Technische Universität Braunschweig

iPAT Institut für Partikeltechnik

‘Wet grinding and dispersing

Influence of different parameters on the grinding and dispersing result

Carsten Schilde and Arno Kwade
Institute for Particle Technology
Technische Universität Braunschweig

Important models and characteristic parameters

iPAT Institut für Partikeltechnik

- Grinding and dispersing result is constant if
  - Kind of stress
  - Number of stress events (per original feed particle)
  - Stress intensity

  are kept constant.

- Stress energy $SE_{GM} = d_{GM}^3 \cdot \rho_{GM} \cdot v_t^2$

$$SE_P = d_{GM}^3 \cdot \rho_{GM} \cdot v_t^2 \left(1 + \frac{EI_P}{EI_{GM}}\right)^{-1}$$

- Specific energy $E_{m,P} = \frac{SZ_M \cdot \overline{SE}}{m_P} = v_E \cdot E_{m,M}$

Content

Filling time

- Grinding time is an important indicator for the progress in comminution
- Continuous process: progress is affected by flow rate of product suspension, which is inversely proportional to the mean residence time of the product particles in the mill
- Filling time is the time which is necessary to fill the free volume of the grinding chamber once with suspension

$$t_F = \frac{V_{GC}\ \ V_{GM}}{\dot{V}_{Susp}}$$

Relation between product fineness and grinding time

iPAT Institut für Partikeltechnik

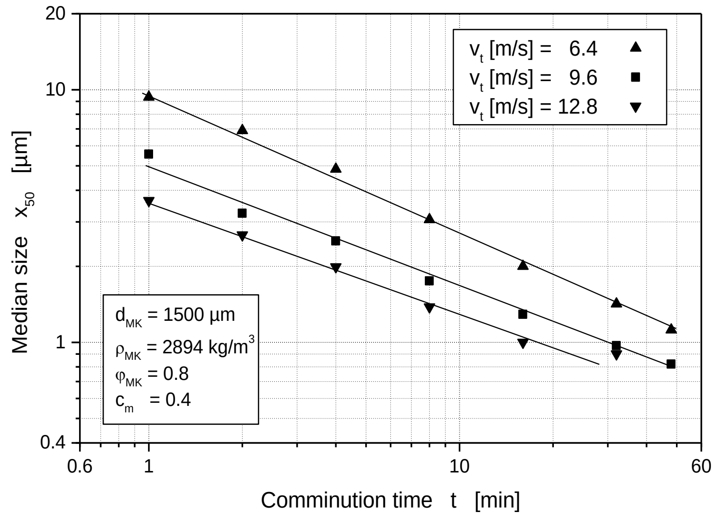


Fig. 4.1

Content

iPAT Institut für Partikeltechnik

Grinding of weak to medium-hard crystalline materials

iPAT Institut für Partikeltechnik

- Deformation of Grinding media lead to energy losses
  ➔ low for hard and crystalline products

$$BI \propto BI_{MK} = d_{MK}^3 \bullet \rho_{MK} \bullet v_t^2$$

- Reduced stress number for constant v_t, d_{GM}, c_m, φ_{GM}

$$BZ \propto BZ_r = n \bullet t \bullet \left(\frac{x}{d_{MK}}\right)^2$$

Product fineness as function of reduced stress number

iPAT Institut für Partikeltechnik

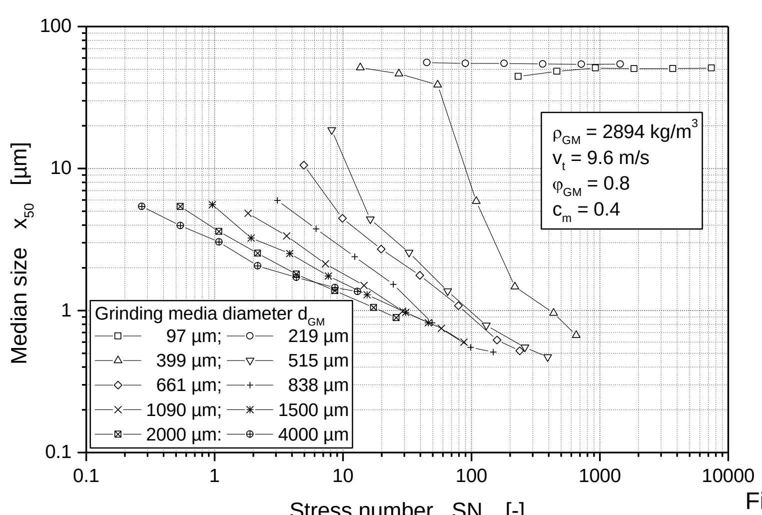


Fig. 4.2

Product fineness as function of reduced stress number at constant stress energy

iPAT
Institut für Partikeltechnik

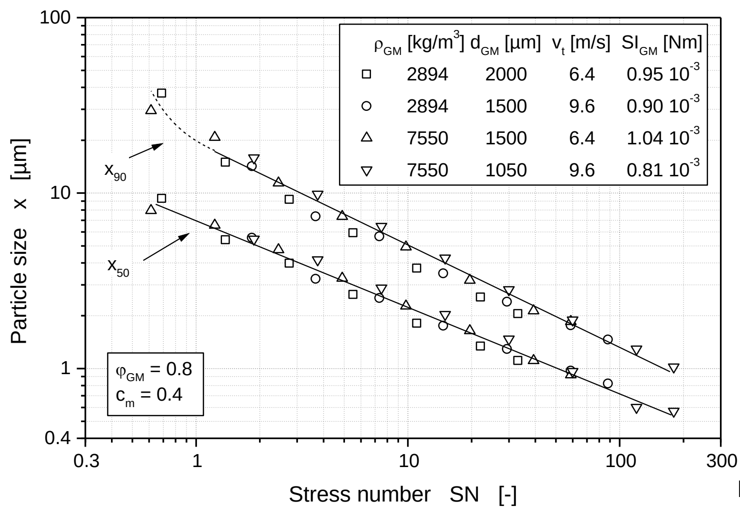


Fig. 4.3

Reduced stress number as function of stress energy for constant product fineness

iPAT
Institut für Partikeltechnik

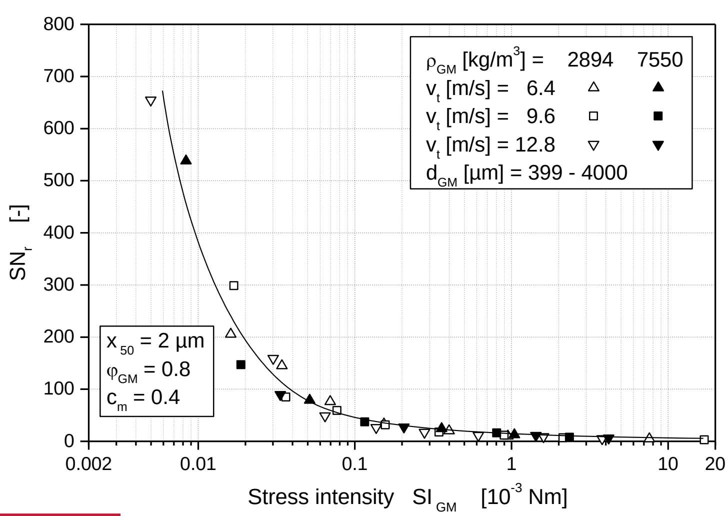


Fig. 4.4

Product fineness as function of specific energy for different tip speeds and grinding media densities

iPAT Institut für Partikeltechnik

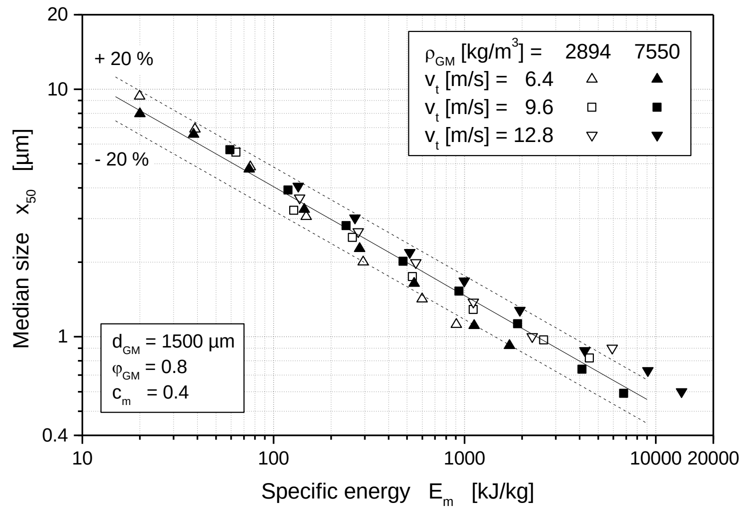
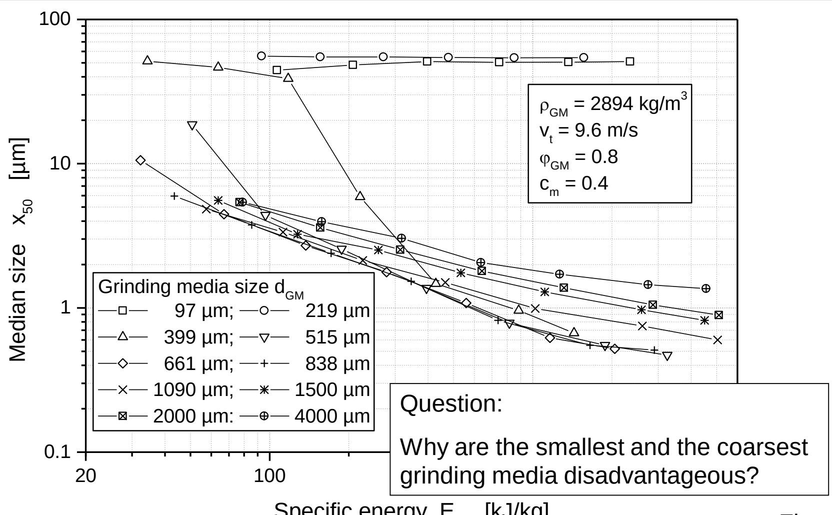


Fig. 4.5

Product fineness as function of specific energy for different grinding media sizes

iPAT Institut für Partikeltechnik



Question:

Why are the smallest and the coarsest grinding media disadvantageous?

Fig. 4.6

Product fineness as function of grinding media size for different tip speeds and grinding media densities

iPAT Institut für Partikeltechnik

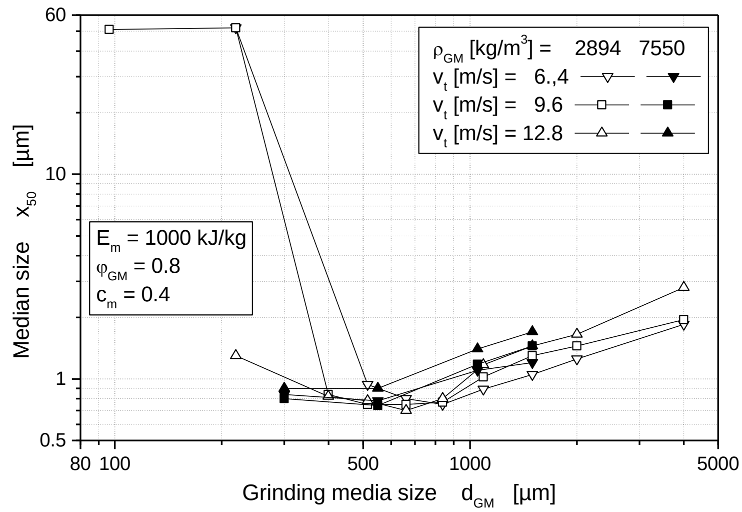


Fig. 4.9

Technische Universität Braunschweig

Product fineness as function of specific energy for different grinding media sizes

iPAT Institut für Partikeltechnik

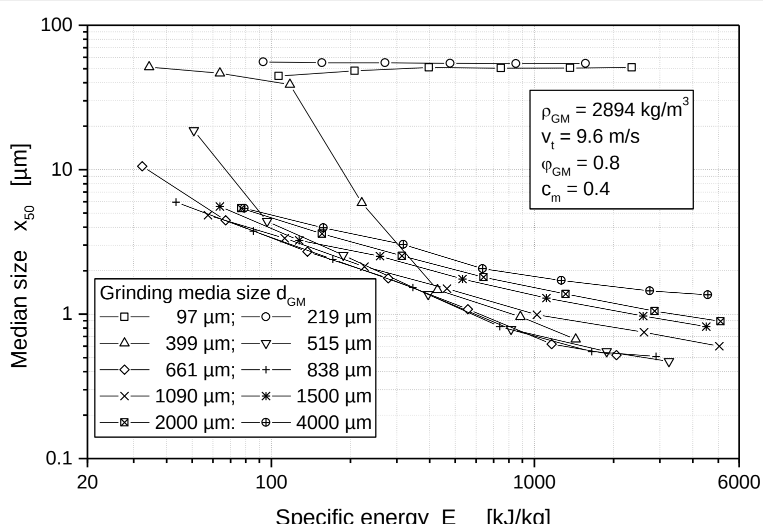


Fig. 4.6

Technische Universität Braunschweig

Product fineness as function of specific energy for constant stress energy (~ 0,9*10^{-3} Nm)

iPAT Institut für Partikeltechnik

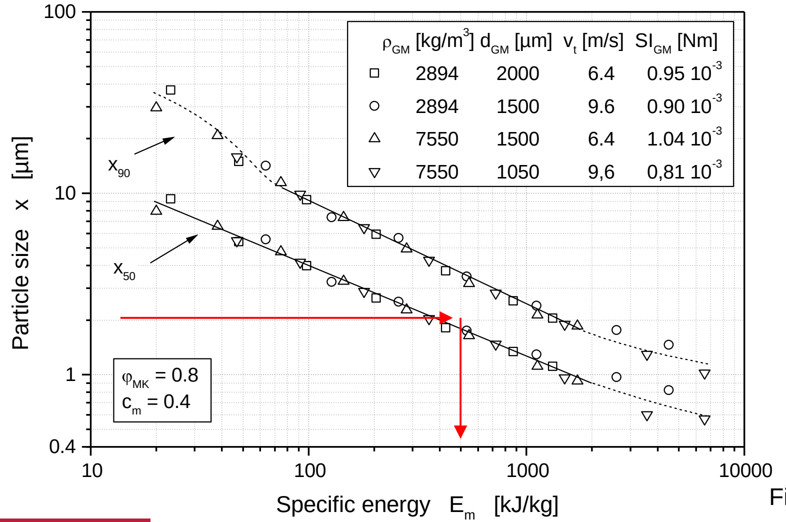


Fig. 4.10

Specific energy required for a median size of 2 µm as function of stress energy

iPAT Institut für Partikeltechnik

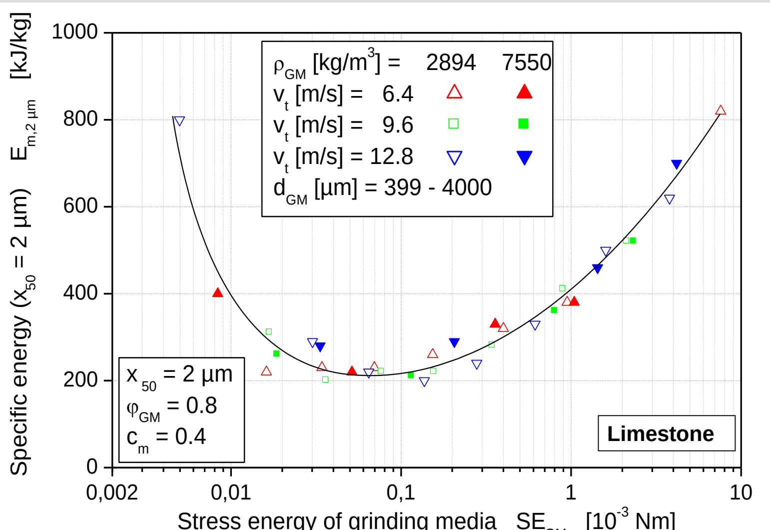


Fig. 4.11

Effect of stress energy on energy utilization

iPAT Institut für Partikeltechnik

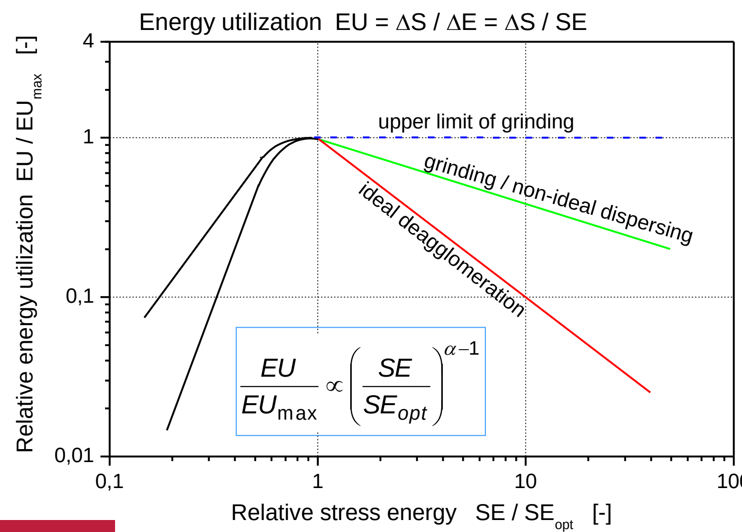


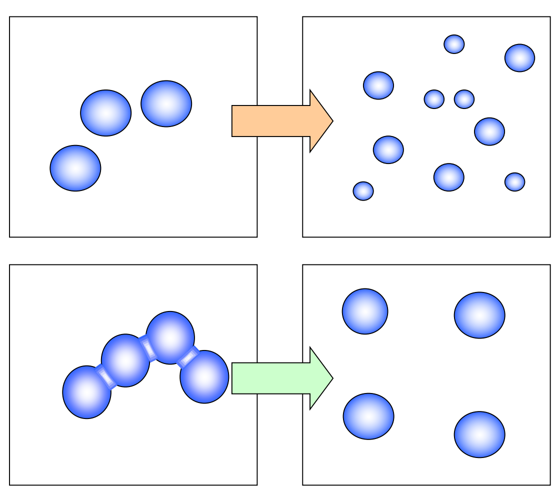
Fig. 3.10

Difference Grinding and Dispersing

iPAT Institut für Partikeltechnik

Grinding:

Dispersing:



Dispersing of inks

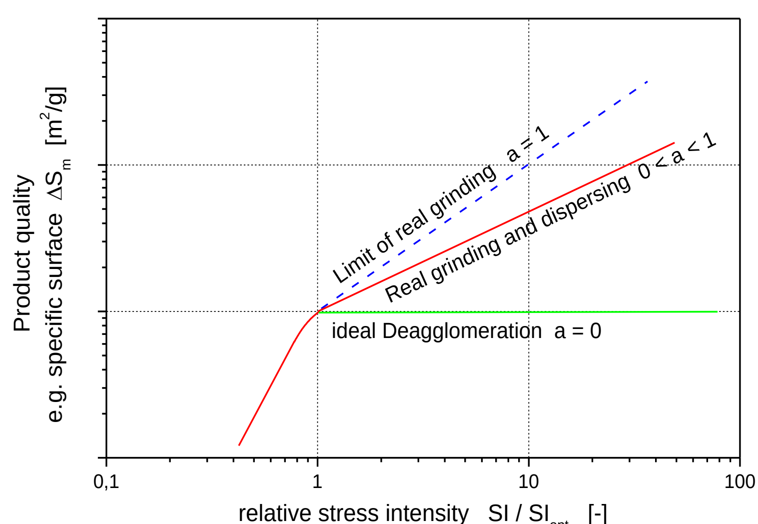
iPAT Institut für Partikeltechnik

- During a dispersion process different sub processes run side by side, which are all together determine the dispersion result:
  - Loading the liquid phase of the dispersion batch with pigment agglomerates and wetting of the solid surface by the liquid phase
  - Mechanical decomposition of the agglomerates (Deagglomeration)
  - Stabilisation of smaller agglomerates and primary particles against a beginning new agglomeration (flocculation)

- Consider
  - Primary particles sometimes so small that further grinding is nearly not possible or also not desired, respectively.
  - Product quality (gloss, intensity of colour,…) depend on the particle size distribution, but also on other factors.
  - Product quality is particularly determined by the formulation

Product quality as function of stress energy

iPAT Institut für Partikeltechnik



Fineness as function of stress number for deagglomeration of an "ideal" pigment

iPAT Institut für Partikeltechnik

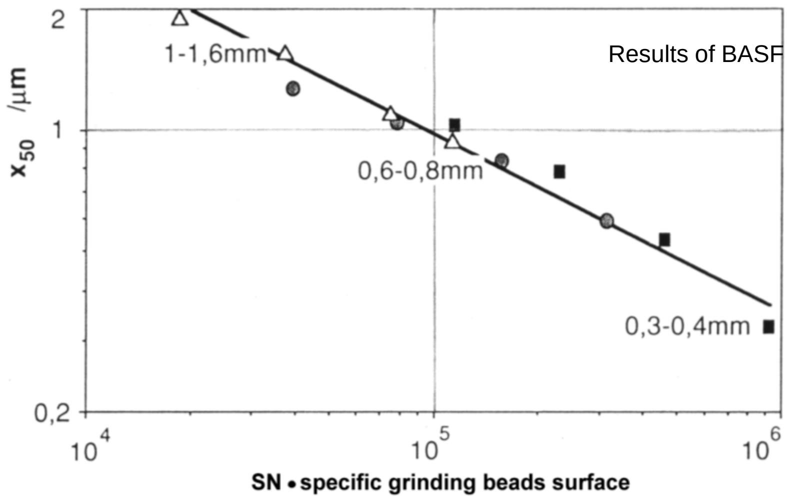


Fig. 4.20

Fineness as function of specific energy for deagglomeration of an "ideal" pigment

iPAT Institut für Partikeltechnik

Results of BASF

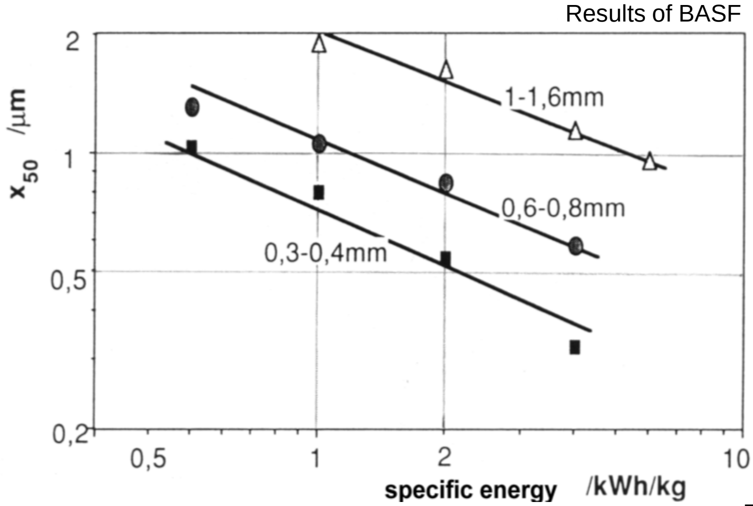


Fig. 4.21

Specific energy as function of stress energy for deagglomeration of an “ideal” pigment

iPAT Institut für Partikeltechnik

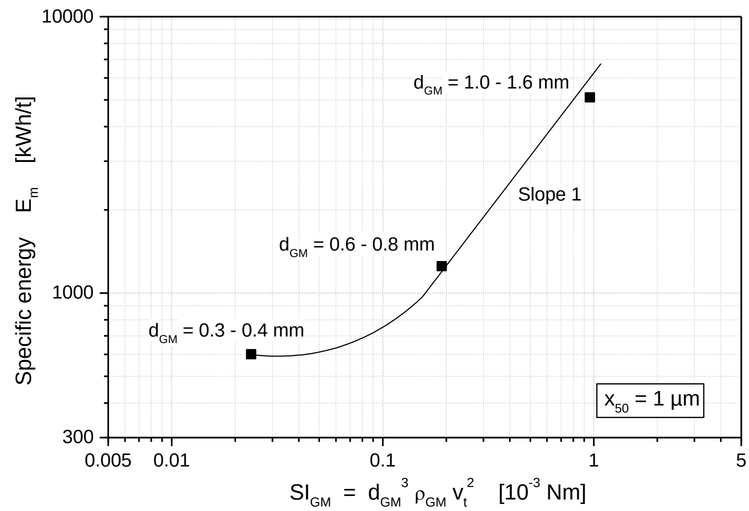


Fig. 4.22

Intensity of colour as function of specific energy for different stirrer tip speeds (dispersing of water basis ink)

iPAT Institut für Partikeltechnik

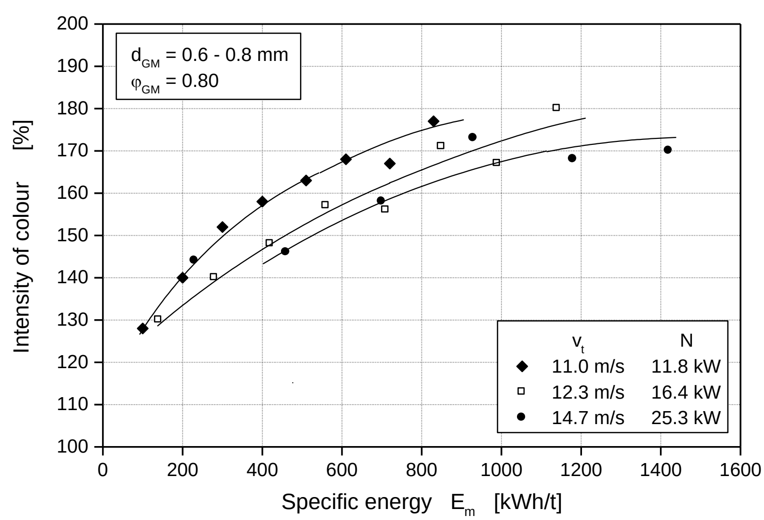


Fig. 4.23

Relative specific energy required to disperse an ink to a transparency of 80% and 100%

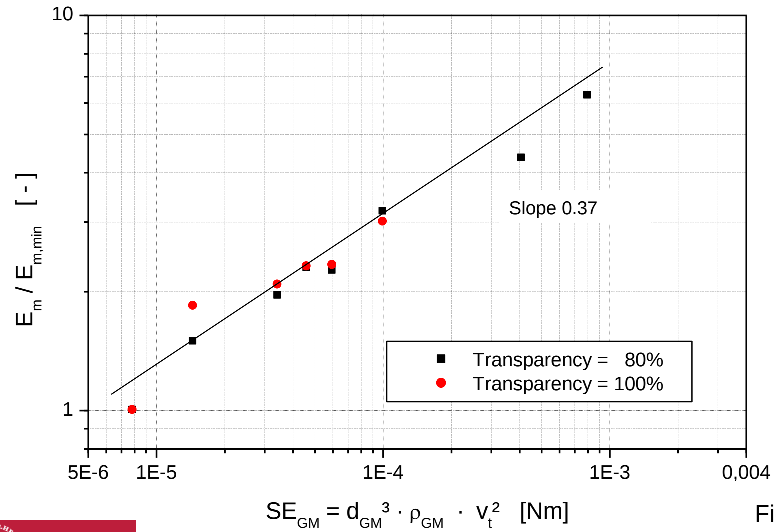


Fig. 4.24

Disintegration of yeast cells
Disintegration rate as function of specific energy

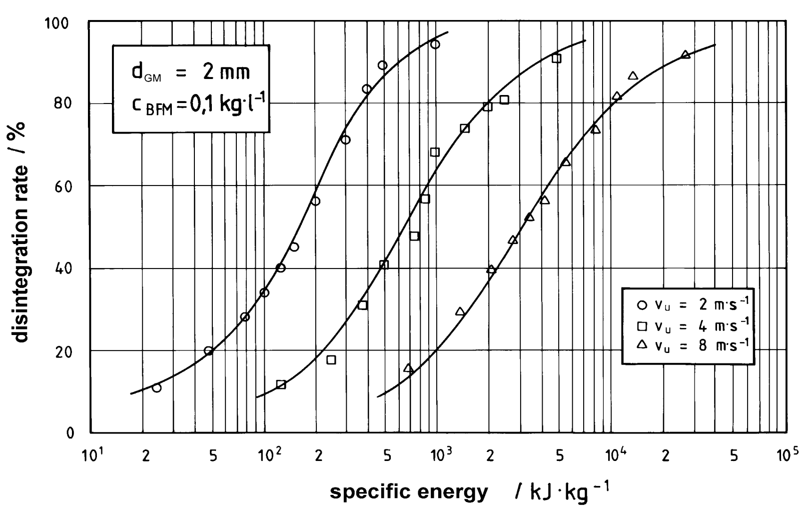


Fig. 4.28

Specific energy for a disintegration rate of 60% as function of stress energy

iPAT Institut für Partikeltechnik

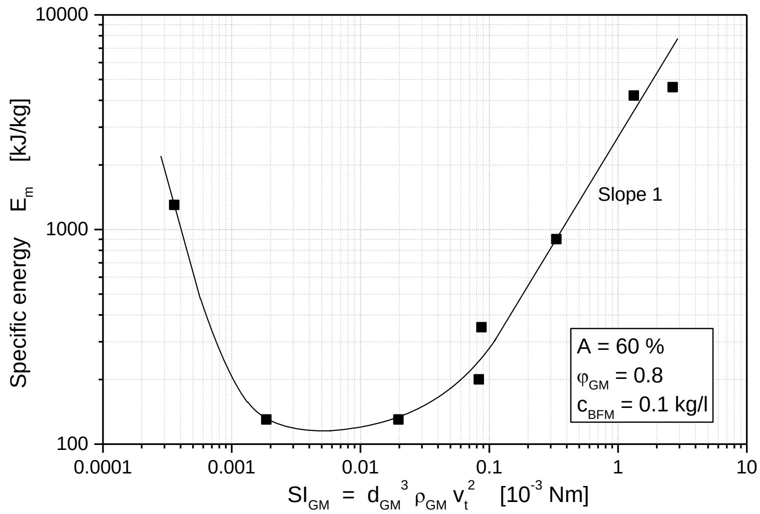


Fig. 4.30

Specific energy consumption for different products as function of stress energy

iPAT Institut für Partikeltechnik

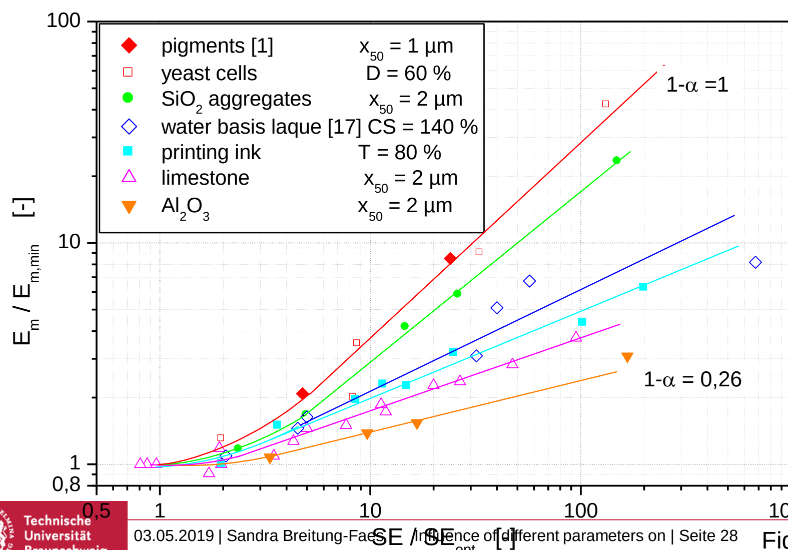


Fig. 4.31

Relation between specific energy required for a certain product quality and stress energy

iPAT Institut für Partikeltechnik

$SE > SE_{opt}$:

$$\frac{E_m}{E_{m,min}} = \left(\frac{SE}{SE_{opt}}\right)^{1-\alpha}$$

where $\alpha = 0$ for ideal deagglomeration and cell desintegration
$0 < \alpha < 1$ für real grinding and dispersing

Exponents α for different products

Tab. 4.1

	Pigment-agglomerats	Yeast-cells	SiO_2-aggregats	Water-basis laque	Printing ink	Lime-stone	Al_2O_3
$1-\alpha$	≈ 1	1	0,77	≈ 0,4	0,37	0,33	0,26
α	≈ 0	0	0,23	≈ 0,6	0,63	0,67	0,74

Conclusion

iPAT Institut für Partikeltechnik

- For each grinding material and each feed size an optimum stress energy of the grinding media exist at which the specific energy requirement is the lowest
- If the stress energy is too small the stress energy is not sufficient to break the product particles and if the stress energy is too high the energy utilization drops because of higher energy dissipations (especially due to friction)
- For many materials and formulations the stress energy can be described by the three operating parameters size and density of the grinding media as well as stirrer tip speed
- For each grinding media an increase in stress energy has a different effect of the increase in specific energy (for $SE > SE_{opt}$) which can be described by an exponent α of a potential function

Production rate of stirred media mills

iPAT Institut für Partikeltechnik

- Basic equation of production rate or mass flow rate:

$$\dot{m}_P = \frac{\overline{P} - P_0}{E_m}$$

- Maximum production rate is achieved, if
  - **power input into grinding chamber, $P - P_0$, is as high as possible**
  - **specific energy for production of certain product quality, E_m, is as low as possible.**
- Set of operating parameters, which causes the highest $P - P_0$ and the lowest E_m

Optimization strategy

iPAT Institut für Partikeltechnik

1. The grinding material has to be chosen which is most favourable with respect to wear and cost of the grinding media itself as well as to wear of the mill
   - Density ρ_{GM} and Young´s modulus El_{GM} of the grinding media
2. The optimum stress energy has to be determined by a few grinding tests
   - Optimum stress energy SE_{GM} or SE_P respectively
3. The stirrer tip speed should be estimated or determined in a way, that the power input is as high as possible. Thereby it has to be ensured that the product temperature is not higher than the maximum product temperature and that the mechanical load of the machinery and the grinding media does not become too high.
   - Stirrer tip speed v_t

Optimization strategy

iPAT Institut für Partikeltechnik

4. Using the optimum stress energy and the maximum stirrer tip speed determined in step 3 the optimum grinding media size can be determined:

$$d_{GM} = \sqrt[3]{\frac{SI_{opt}}{v_t^2 \; \rho_{GM}}} \quad \text{with} \quad v_t = \pi \; d_S \; n \qquad (4.13)$$

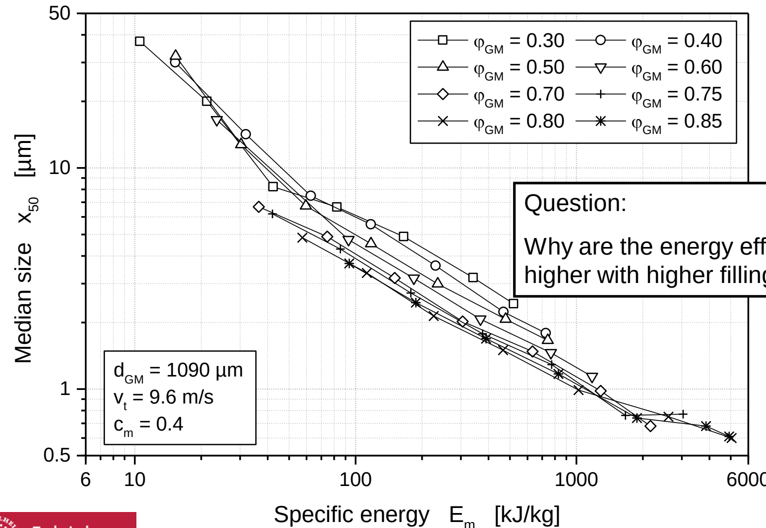
5. If the grinding media size cannot be chosen as necessary according to equation (4.13), the smallest grinding media size being possible should be employed.
6. An iteration step should prove, that for the specific grinding media size obtained in step 4 the power input is still as high as possible. If this is not true, step 3 to 5 have to be repeated
7. It has to be noted, that beside a maximum power input and optimum stress energy further conditions like wear, grinding media packing and residence time distribution has to be taken into account as well.

Content

iPAT Institut für Partikeltechnik

Product fineness as function of specific energy for different filling ratios of the grinding media

iPAT Institut für Partikeltechnik



Question:

Why are the energy efficiency higher with higher filling ratios?

Fig 4.33

Effect of filling ratio on relationship between product fineness and specific energy

iPAT Institut für Partikeltechnik

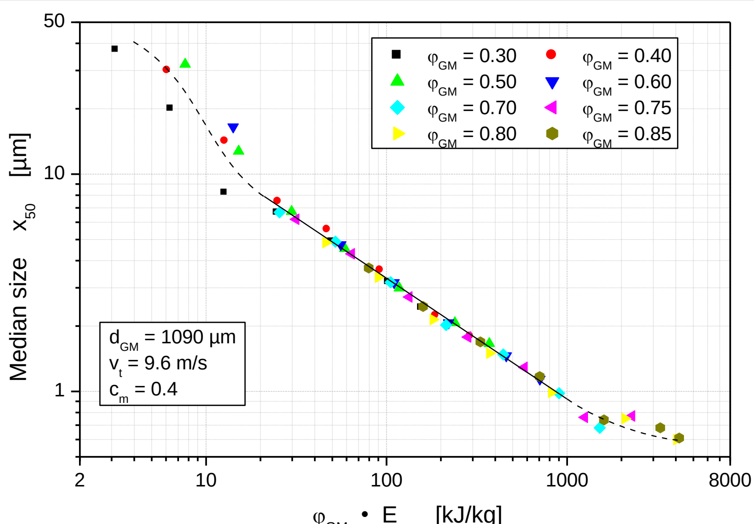
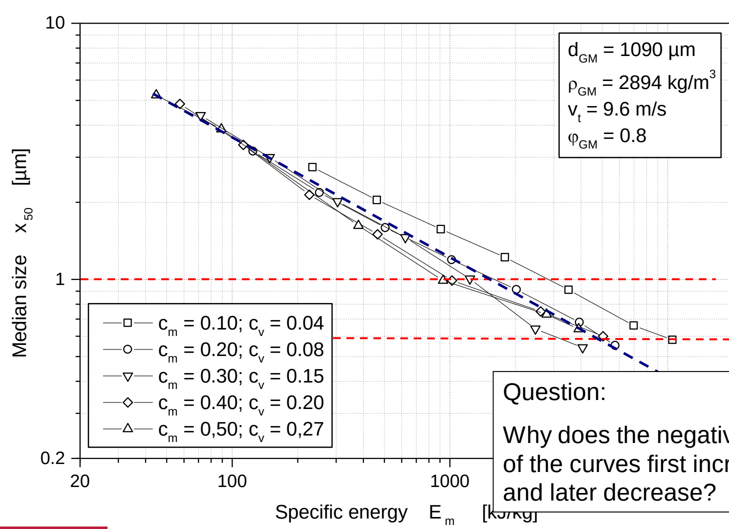


Fig. 4.34

Content

Effect of solids concentration on relation between product fineness and specific energy



Question:

Why does the negative slope of the curves first increase and later decrease?

Fig 4.36

Specific energy as function of solids mass concentration for different product median sizes

iPAT Institut für Partikeltechnik

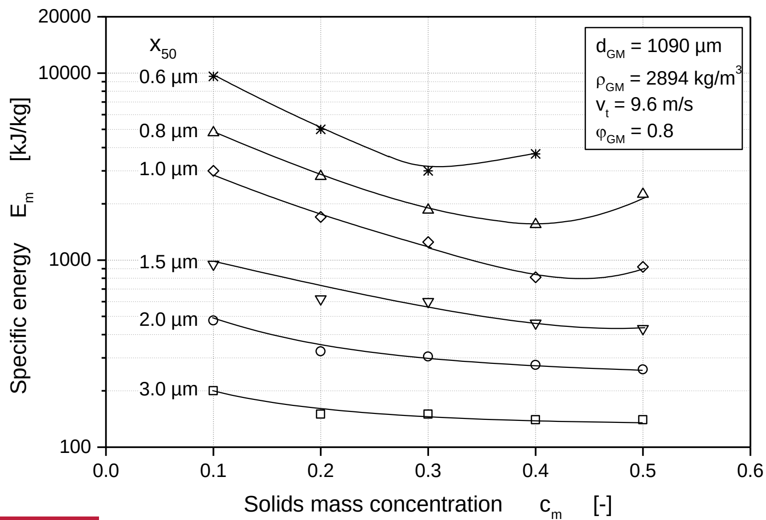


Fig 4.37

Torque of the stirrer as function of median size for different solids mass concentrations

iPAT Institut für Partikeltechnik

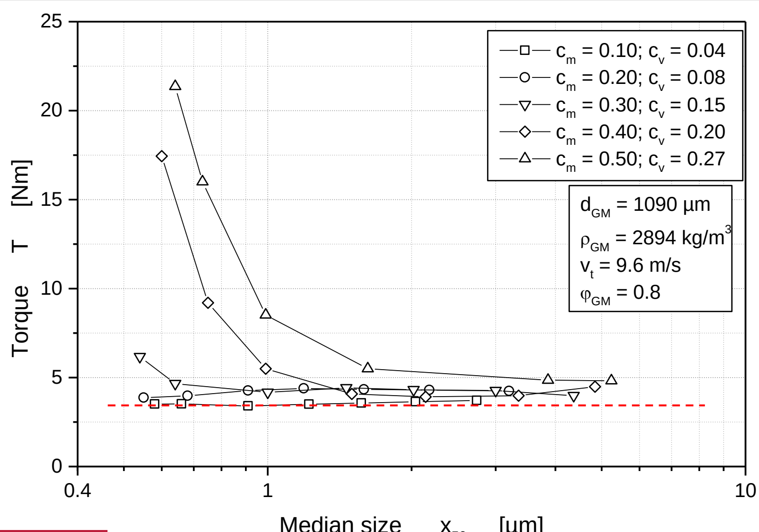


Fig 4.38

Effect of dispersing agent on relation between product fineness and specific energy

iPAT Institut für Partikeltechnik

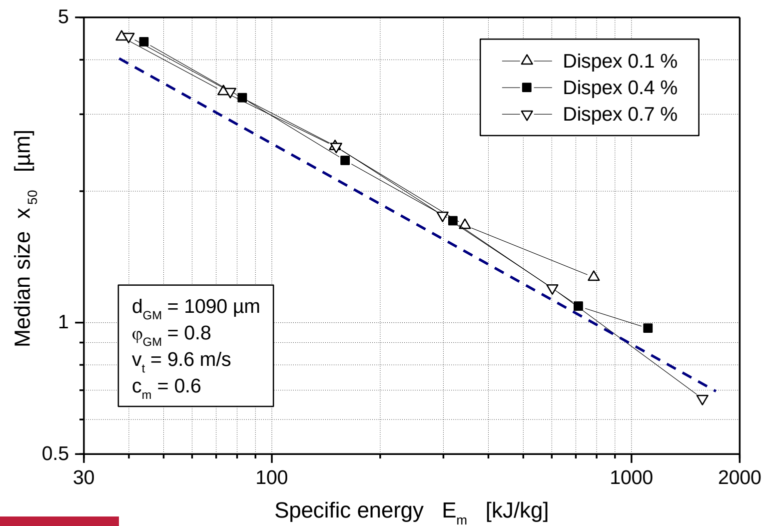


Fig 4.39

Effect of fluid base on specific energy requirement

iPAT Institut für Partikeltechnik

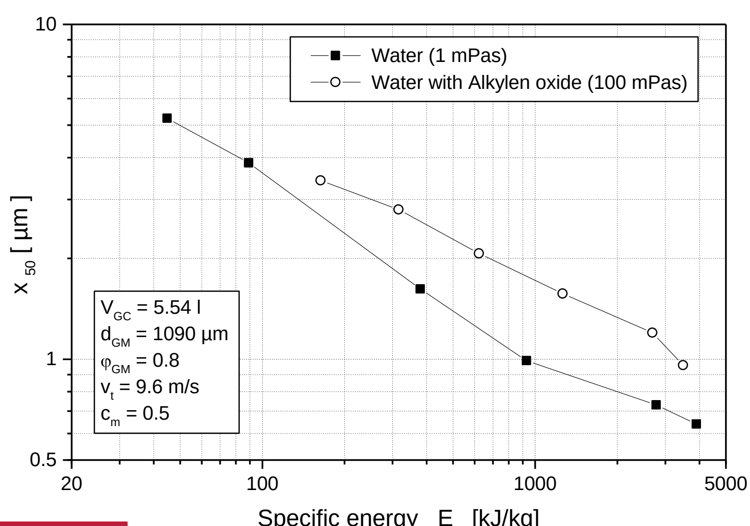


Fig 4.43

Content