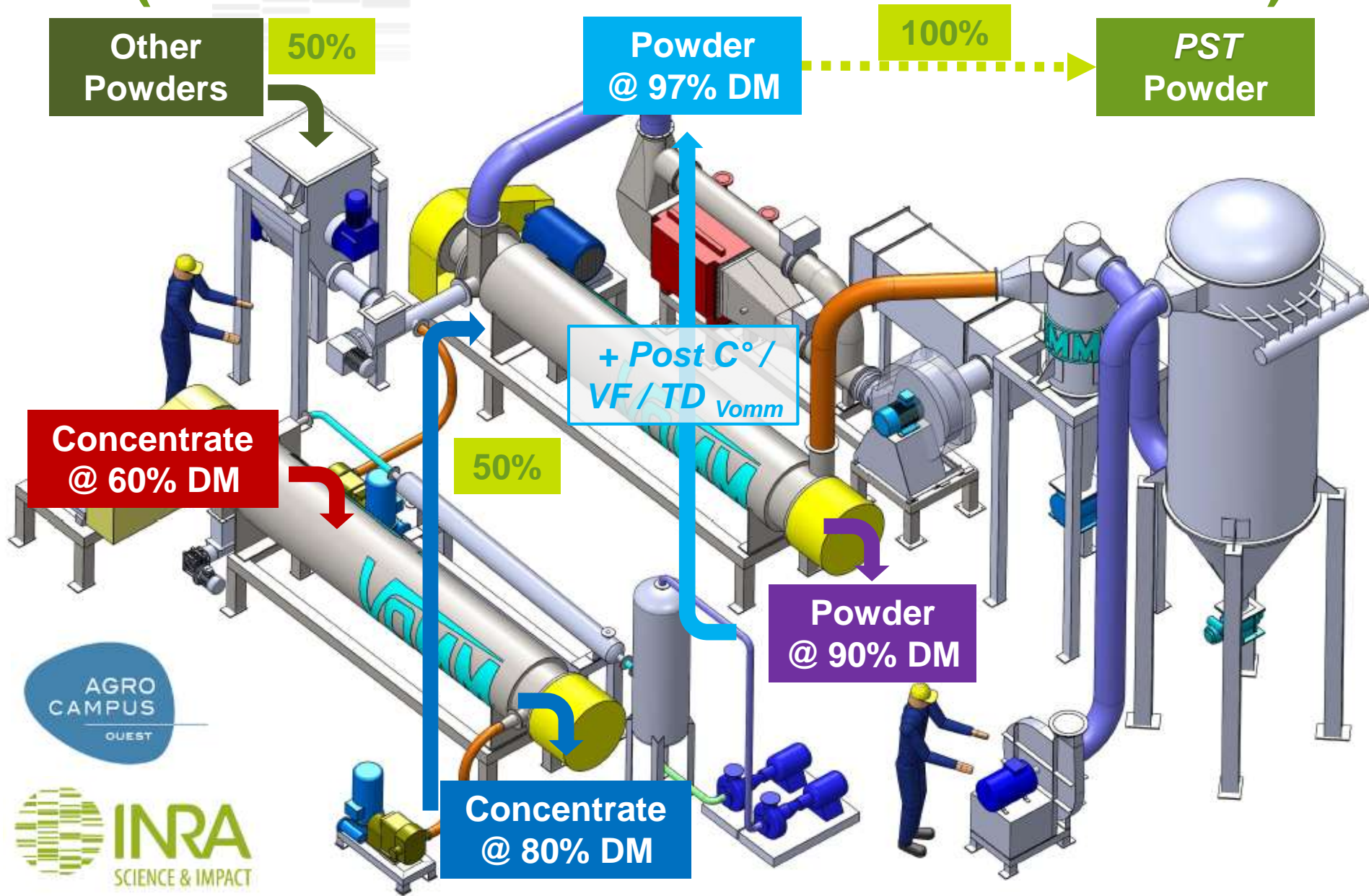
*Comparison of the energy costs between PST and Standard processes for the production of 1,701 kg.h<sup>-1</sup> of permeate powder at 97% DM from 30,000 kg.h<sup>-1</sup> of liquid at 5.5% DM.*

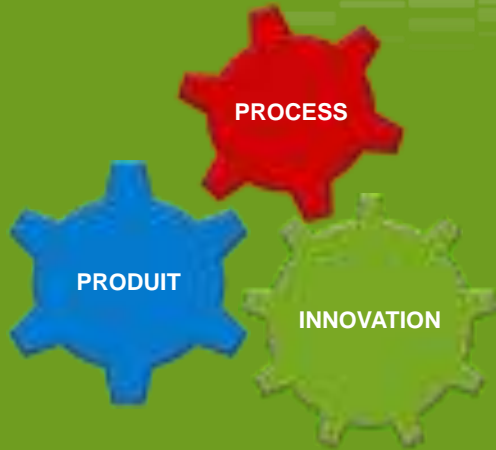


# The patented PST process (*Poudre Sans Tour* / Towerless Powder)



# The patented PST process (*Poudre Sans Tour / Towerless Powder*)





\_01.5

# How to optimize the SD parameters of dairy and food concentrates?

**SD2P**  
Spray Drying Parameters  
Simulation & Determination

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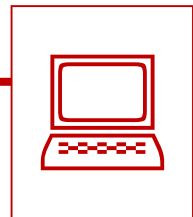
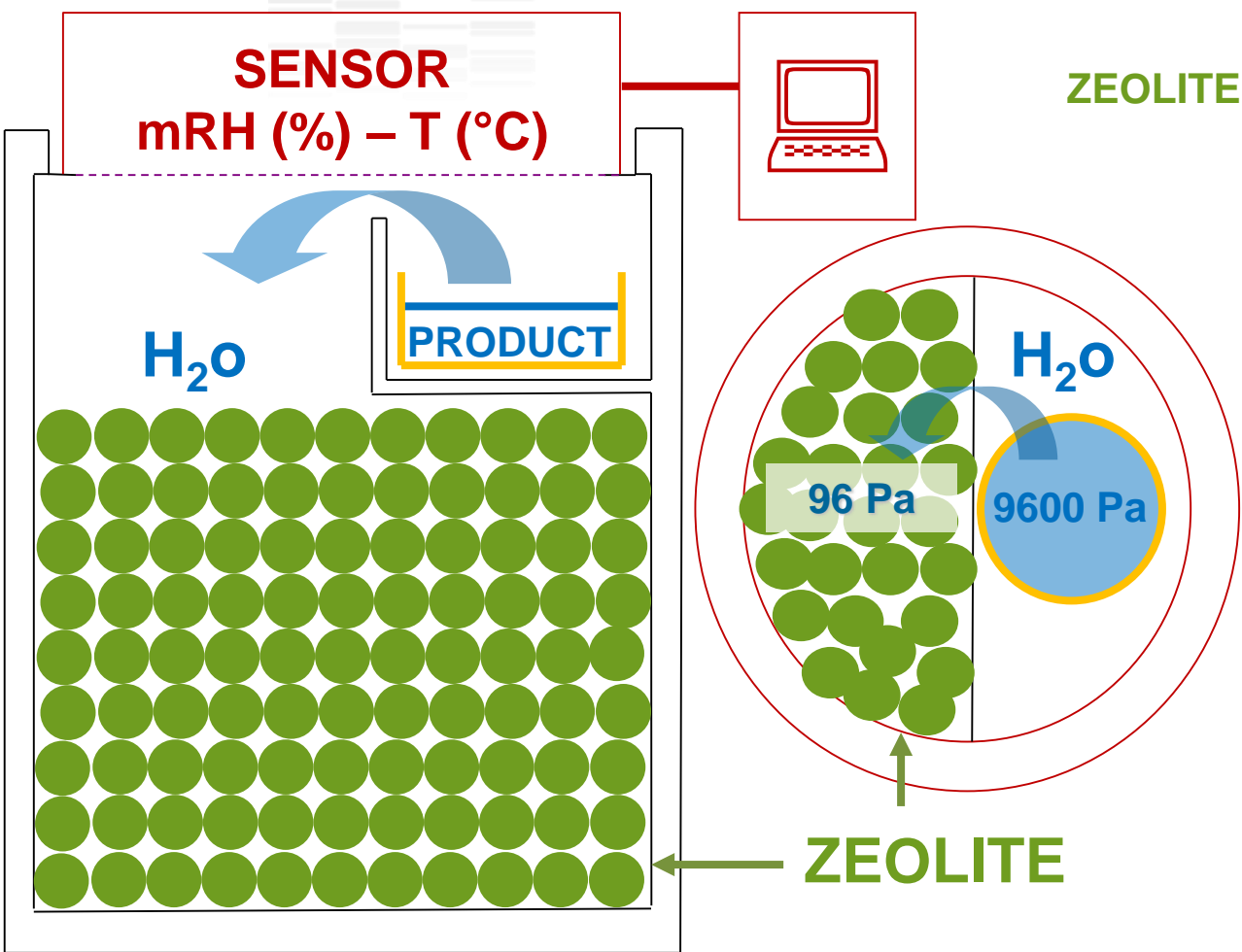
UMR 1253 Science et Technologie du lait et de l'Oeuf  
65, rue de Saint Brieuc  
35042 RENNES Cedex

IDDN.FR.001.480002.002.R.P.2005.000.30100

**Version 5.0 2010**

Le logiciel SD2P (Drying), enregistré à l'APP sous le n° IDDN.FR.001.480002.002.R.P.2005.000.30100, est un programme informatique développé par l'INRA servant à déterminer les paramètres de séchage à priori en intégrant la disponibilité de la matrice à sécher et les caractéristiques de l'équipement. Son utilisation est régie par une licence sur logiciel convenue par INRA Trésorerie. Le fait que vous puissiez accéder à cet en-tête signifie que vous avez pris connaissance de cette licence et que vous en avez accepté les termes.

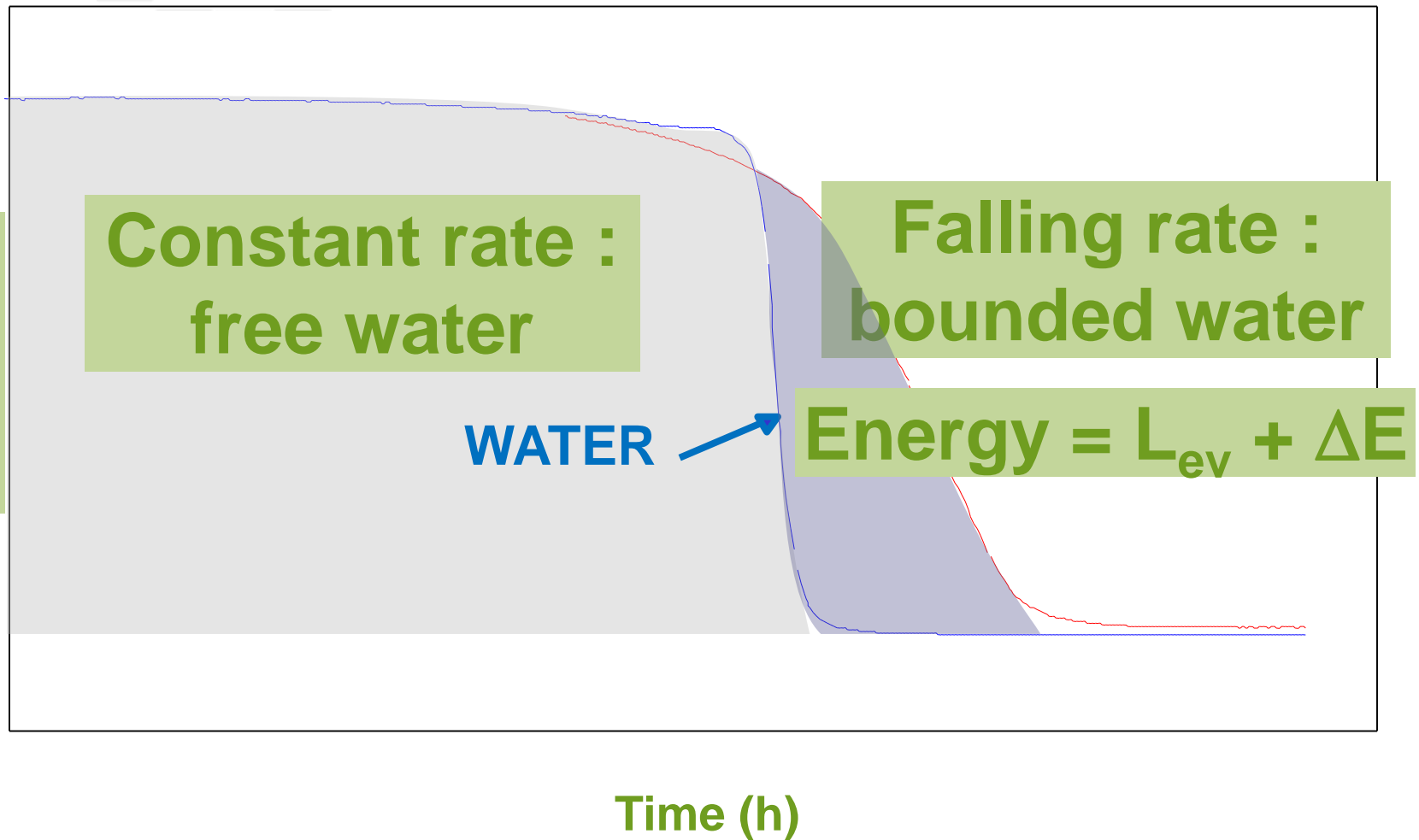
# Step ①: Concentrate desorption by $a_w$ -metry



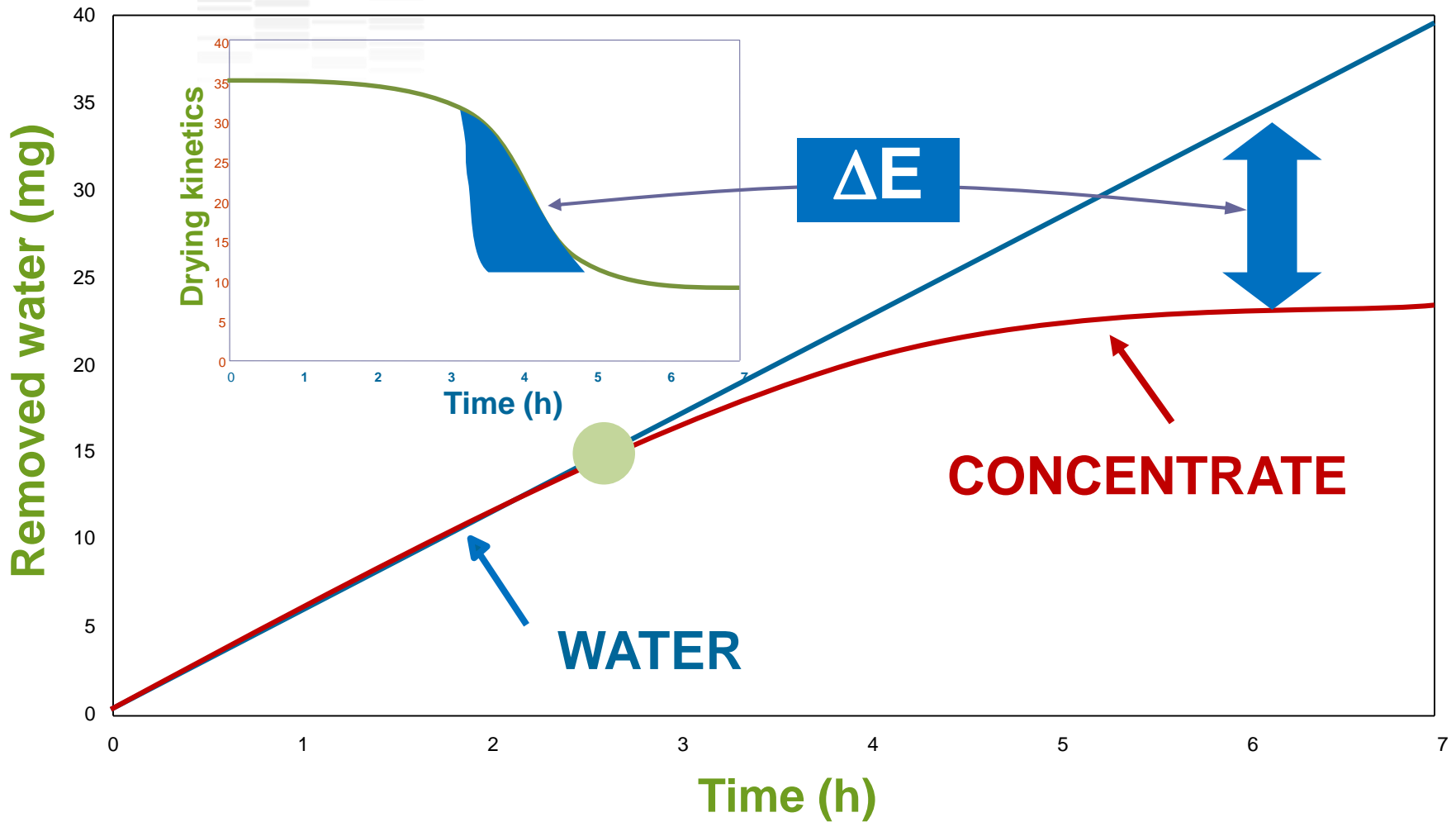
## Step ②:

# Desorption curve vs. time

Drying kinetics



# Step ③: Desorption curve vs. time



# Step ④: Calculation by INRA Software SD<sup>2</sup>P<sup>®</sup> integrating the ratio of bound and unbound water.



**Contacts**

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IDDN.FR.001.480002.002.R.P.2005.000.30100

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## SD2P

Spray Drying Parameters  
Simulation & Determination



SD2P  
Spray Drying Parameters  
Simulation & Determination

Version 5.0 2010







Reduce	Settings	Mass flow rate (kg DA/h)	Enthalpy (kJ/kg DA)	Temperature (°C)	AH (g/kg DA)	RH (%)
			38	20	7	47,8
	Inlet air after heating 'I'	75000	248	225.2	7	0,04
	Cooling air 'C'	2000	38	20	7	47,8
	Recirculation air 'R'	2000	38	20	7	47,8
	Complementary air 'C'	0	17,5	0	7	183,3
	Air mix (I+C+R+C)	79000	237,4	214,2	7	0,05
	Outlet air 1 stage (I+C+R+C)	79000	213,2	89,8	45,8	10
	IFB inlet air before heating		37,8	20	7	47,8
	IFB inlet air after heating 'B'	15000	118,2	98.4	7	1,2
	IFB outlet air 'B'	15000	86	56.8	11	10,2
	Overall outlet air (I+C+R+C+B)	94000	192,9	84.8	40,2	10,7

Evaporation capacity (kg/h)	3125,2
Water flow rate in concentrate (kg/h)	3250,2
Concentrate flow rate (kg/h)	6500.4
Concentrate flow rate (l/h)	5417
Concentrate density (-)	1,2
Concentrate dry matter (%)	50
Powder moisture (%)	4
Powder flow rate (kg/h)	3385.6
Concentrate temperature (°C)	45
Concentrate Cp (kJ/(kg.°C))	3,5

Wet bulb temperature of overall outlet air (°C)	47,6		
Dew temperature of overall outlet air (°C)	36,8		
Energy balance (kJ/kg water)	5426		
Energy consumption ratio (60°C) (kg vapour/kg water)	2,3		
Yield (60°C) (%)	43,5		
Cost (\$/ton water)	90.4		
Cost (\$/ton powder)	83.5		
kWh cost (\$)	0,06		
Corresponding standard breakpoint (%)	100		
Default	Print	Export	Quit





Reduce	Settings	Mass flow rate (kg DA/h)	Enthalpy (kJ/kg DA)	Temperature (°C)	AH (g/kg DA)	RH (%)
			38	20	7	47,8
		75000	204	182,2	7	0,11
		2000	38	20	7	47,8
		2000	38	20	7	47,8
		0	17,5	0	7	183,3
		79000	195,6	174,3	7	0,13
		79000	177,9	83,4	35,2	10
			37,8	20	7	47,8
		15000	105	85,5	7	1,9
		15000	81,1	54,7	9,9	10,2
		94000	162,5	79	31,2	10,6

Evaporation capacity (kg/h)	2271,3	Wet bulb temperature of overall outlet air (°C)	43,6
Water flow rate in concentrate (kg/h)	2362,2	Dew temperature of overall outlet air (°C)	32,2
Concentrate flow rate (kg/h)	4724,3	Energy balance (kJ/kg water)	5927
Concentrate flow rate (l/h)	3936,9	Energy consumption ratio (60°C) (kg vapour/kg water)	2,5
Concentrate density (-)	1,2	Yield (60°C) (%)	39,8
Concentrate dry matter (%)	50	Cost (\$/ton water)	98,8
Powder moisture (%)	4	Cost (\$/ton powder)	91,2
Powder flow rate (kg/h)	2460,6	kWh cost (\$)	0,06
Concentrate temperature (°C)	45	Corresponding standard breakpoint (%)	100
Concentrate Cp (kJ/(kg.°C))	3,5		

Default

Print

Export

Quit



Reduce	Settings	Mass flow rate (kg DA/h)	Enthalpy (kJ/kg DA)	Temperature (°C)	AH (g/kg DA)	RH (%)
			38	20	7	47,8
		75000	232,5	209,3	7	0,06

**new HA2**

Considering the desorption behavior of the product and with comparison to the standard (by default, skim milk), it is recommended to limit the evaporation capacity to 66,1% of total capacity. Do you want to run one more time the program, taking into account a corresponding new HA2 value of 0,022?

Oui  Non

IFB inlet air after heating 'B'	15000	92,1	72,9	7	3,2
IFB outlet air 'B'	15000	73,9	51,5	8,4	10,1
Overall outlet air (I+C+R+C+B)	94000	158,7	78	30,2	10,7

Evaporation capacity (kg/h)	2177,7	Wet bulb temperature of overall outlet air (°C)	46,2
Water flow rate in concentrate (kg/h)	2264,8	Dew temperature of overall outlet air (°C)	31,7
Concentrate flow rate (kg/h)	4529,6	Energy balance (kJ/kg water)	7047
Concentrate flow rate (l/h)	3774,7	Energy consumption ratio (60°C) (kg vapour/kg water)	3
Concentrate density (-)	1,2	Yield (60°C) (%)	33,5
Concentrate dry matter (%)	50	Cost (\$/ton water)	117,4
Powder moisture (%)	4	Cost (\$/ton powder)	108,4
Powder flow rate (kg/h)	2359,2	kWh cost (\$)	0,06
Concentrate temperature (°C)	45	Corresponding standard breakpoint (%)	66,1
Concentrate Cp (kJ/(kg.°C))	3,5		

Default Print Export **Quit**

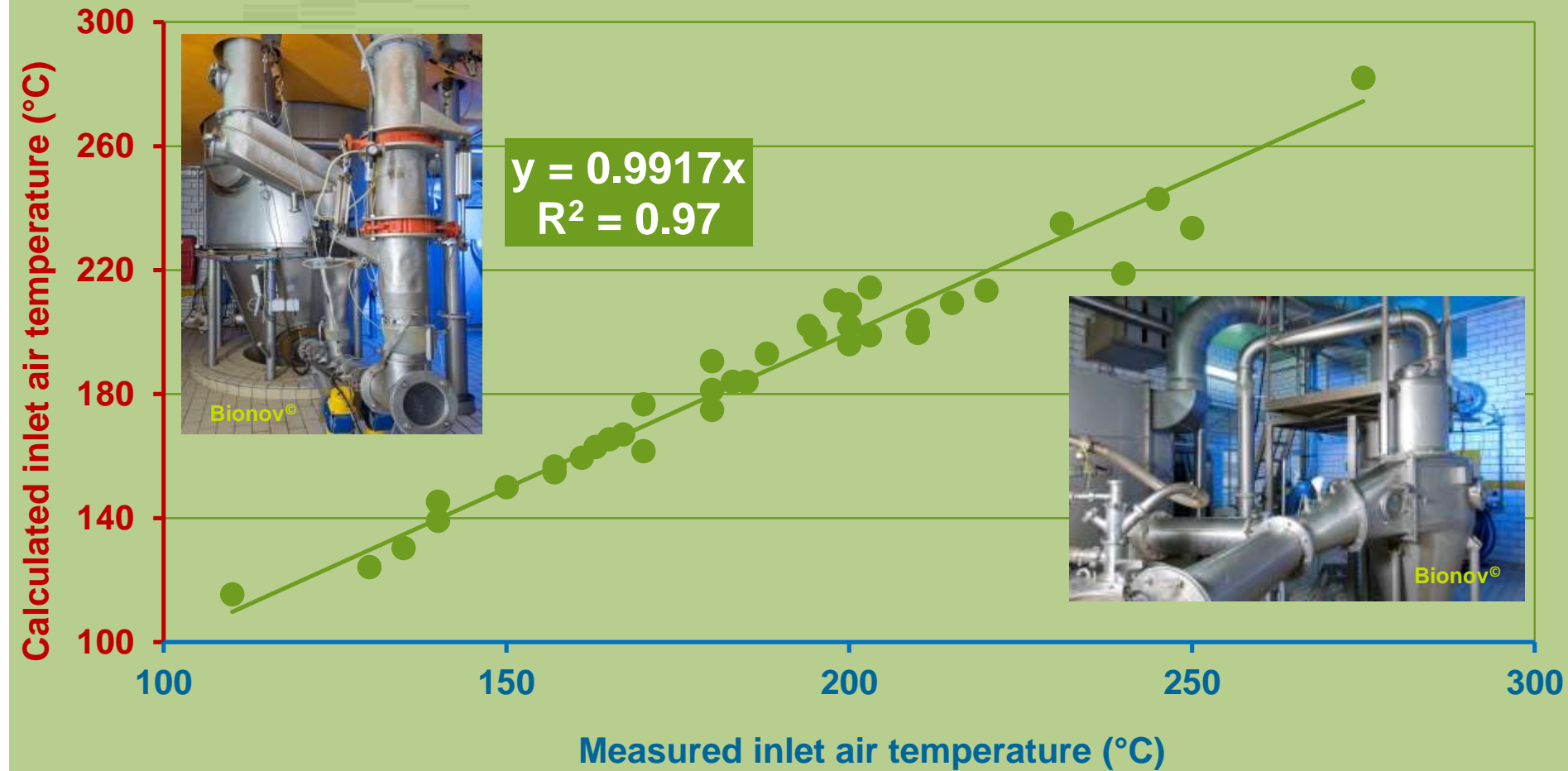


	Mass flow rate (kg DA/h)	Enthalpy (kJ/kg DA)	Temperature (°C)	AH (g/kg DA)	RH (%)
Inlet air before heating		38	20	7	47,8
Inlet air after heating 'I'	75000	180,3	158,5	7	0,19
Cooling air 'C'	2000	38	20	7	47,8
Recirculation air 'R'	2000	38	20	7	47,8
Complementary air 'C'	0	17,5	0	7	183,3
Air mix (I+C+R+C)	79000	172,5	151,9	7	0,22
Outlet air 1 stage (I+C+R+C)	79000	141,5	75,2	24,8	10
IFB inlet air before heating					
IFB inlet air before heating		37,8	20	7	47,8
IFB inlet air after heating 'B'	15000	84	65	7	4,5
IFB outlet air 'B'	15000	71,4	50,4	7,9	10
Overall outlet air (I+C+R+C+B)					
Overall outlet air (I+C+R+C+B)	94000	130,3	71,3	22,1	10,5

Evaporation capacity (kg/h)	1419,7	Wet bulb temperature of overall outlet air (°C)	41
Water flow rate in concentrate (kg/h)	1476,5	Dew temperature of overall outlet air (°C)	26,3
Concentrate flow rate (kg/h)	2953	Energy balance (kJ/kg water)	7974
Concentrate flow rate (l/h)	2460,8	Energy consumption ratio (60°C) (kg vapour/kg water)	3,4
Concentrate density (-)	1,2	Yield (60°C) (%)	29,6
Concentrate dry matter (%)	50	Cost (\$/ton water)	132,9
Powder moisture (%)	4	Cost (\$/ton powder)	122,7
Powder flow rate (kg/h)	1538	Wh cost (\$)	0,06
Concentrate temperature (°C)	45	Corresponding standard breakpoint (%)	66,1
Concentrate Cp (kJ/(kg.°C))	3,5		

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# Results



Schuck P. et al. Drying by desorption: a tool to determine spray drying parameters. *J Food Eng.* 94,199–204 (2009),

Patel K. et al. One-dimensional simulation of co-current, dairy spray drying systems – pros and cons. *Dairy Sci Technol.* 90, 181-210 (2010),

Zhu P., et al. Simulating industrial spray drying operations using a reaction engineering approach and a modified desorption method. *Drying Technol.* 29, 419-428 (2011).

Zhu P. et al. Prediction of dry mass glass transition temperature and the spray drying behaviour of a concentrate using a desorption method. *J Food Eng.* 105, 460-467 (2011).

# Calibration: A new desorption cell

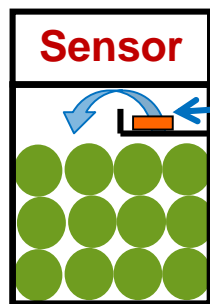
## ❖ New desorption cell:

- ➔ Precise weight scale.
- ➔ RH sensor.

## ❖ Desorption method:

- ➔ Concentrate:  $160 \pm 1$  mg
- ➔ Zeolite: 120 mL
- ➔ Drying temperature:  $40 \pm 1$  °C
- ➔ Water, skim milk, infant formula, etc.

## Traditional desorption cell

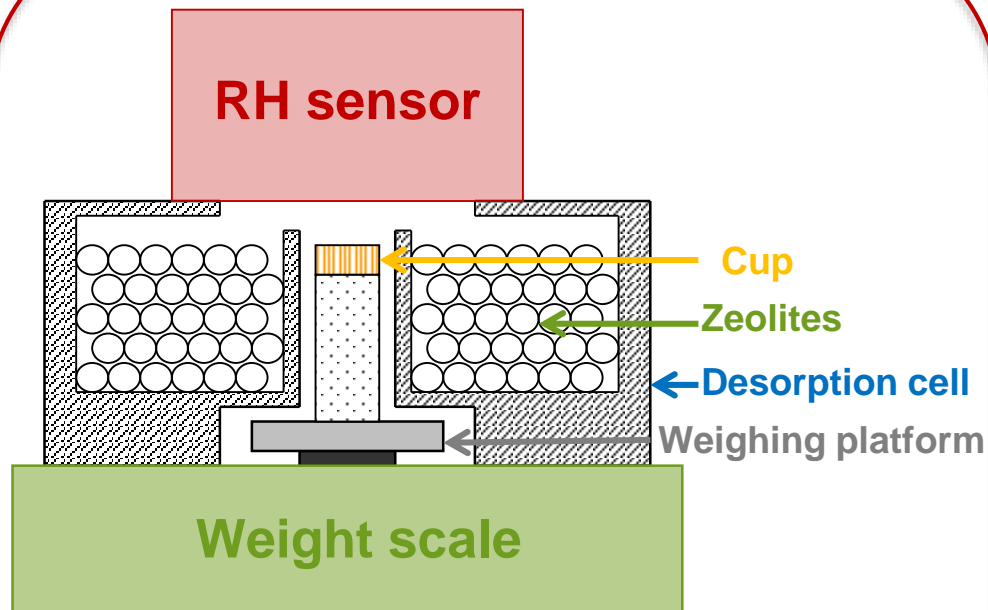


Sensor

Concentrate  
( $\approx 100\%$  RH)

Zeolites  
( $\approx 0.4\%$  RH)

## New desorption cell



RH sensor

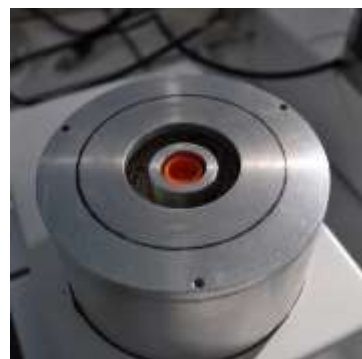
Cup

Zeolites

Desorption cell

Weighing platform

Weight scale

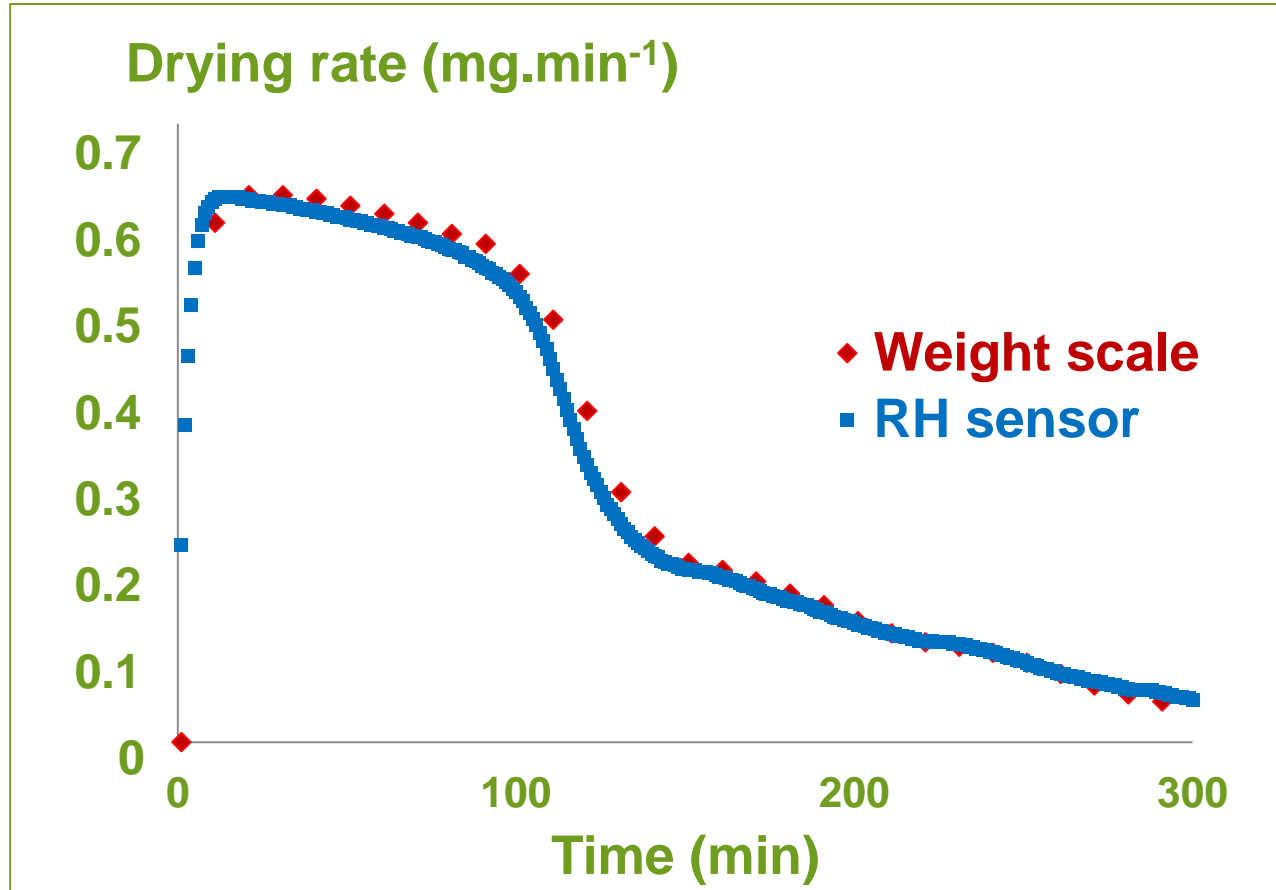


# Results & Discussion

## Skim milk at 40% total solid content

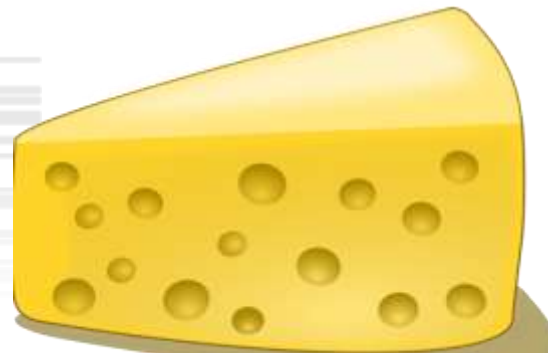
❖ Good agreement between the measured and the calculated mass under the tested drying conditions:

- ➔ Average difference < 2%.
- ➔ Mass estimation by the RH method is reliable.



Zhu P. et al. Prediction of drying of dairy products using a modified balance-based desorption method. Dairy Sci Technol. 93, 347-355 (2013).

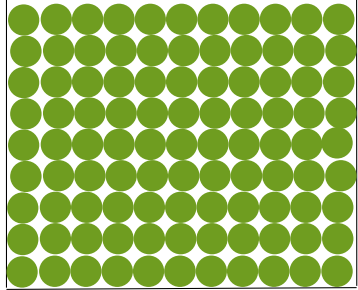
# Annexe



SENSOR  
mRH (%) – T (°C)

H<sub>2</sub>O

PRODUCT



**Table 2**

Composition of model, soft and hard cheeses, at different ripening times. Values are given as a mean ± one standard deviation (based on 3 replicates). Different letters for mean values correspond to significant differences at  $p < 0.05$ .

Cheese	Ripening day	Fat content (%)	Moisture content (%)	Free moisture in non-fat cheese (%)
Model	0	0	77.8 <sup>a</sup> ± 0.1	75 <sup>a</sup>
Soft	1 (before brining)	21 ± 0.1	58.8 <sup>b</sup> ± 0.2	64 <sup>a</sup> ± 2.2
	1 (after brining)	21 ± 0.1	57.2 <sup>b</sup> ± 0.2	62 <sup>a</sup> ± 0.1
	15	21 ± 0.1	41.4 <sup>bc</sup> ± 0.1	37 <sup>b</sup> ± 1.9
Hard	1	29.6 ± 0.1	36.7 <sup>c</sup> ± 0.1	29 <sup>b</sup> ± 2.9
	8	29.8 ± 0.1	35.4 <sup>c</sup> ± 0.1	26 <sup>b</sup> ± 1.1
	48	29.8 ± 0.1	36.3 <sup>c</sup> ± 0.1	29 <sup>b</sup> ± 0.8

The results are expressed as the mean ± one standard deviation of the mean ( $n = 3$ ).



Chapeau AL. et al. The influence of (FRAP). Food Chemistry 192, 660-667 (2016)..

# SD<sup>2</sup>P<sup>®</sup>

❖ With this method, it is possible to predict and optimize the **spray drying parameters** ( $\pm 1-5\%$ ) for food products in relation to their desorption behavior

❖ **Validation tests** (>200 products) indicate that this method could be applied to a large range of food products & spray dryer types.

❖ For reasons of calculation speed and reliability, the method has been computerized. **Spray Drying Parameters Simulation & Determination Software (SD<sup>2</sup>P<sup>®</sup>)**  
[N° IDD.N.FR.001.480002.003.R.P.2005.000.30100](http://www.inra.fr/SD2P)

❖ Up-to-date, 34 licenses have been sold at 26 factories [80% Dairy (4 of the Top 5 and 9 of the Top 25) – 20% Non Dairy], from 8 different countries:



❖ Top 1 for Inra licenses and Top 15 for Inra licenses and patents, since 1946



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YOUR ATTENTION**



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