(Continuous) high shear granulation

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Content

- Introduction:
  -How to make powders and granules
  -Type of industries, typical size of granulators
  -Continuous granulation
  -Current 'art'
  -Cases of control
  (-Case of aspertame)

  -State-of-the-Art in industrial processes
  -Future of control of these granulators
  -Will high shear granulation survive the next decades?

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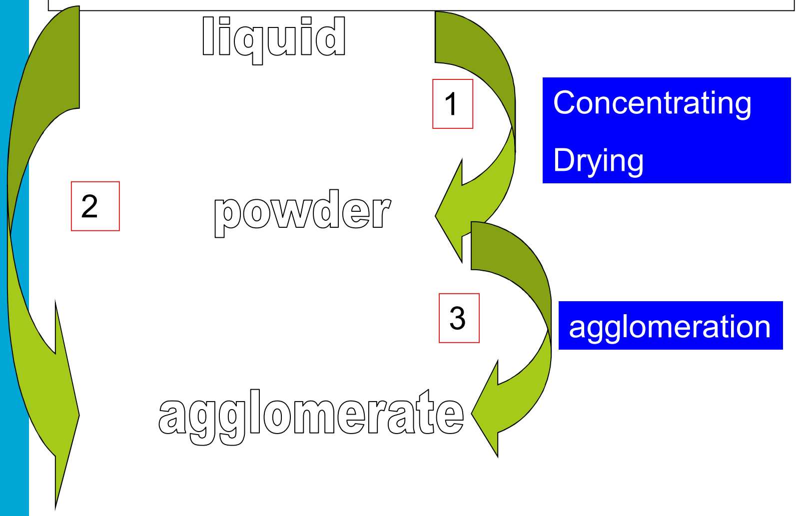
How to make powders and agglomerates



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Liquid to Powder (LP)	Liquid to Agglomerate (LA)	Powder to Agglomerate (PA)

- Spray drying
- Flash drying

•Multi stage drying
•Filtermat
•Fluid bed agglomeration
•AGT
•Procell
•Cont. fluid bed aggl.
•Fluid bed coating
•Pan coating
•Drum coating
•(Prilling)

- Low shear granulation
- Pan and drum granulation
- Low-medium shear granulation
- High Shear granulation
- Fluid bed granulation
- Extrusion
- Pelletising
- Briquetting
- Tabletting
- (Sintering)

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Liquid to Powder (LP)	Liquid to Agglomerate (LA)	Powder to Agglomerate (PA)

- Spray drying
- Flash drying

- **Multi stage drying**
- **Filtermat**
- **Fluid bed agglomeration**
- **AGT**
- **Procell**
- **Cont. fluid bed aggl.**
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- **Pan coating**
- **Drum coating**
- **(Prilling)**

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- (Sintering)

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Which industries use h.s. granulation

- Pharmaceutical (batch)
- Food and food additives (batch, cont..)
- Waste handling industries (continuous)
- Fertiliser industries (continuous)
- Detergent industries (continuous)

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Typical size of granulators

- Pharmaceutical: 5-200 litres
- Food and food additives: 20-5000 liters
- Waste handling industries: 0.1-100 T/day
- Fertiliser industries 10-1000 T/day
- Detergent industries: 0.1-10 T/day

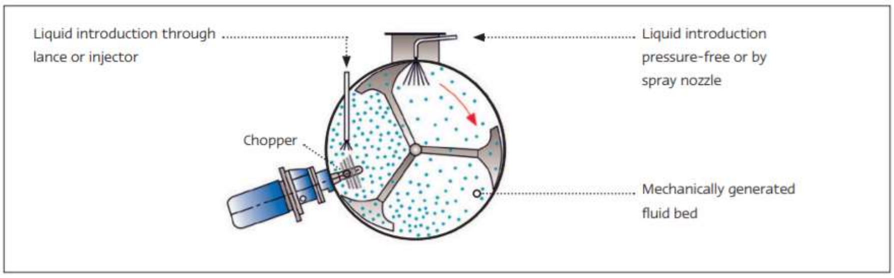
Definition of Lödige on continuous High shear granulation

- ***Mixing and Granulating Systems***

Continuous Mixer KM

The continuous ploughshare® mixer operates on principle of the mechanically generated fluid bed – the mixing technique developed and introduced by Lödige. Ploughshare® shovels rotate close to the inner wall of a horizontal, cylindrical drum and thrust the mix components from the bed of product into the open mixing space. The mechanically generated fluid bed ensures intensive mixing of even large quantities of product in a very short period of time. The quality of the mix is obtained when the product reaches the mixer outlet.

Typical HS granulator



Various types of liquid dosing in a horizontal Lödige Ploughshare® Mixer

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Glatt High shear device

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A continuous High shear granulator

CB High Speed Processor

CoriMix® CM 700

LÖDIGE PROCESS TECHNOLOGY

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A continuous High shear granulator

Sizes:

KM 1200 D
Application: production of fertilizer

Model	Volume [Liter]	Throughput [approx. t/h]	Dimensions L x W x H [mm]
KM 150 D	150	4,5	2 x 1
KM 300 D	300	9	3 x 1
KM 600 D	600	18	4 x 1,5
KM 1200 D	1200	36	4 x 1,5
KM 2000 D	2000	60	5 x 1,5
KM 3000 D	3000	90	6 x 1,5
KM 4200 D	4200	126	7 x 2
KM 6000 D	6000	180	8 x 2,5
KM 8000 D	8000	240	8 x 2,5
KM 10000 D	10000	300	9 x 3
KM 13500 D	13500	405	10 x 3
KM 15000 D	15000	450	11 x 3
KM 20000 D	20000	600	12 x 3
KM 30000 D	30000	900	14 x 3,5

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LÖDIGE PROCESS TECHNOLOGY

Fully welded mixing elements without any gaps or dirt traps (Hygienic Design)

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Choppers: create the shear

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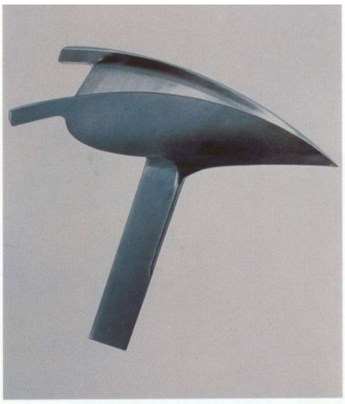
Plough shares; mixing devices



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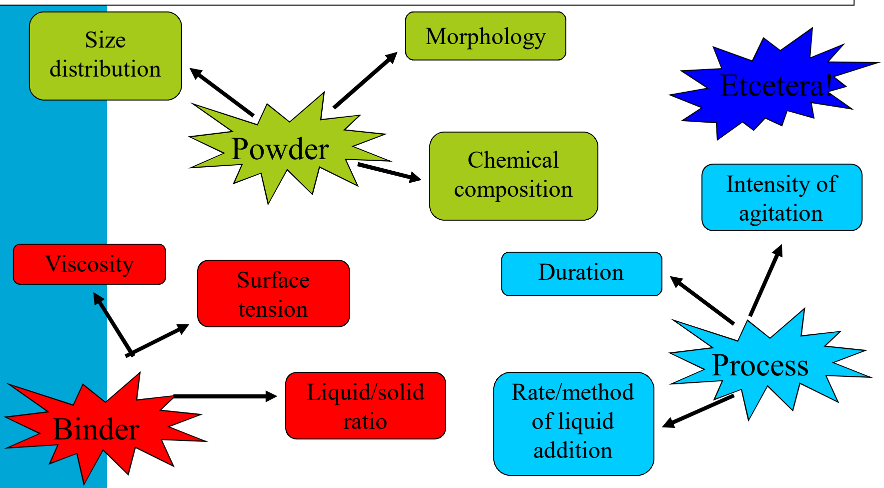
What influences granulation



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Granule growth, batch operation

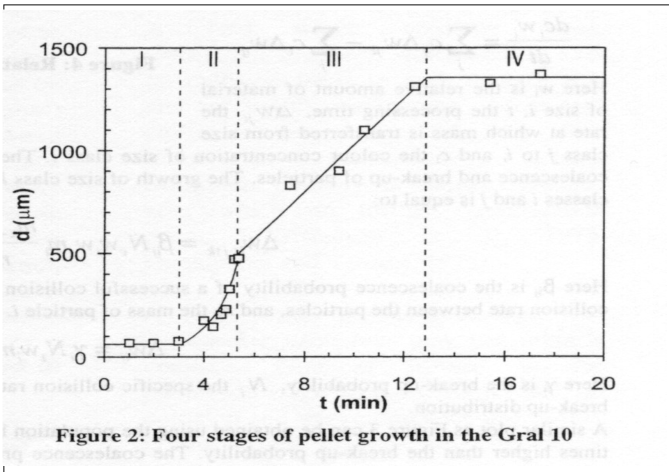

Figure 2: Four stages of pellet growth in the Gral 10

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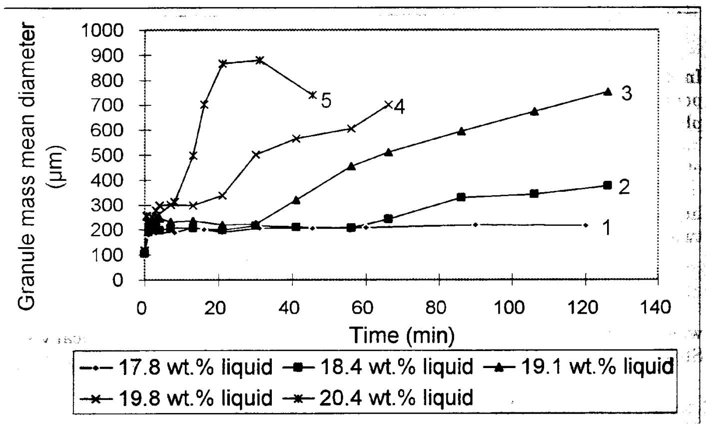
Granule growth, batch operation



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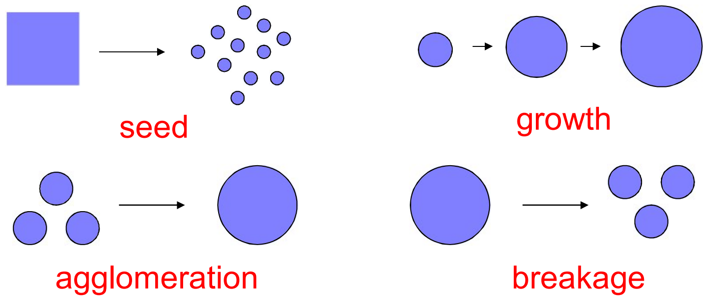
Particle formation, Steady growth



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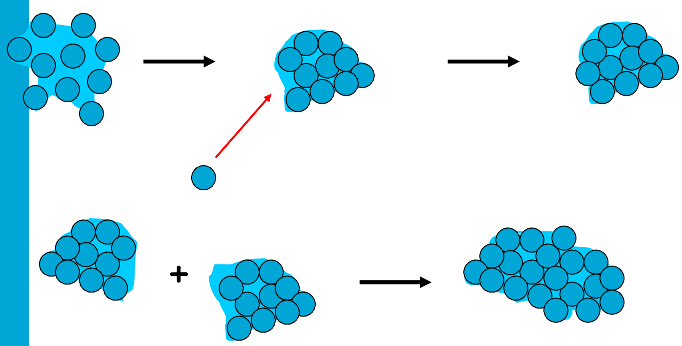
Particle formation; induction growth



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Surface wetness

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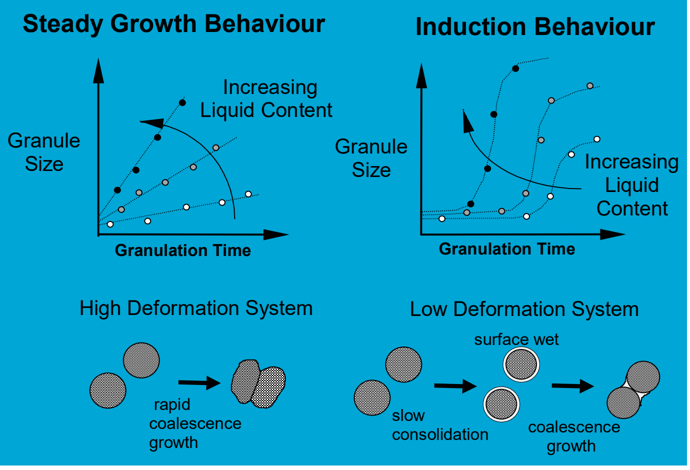
Regime maps

- Regime map for granule growth:



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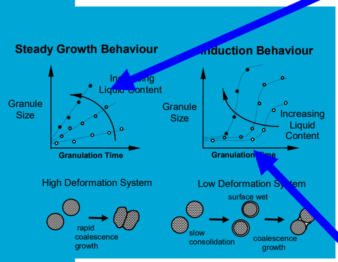
Particle growth



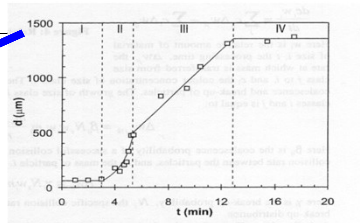
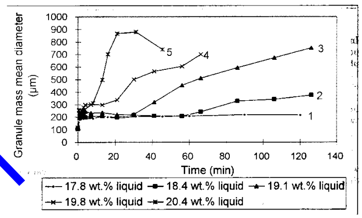


Figure 2: Four stages of pellet growth in the Gral 10



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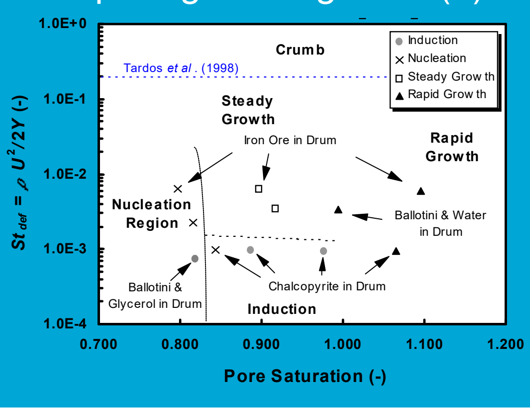
Granulation regime map (Iveson et al.)

- Regime map for granule growth (2)



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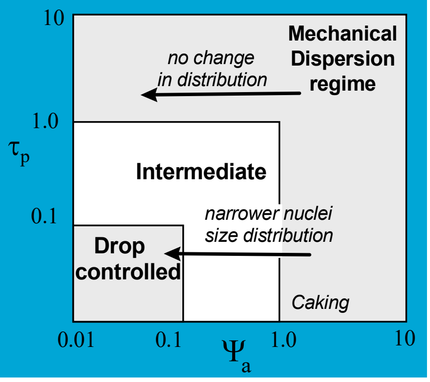
Regime Maps

- Liquid addition/nucleation important
  - more attention (Regime map):

ψ_a: dimensionless spray flux (measure for surface coverage of binder)

τ_p: drop penetration time



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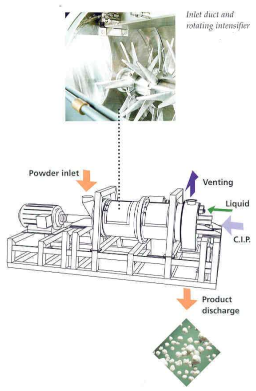
Continuous granulation

- What is different compared to batch
  - continuous feed
  - changing feed in time
  - recycle loops
  - one can control during granulation, contrary to batc granulation



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Continuous granulation

Case study continuous granulation control

DSM Research

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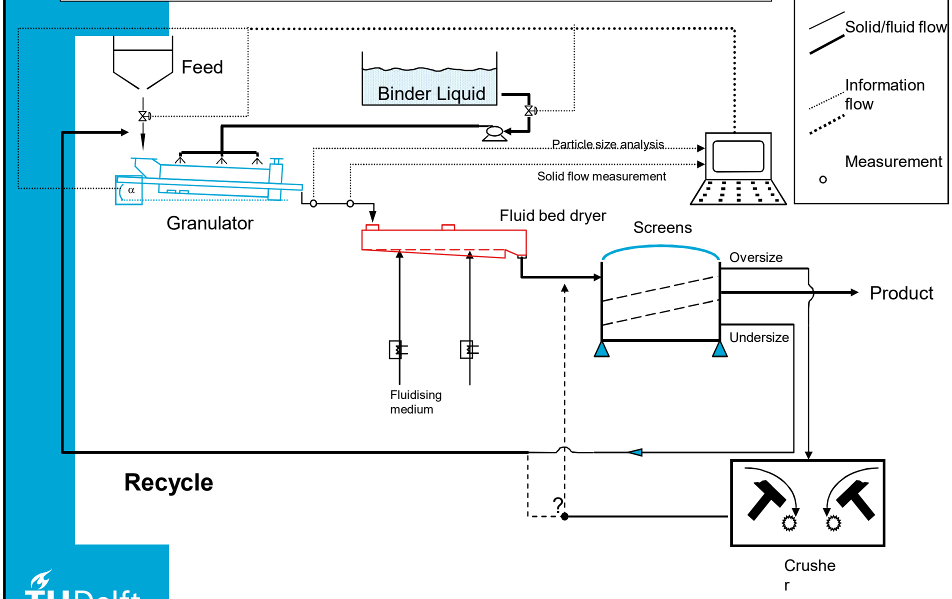
Granulation



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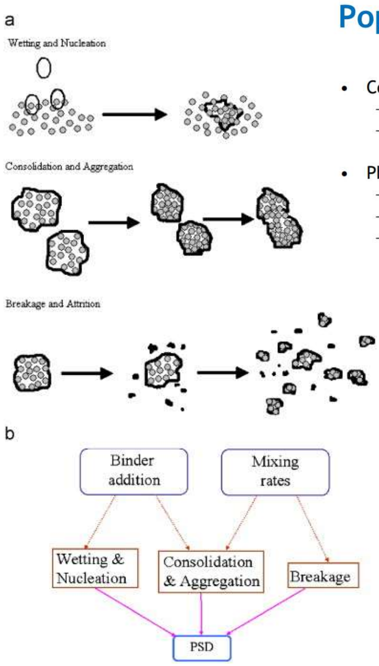
The Pilot Plant at the U. of Queensland

- 1.80m drum, 3 sections, slight angle with horizontal
- 2 spray nozzles in first section
- Residence time 10 min
- Hans Wildeboer

Movie

Population balance



- Conversation law on particles
  - Similar to mass & heat balance
  - Describes changes of particle ensembles
- Phenomena to describe
  - Nucleation & Growth
  - Agglomeration
  - Breakage

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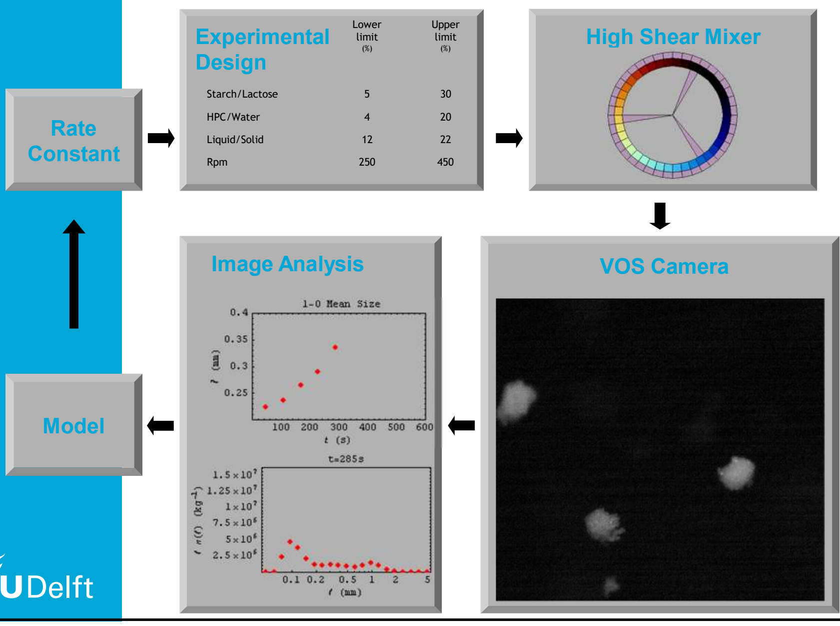
Plant Model



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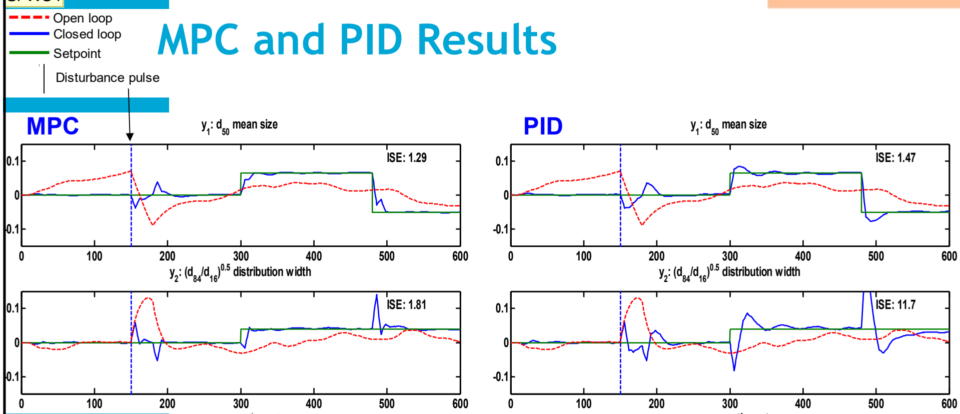
MPC and PID Results

CFWS1



Integral Square Error (ISE)

	MPC	PID
y1	1.3	1.5
y2	1.8	11.7

Setpoint changes

time	y1	y2
0	0	0
300	0.065	0.04
480	-0.05	0.04

- Two setpoint changes at 300 and 480 seconds
- Pulse change in feed flow rate at 150 seconds
- Noise in the granulation process: aggregation rate (=u_1)

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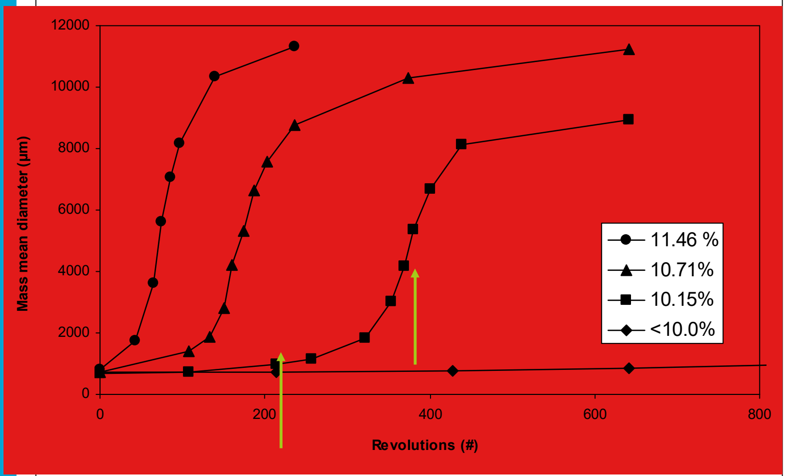
Slide 34

CFWS1 last year we had different outputs.
Constantijn Sanders; 11-6-2007

Continuous Granulation



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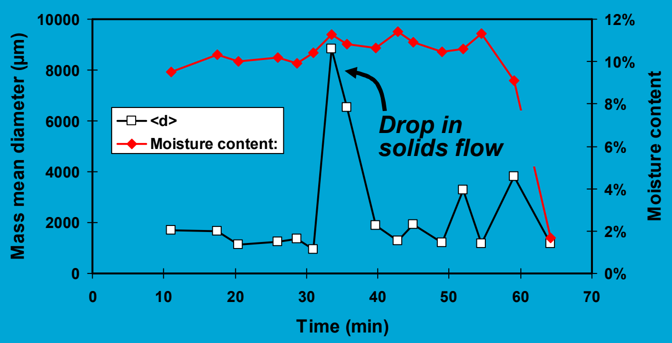
Continuous granulation; model based control

- Importance of properly functioning equipment (hopper):



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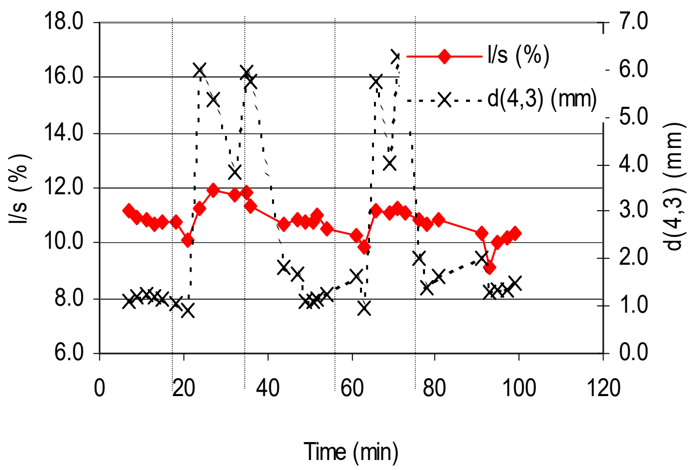
Continuous granulation; model based control



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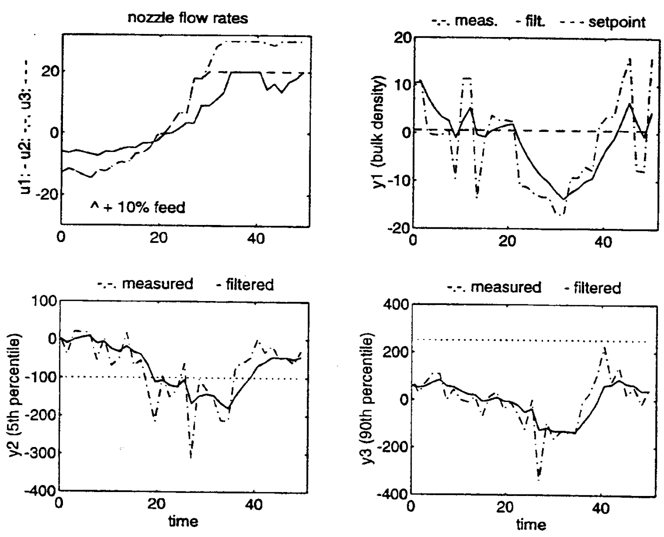
Continuous granulation; model based control



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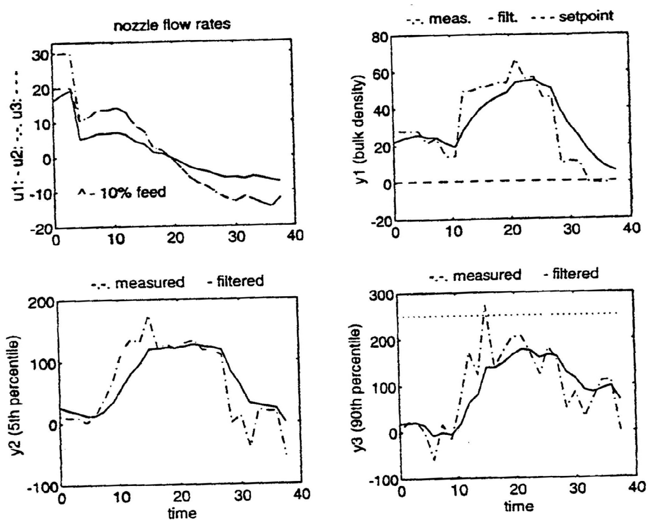
Continuous granulation; model based control



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What more do we need...

- Models for granulator, crusher, screens, and dryers
- On line analysis of relevant particle properties
- Control strategies (feed forward, feed back, expert systems etc.)
- Multi-dimensional population balance models

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Multi-dimensional population balances

Problems with one-dimensional population balances:

- One-dimensional population balance modelling mainly suitable for simulation of ‘regimes’, not for process optimization or process design
- Highly empirical->Does not reveal much about the mechanism

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Multi-dimensional population balances

- In granulation, moisture content and porosity have profound effect on the behaviour of the granules
- Moisture content and porosity are not the same for all granules!
- In order to improve the model for granulation, these properties should be incorporated.

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Multi-dimensional population balances

- Model for agglomeration only:

$$\frac{\partial n(\upsilon_s,\upsilon_l,\upsilon_a,t)}{\partial t} = B(\upsilon_s,\upsilon_l,\upsilon_a,t) - D(\upsilon_s,\upsilon_l,\upsilon_a,t)$$

$$B = \frac{1}{2}\int_0^{v_s}\int_0^{v_l}\int_0^{v_a} \Omega n(x,y,z,t)\, n(v_s - x, v_l - y, v_a - z, t)\, dv_s\, dv_l\, dv_a$$

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What is the current state of the art

- Circuits are controlled by experienced operators
- Model for granulator is available, but mostly developed in house
- On-line analysis is not yet available, except for psd measurements
- Sensors for psd available, the rest still difficult
- Population balances for feed forward control is developed now
- Expert systems are being tested

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Who are doing the development

- Companies who use the granulators (Merck, DuPont, DSM, P&G, Unilever, AKZO-Nobel and more), Glatt
- Universities (Univ. Delft, Queensland, Sheffield, Magdenburg, Birmingham, Imperial College London, etc

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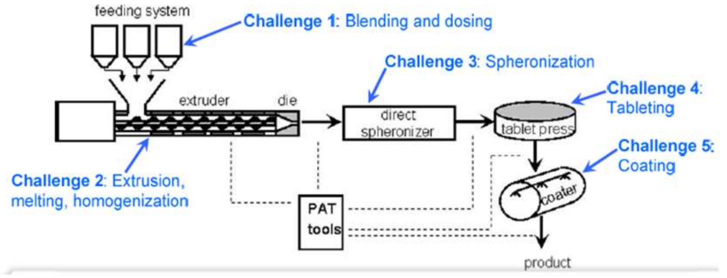
Will high shear granulation survive the next decades

-extrusion is coming up in the pharmaceutical industry as a replacement of the high shear granulation
-if proven to be better/more efficient this might be a game changer



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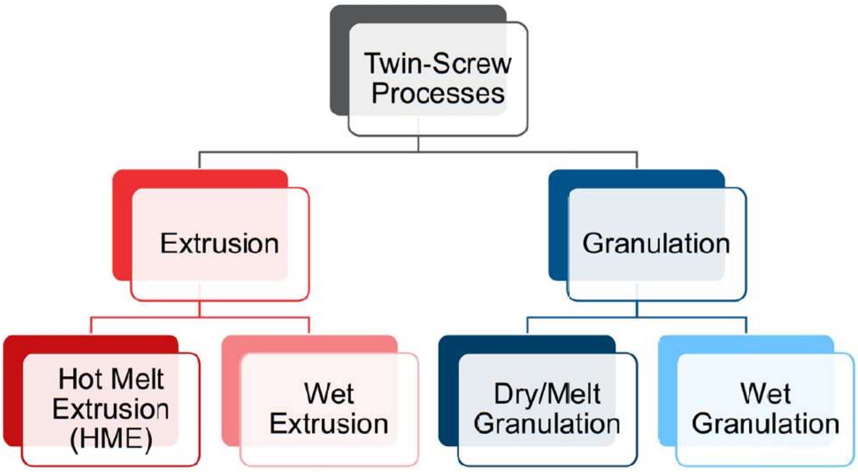
Overview on Twin-Screw Processes



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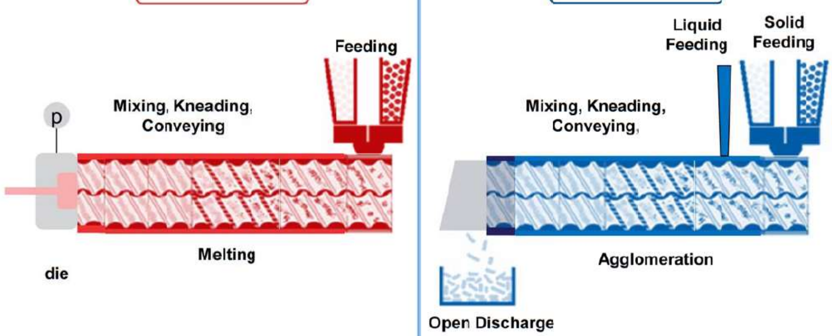
Twin-Screw Processes

Extrusion

Granulation



Product:
Strand
⇒ Cooling, Cutting/Pelletizing

Product:
Wet Granules
⇒ Drying

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https://www.thermofisher.com/nl/en/home/industrial/pharma-biopharma/drug-formulation-manufacturing.html

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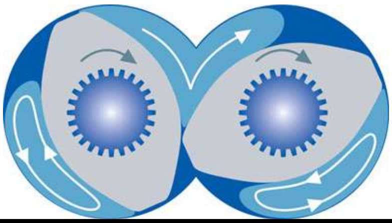
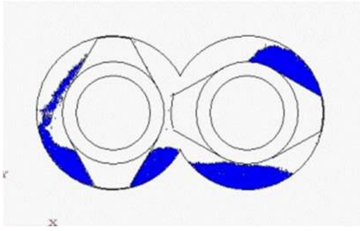
Very similar to High shear granulation





https://tools.thermofisher.com/content/sfs/brochures/TEK-16-013-Twin-Screw-Broschure.pdf

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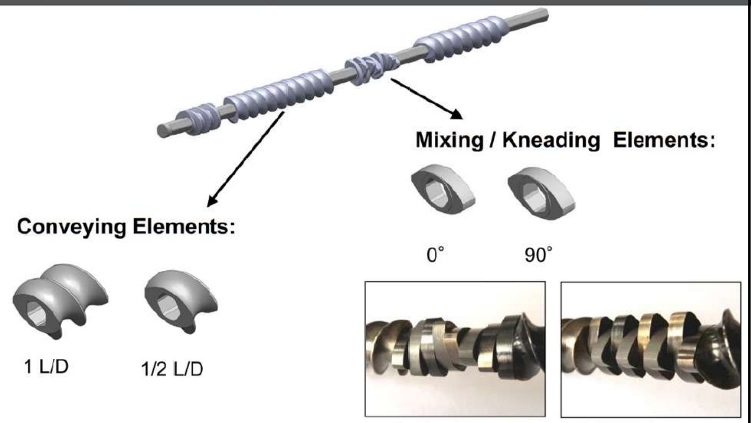
Segmented screw design



Angle determines: residence time, shear, mechanical stress, mechanism of mixing

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- Parallel, intermeshing, co- rotating twin-screws
  - Origin: IG Farben, Wolfen (Germany), early 1940s
  - Patent: Bayer AG, Erdmenger, 1953
  - Now: Conveying, mixing, kneading and compression of the material in combination with heating/cooling
    ⇒ Melting, mixing and shaping of material
    ⇒ Agglomeration of material

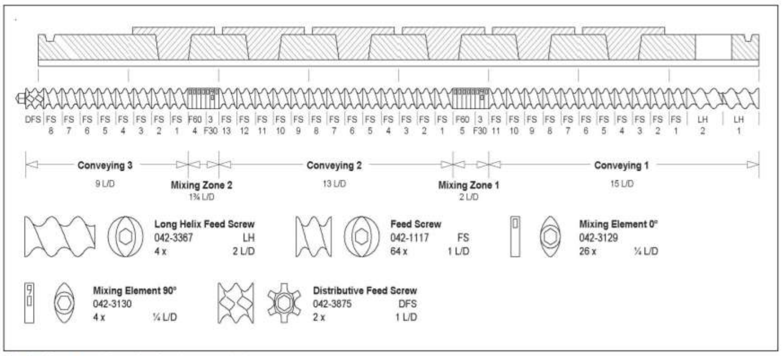

Fig. 3: Screw configuration for dry granulation.

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https://tools.thermofisher.com/content/sfs/brochures/LR79-e-Dry-granulation-as-a-twinscrew-process-in-pharmaceutical-applications.pdf 51

Granulated product from an Extruder-mixer

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Cases granulation

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Continuous granulation

Case study; granulation of aspartame

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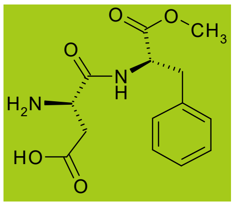
Case study – granulation and drying

- formation of aspartame granules in a turbo dryer
- aspartame ($C_{14}H_{18}N_2O_5$)
  - discovered in 1965
  - dipeptide of L-aspartic acid and L-phenyl alanine
  - most widely used artificial sweetener:
    beverages, table-top sweetener,
    dairy products, confectionaries
  - crystalline material



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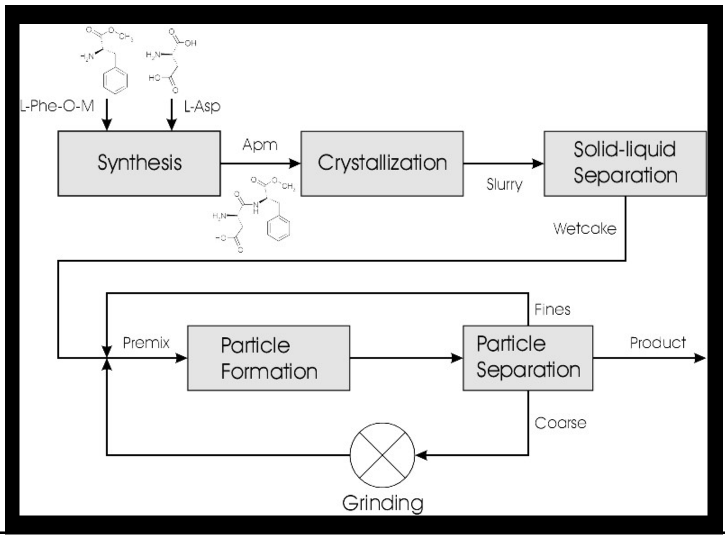
Aspartame production process



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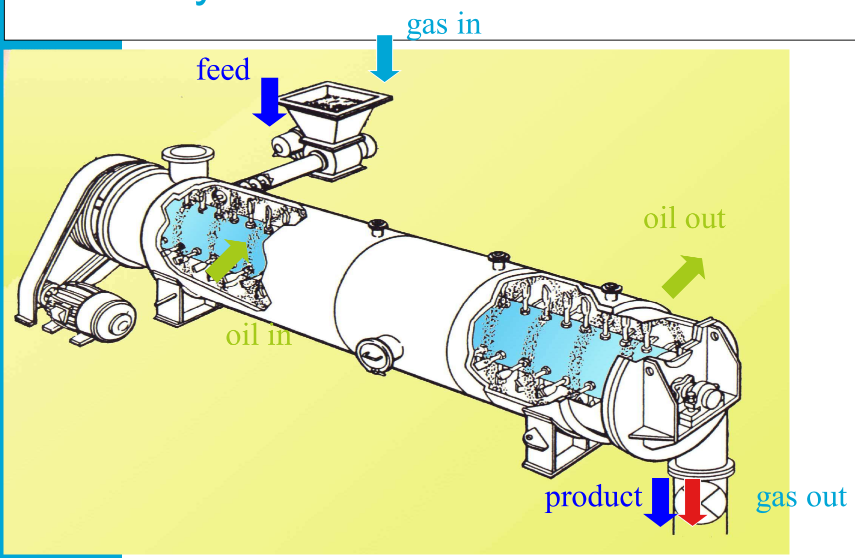
Turbo dryer – schematic



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Turbodryer

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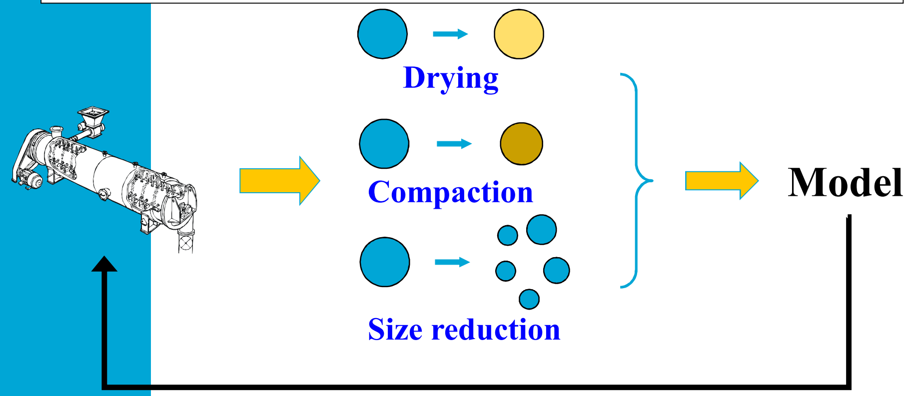
Aim and approach

- Control the particle size distribution of the product without adversely influencing other product properties



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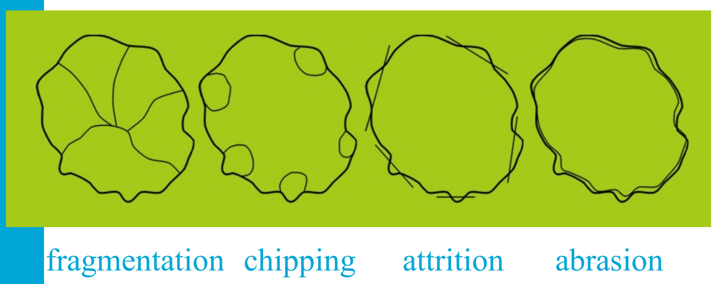
Size reduction – mechanisms

breakage behavior depends on the strength of the particles and on the direction and the extent of the applied forces



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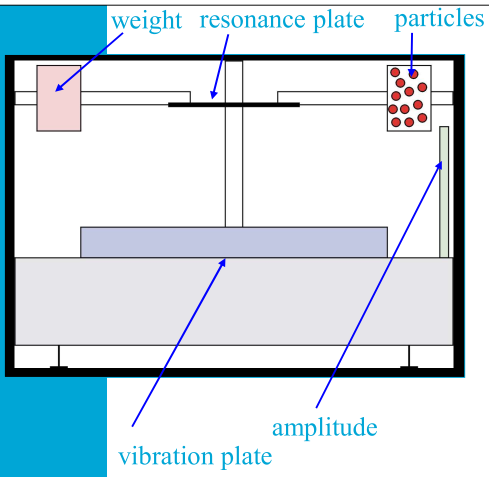
Size reduction – experiments



- 100 collisions per second
- no particle-particle interactions
- amplitude controls impact velocity
- controlled damage

experiments:
- mc = 0.02-0.33
- d_p = 600-700 µm
- v_{imp} = 6 m/s
- t_{vib} = 5-1280 s

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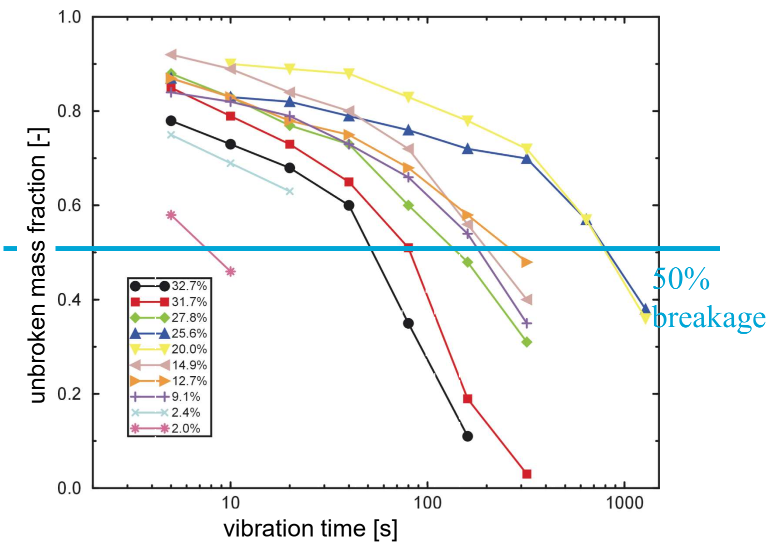
Size reduction – breakage curves



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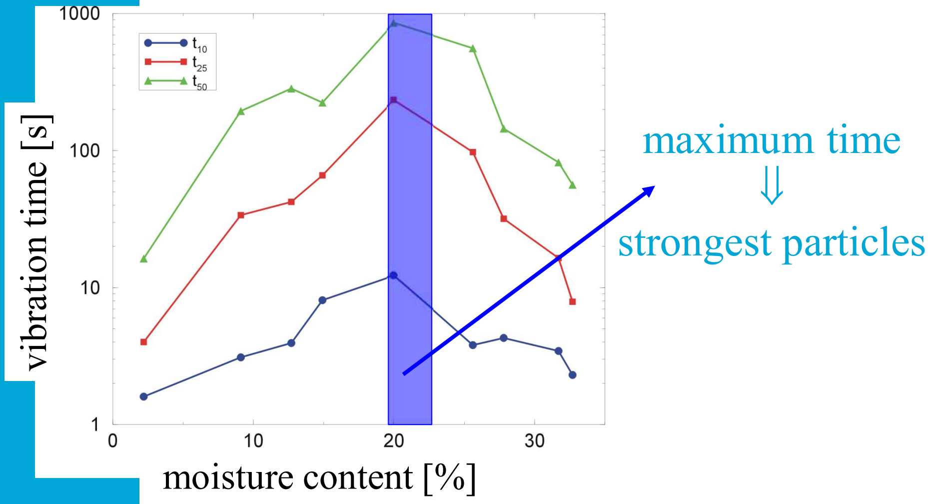
Size reduction – breakage times



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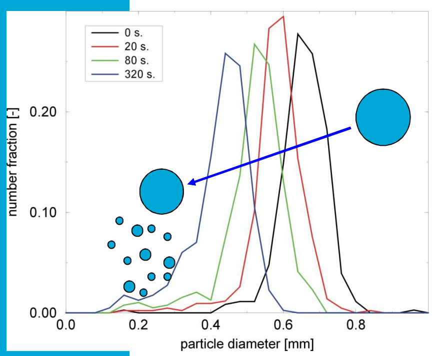
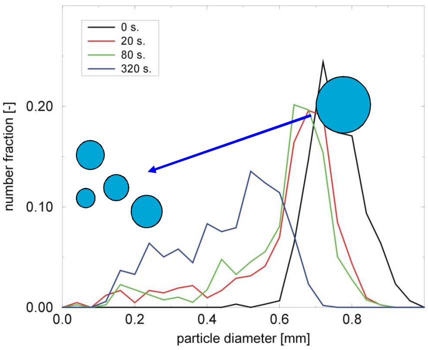
Size reduction – particle size distribution



mc = 12.7%



mc = 31.7%

- low moisture content: attrition
- high moisture content: fracture

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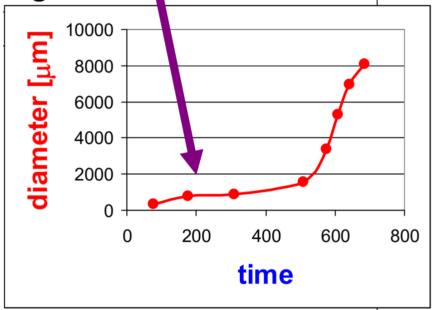
Compaction

- important mechanism in numerous particulate processes (e.g. induction time behavior in granulation)



- in turbo dryer
  - determines bulk density
  - strong interaction with drying

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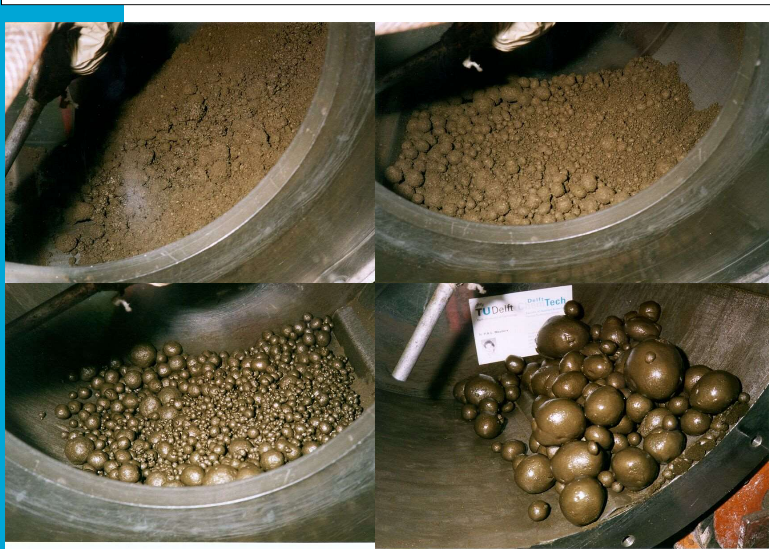
Compaction – example



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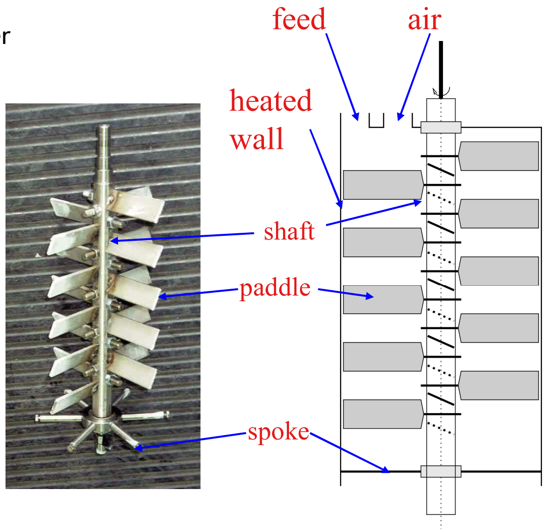
Compaction - experiments

- Open turbo dryer



measure:
- psd
- porosity
- moisture content

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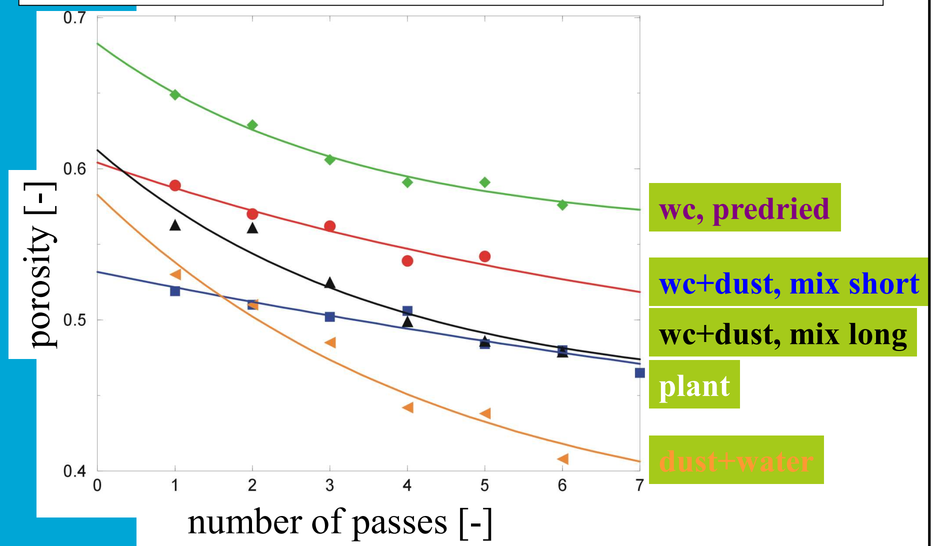
Compaction – porosity



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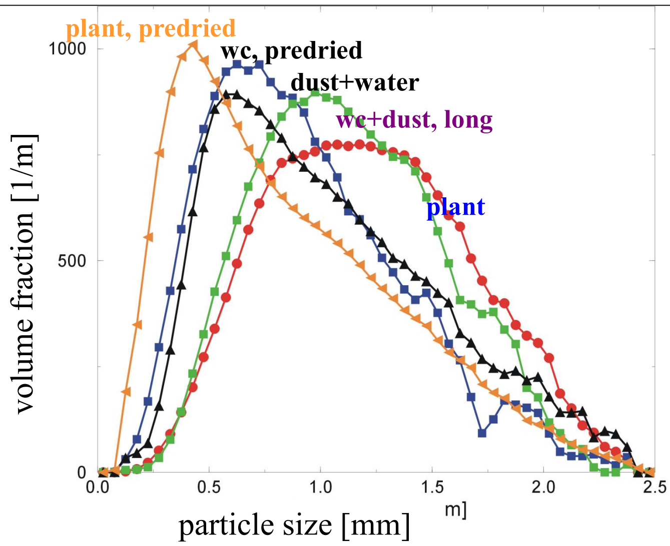
Compaction – particle size distribution



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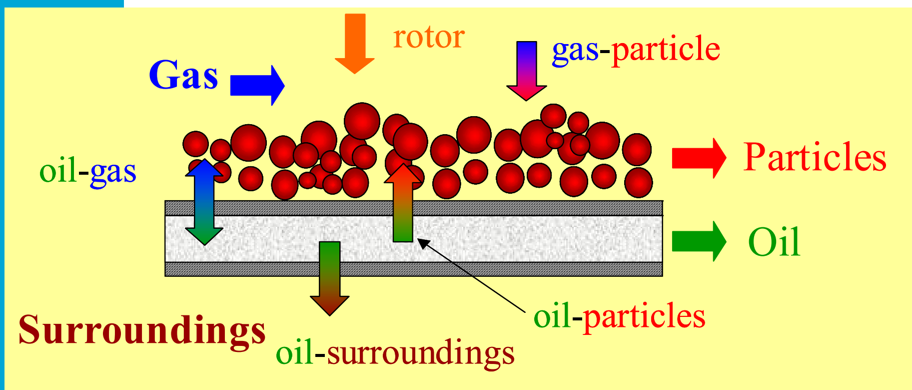
Modeling – schematic



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Modeling - approach

- predict outlet conditions: temperatures, moisture contents, psd
- validation using pilot plant experiments
- assumptions
- correction factors:
  - particle rotation (gas-particles)
  - heat from the wall (oil-particles)
- influence of rotor fitted from experiments
- use residence time experiments to describe particle motion

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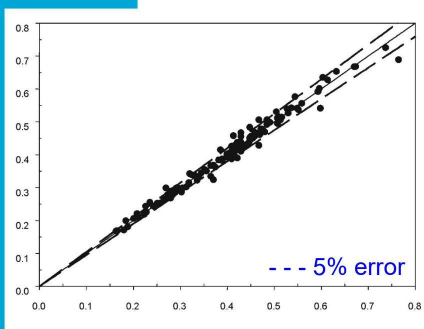
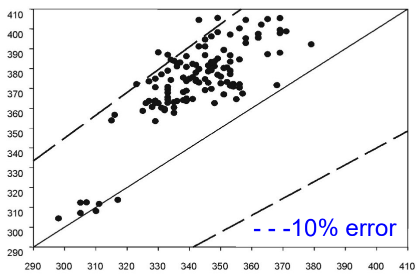
Modeling – predictions

- relatively good prediction of outlet conditions

moisture content solids



gas temperature



- pre

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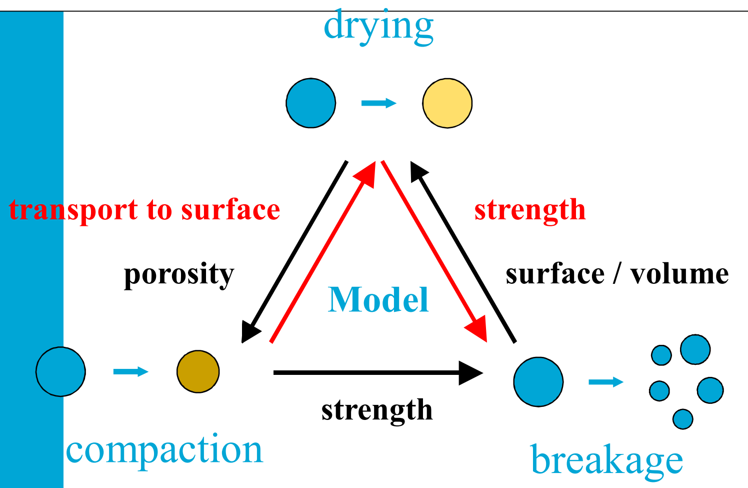
Conclusion – schematic



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