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How does increased filler amount affect properties of graphical and packaging papers? – Modelling studies

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Outline

1. Background – quality of paper for recycling
2. Pulp vector
3. Modells for mechanical and optical paper properties (and the influence of fillers)
4. How does increased filler amount affect properties of graphical and packaging papers? – Modelling studies
5. Summary

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1. Background

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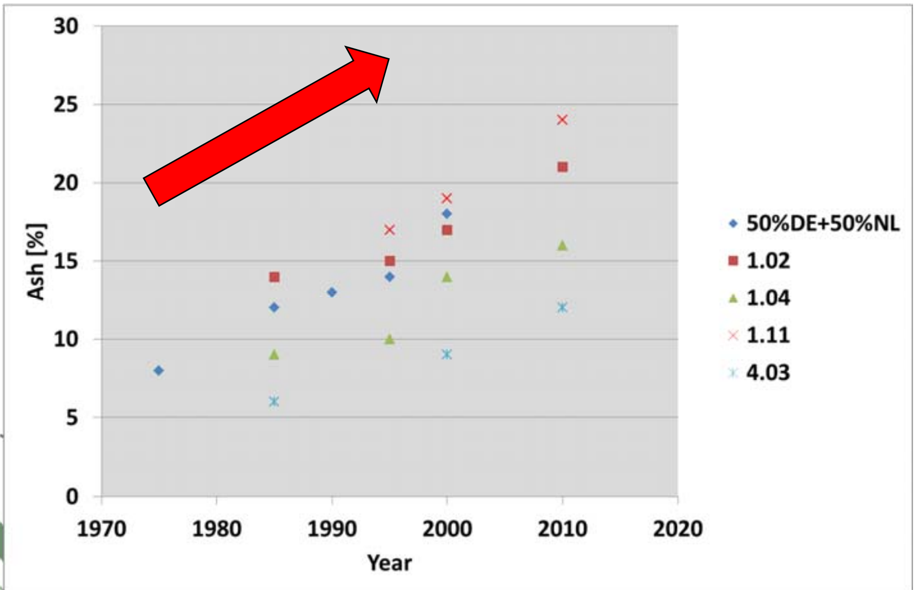
Background – Ash content in *PfR*

Increase of ash content due to

- Increase of application of filler and coating pigments
- Increase of utilization rate of paper for recycling (*PfR*)



Sources:

Voith 2004

TU Darmstadt 2010

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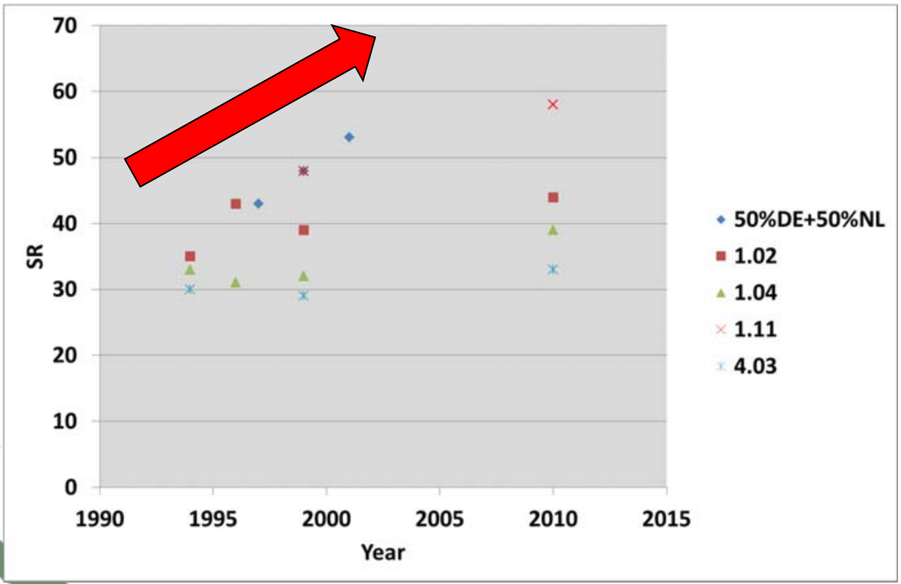
Background – Schopper-Riegler value of *PfR*

Deterioration of dewatering behaviour



Source:

Voith 2004

TU Darmstadt 2010

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2. Pulp Vector

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Pulp vector

Summary of pulp characteristics which
- highly influence the paper properties and paper machine behaviour
- can be changed by raw material selection and stock preparation processes

How fillers are taken into account

			Characteristic	Symbol	Unit	
			Spec. Mass (otro)	w	g/m2	Easy to measure
			Schopper-Riegler Value	SR	°	Easy to measure
			Water Retention Value	WRV	%	Measureable
Fibres	Morphological characteristics	Fines	Fines fraction (Mass share)	FS	%	Easy to measure
Fibres	Morphological characteristics	Fines	Fibre lenghth (Fines Fraction)	FLFS	µm	Easy to measure
Fibres	Morphological characteristics	Short fibres	Short fibre fraction (Mass share)	SF	%	Easy to measure
Fibres	Morphological characteristics	Short fibres	Fibre lenghth (Short Fibre Fraction)	FLSF	µm	Easy to measure
Fibres	Morphological characteristics	Short fibres	Fibre width (Short Fibre Fraction)	WISF	µm	Easy to measure
Fibres	Morphological characteristics	Short fibres	Cell wall thickness (Short fibre fraction)	CWTSF	µm	Easy to measure
Fibres	Morphological characteristics	Long fibres	Long fibre fraction (Mass share)	LF	%	Easy to measure
Fibres	Morphological characteristics	Long fibres	Fibre lenghth (Long Fibre Fraction)	FLLF	µm	Easy to measure
Fibres	Morphological characteristics	Long fibres	Fibre width (Long Fibre Fraction)	WILF	µm	Easy to measure
Fibres	Morphological characteristics	Long fibres	Cell wall thickness (Long fibre fraction)	CWTLF	µm	Easy to measure
Fibres	Physical characteristics		Stiffness	d		Not easy to measure
Fibres	Physical characteristics		Elastic Modulus	Ef	GPa	Not easy to measure
Fibres	Physical characteristics		Shear Modulus	Gf	Gpa	Not easy to measure
Fibres	Physical characteristics		Tensile Strength	FZ	MPa	Not easy to measure
Fibres	Physical characteristics		Bonding Strength	b	MPa	Not easy to measure
Fibres	Physical characteristics		Spec. Light Scattering Coeff.	SFib	m2/kg	Measureable
Fibres	Physical characteristics		Spec. Light Absorption Coeff.	KFib	m2/kg	Measureable
Fibres			~~Lignin Content~~	~~LIG~~	%	Measureable
Minerals			Minerals (as Ash 525°)	ASH525	%	Easy to measure
Minerals			Spec. Light Scattering Coeff.	SFill	m2/kg	Measureable
Minerals			Spec. Light Absorption Coeff.	KFill	m2/kg	Measureable
Dirts			~~ERIC value~~	~~ERIC~~	%	Measureable
Dirts			Ink Detachment	ID	%	Measureable
Dirts			Specific Dirt Area	Aink	mm²/m²	Measureable
Dirts			Small dirts (<100 µm)	SD	%	Measureable
Dirts			Large dirts (>100 µm)	LD	%	Measureable
Dirts			Spec. Light Scattering Coeff.	SInK	m2/kg	Measureable
Dirts			Spec. Light Absorption Coeff.	KInK	m2/kg	Measureable

Easy to measure

Measureable

Not easy to measure

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3. Modells for mechanical and optical paper properties (and the influence of fillers)

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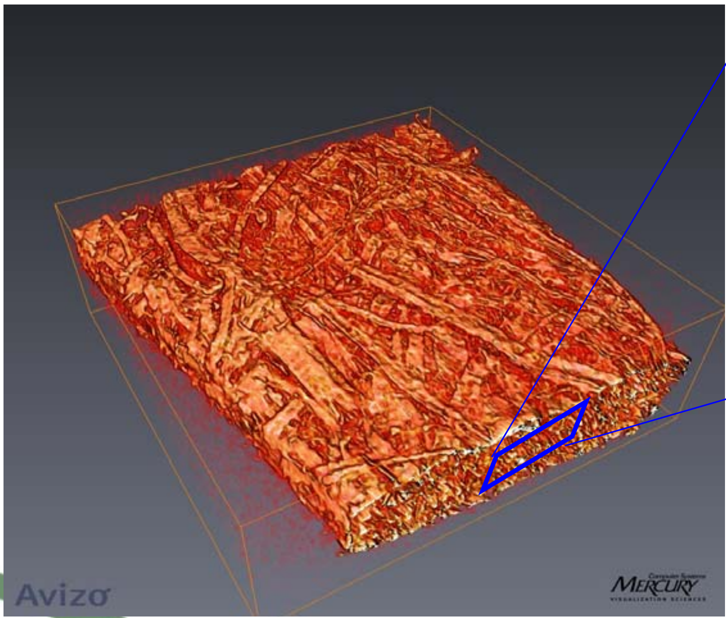
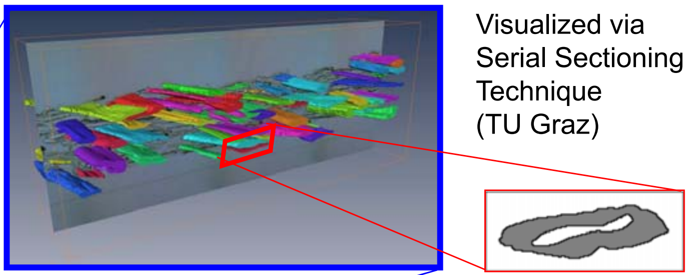
Fibre Network of a paper sheet



CT image of a paper sample (1mm x 1mm x 0,2mm)



Visualized via Serial Sectioning Technique (TU Graz)

Paper – a packed stochastic network of flat nearly collapsed cellulose fibres with stochastically distributed fibre dimensions

Fibre dimensions (typically):
Length (*FL*) ~ 0,5 … 3 mm
Diameter (*D*) ~ 5 … 30 µm
Height (*H*) ~ 2 … 10 µm

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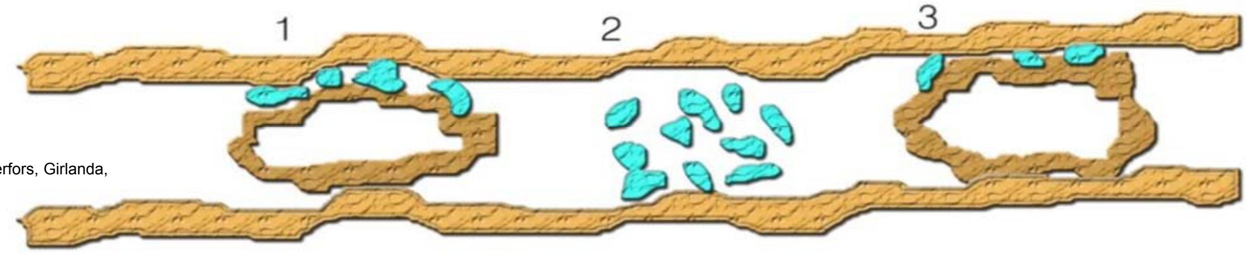
Basic Mechanisms of Filler Inclusion



Q.: Fellers, Ankerfors, Girlanda, Lucisano 2007

Prevention of bonding

Weakening of bonding

Fibre Network Spec. Volume / Relative Bonded Area	↗ ↘	→ →	→ →
Specific Bond Strength (per bonded area)	→	→	↘

Mechanical paper properties

Expansion

Mean Fibre Network "Distance"

$$d(ASH_{525}) = d_0 \cdot \frac{(1-\delta \cdot ASH_{525})}{1-ASH_{525}}$$

Integration

Shear Bond Strength

$$b(ASH_{525}) = b_0 \cdot \frac{(1-ASH_{525})}{1-\beta \cdot ASH_{525}}$$

Density / Spec. Volume

$$\frac{1}{\rho_0} := V_0 := \frac{d}{D \cdot \rho_W}$$

Relative Bonded Area

$$RBA = \frac{D^2}{d(D+H)}$$

Elastic Modulus

$$E = \frac{1}{3}\left(1-\frac{D}{FL \cdot RBA}\sqrt{\frac{E_f}{2G_f}}\right)\frac{\rho_0}{\rho_W}E_f$$

Page & Seth (2008)

Tensile Index

$$\frac{1}{T} = \frac{9}{8Z} + \frac{12 \cdot A_Q \cdot \rho_W}{b \cdot P \cdot FL \cdot RBA}$$

Page (1969)

Optical paper properties - Kubelka-Munk-Theory

Explains optical behaviour of semi transparent materials due to light reflectance, transmittance and adsorption.

Linear mass weighted additivity

$$K_i = \frac{w_{Fib,i}K_{Fib,i} + w_{Ash,i}K_{Fill,i} + w_{Ink,i}K_{Ink,i}}{w_i}$$

$$S_i = \frac{w_{Fib,i}S_{Fib,i} + w_{Ash,i}S_{Fill,i} + w_{Ink,i}S_{Ink,i}}{w_i}$$

influenced by fillers

Reflectance/Transmittance (Single layer)

$$R_{0,i} = \frac{\exp\left(S_i w_i\left(\frac{1}{R_{\infty,i}} - R_{\infty,i}\right)\right) - 1}{\frac{1}{R_{\infty,i}}\exp\left(S_i w_i\left(\frac{1}{R_{\infty,i}} - R_{\infty,i}\right)\right) - R_{\infty,i}}$$

$$R_{\infty,i} = 1 + \frac{K_i}{S_i} - \sqrt{\frac{K_i^2}{S_i^2} + 2\frac{K_i}{S_i}}$$

$$T_i = \frac{(1-R_{\infty,i})^2 \exp\left(-\frac{1}{2}S_i w_i\left(\frac{1}{R_{\infty,i}} - R_{\infty,i}\right)\right)}{1-R_{\infty,i}^{\ 2}\exp\left(S_i w_i\left(\frac{1}{R_{\infty,i}} - R_{\infty,i}\right)\right) - R_{\infty,i}}$$

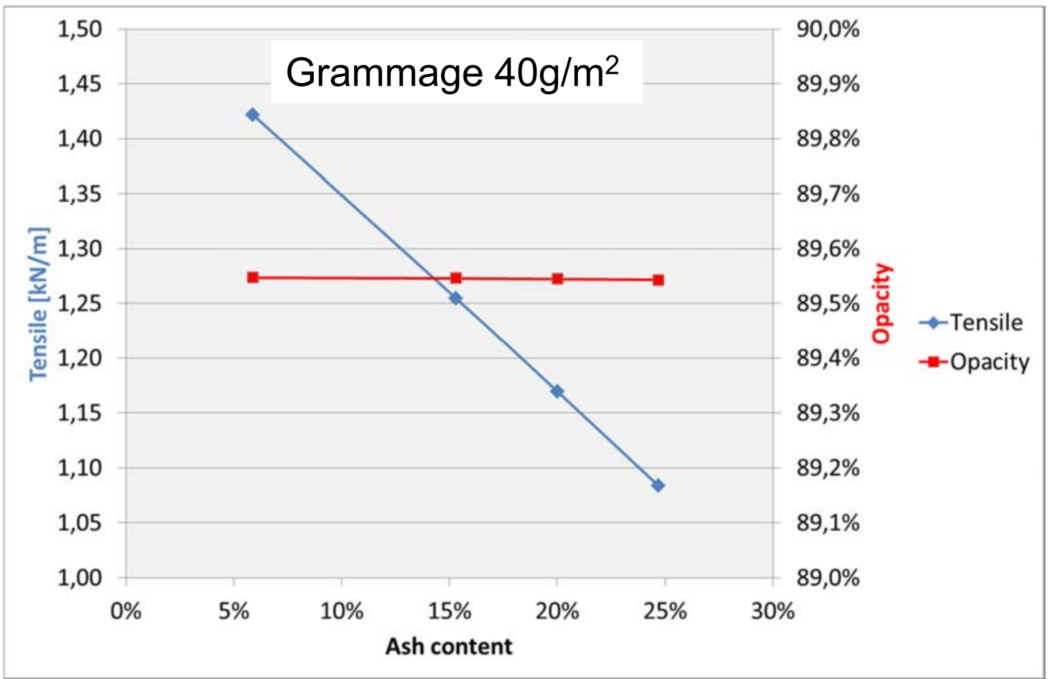
Opacity/Brightness

$$O = \frac{R_0}{R_\infty}$$

$$R_{\infty,457}$$

4. How does increased filler amount affect properties of graphical and packaging papers? – Modelling studies

Example 1.1: Influence of ash content on Opacity and Tensile-Index



Reducing ash content - an option to reduce grammage?

Used Kubelka-Munk coefficients for simulating Opacity

Fibre:
S_{Fib}=75 m^2/kg, K_{Fib}=1.0 m^2/kg

Ash:((Mixture of pigments, ink and other inorganics):
S_{Fill}=151 m^2/kg, K_{Fill}=0.58 m^2/kg

The optical behavior of other Fibre/Filler-Systems can be different than this one.

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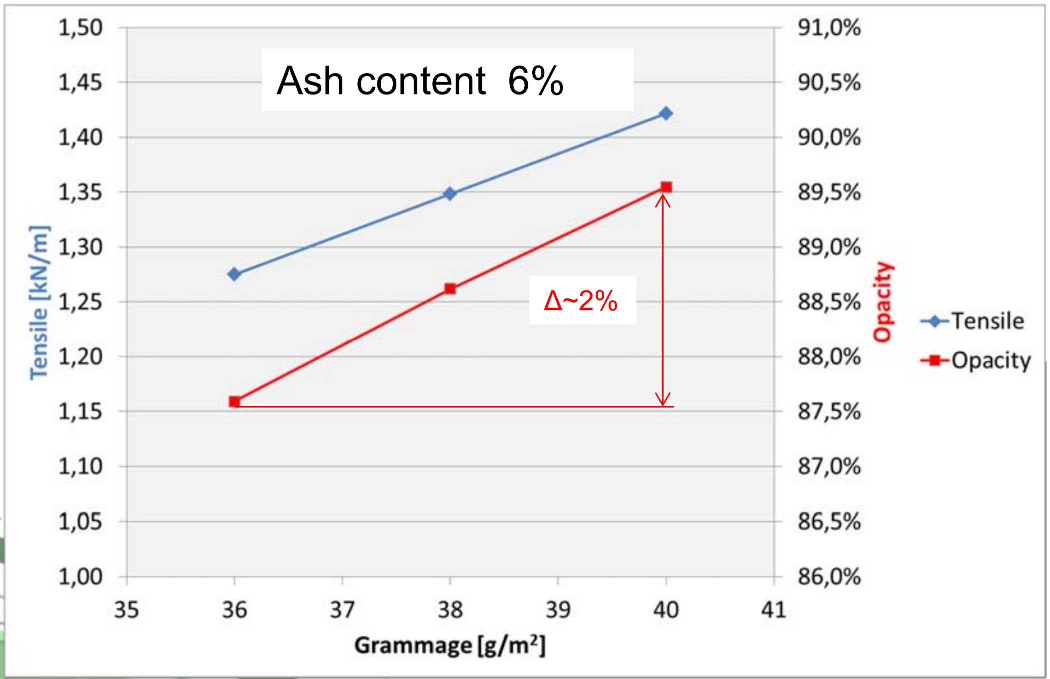
Example 1.2:
Influence of grammage on Opacity and Tensile-Index



Lower grammage → Lower opacity but tensile is significantly over 1.1 kN/m

Can fresh filler compensate the opacity loss?

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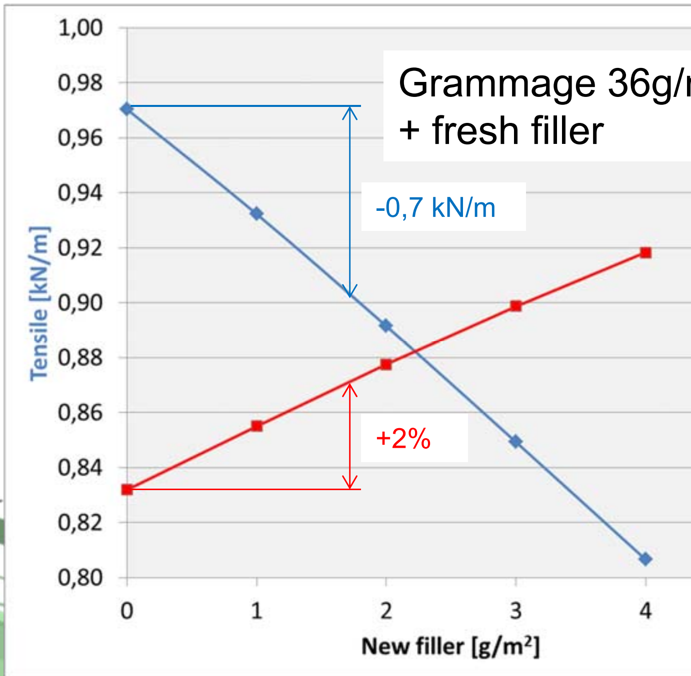
Example 1.3:
Influence of fresh filler on Tensile Index and Opacity



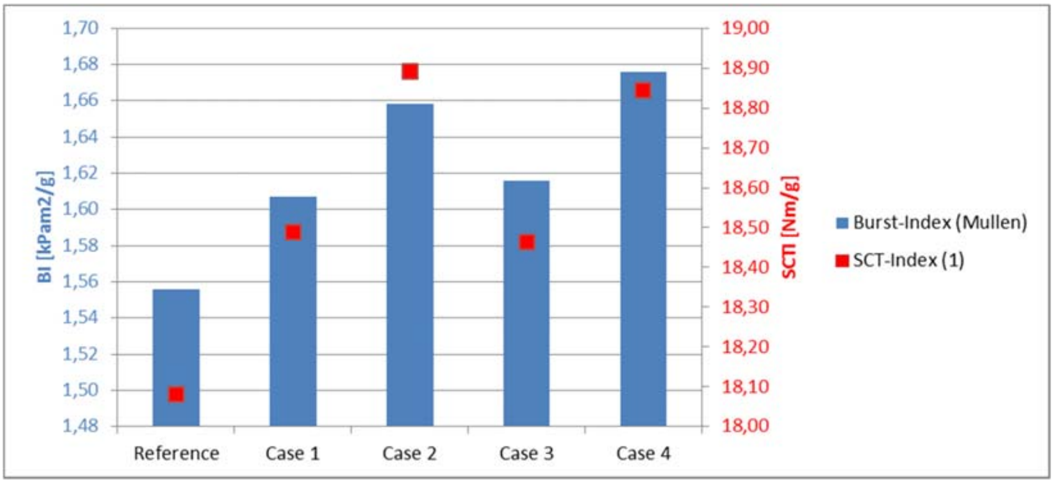
Used Kubelka-Munk coefficients for simulating Opacity

Fibre:
S_{Fib}=69 m²/kg, K_{Fib}=0.92 m²/kg
New Filler:
S_{Fill}=1000 m²/kg, K_{Fill}=1.6 m²/kg

About 1.7g/m² fresh filler is necessary to compensate 2% opacity loss;
Tensile will drop for 0.07 kN/m additionally

Total (1.1 – 1.3):
Taking out 4g/m² ash and addition of 1.7 g/m² fresh filler yields a 6% lighter paper sheet with same or better properties

Example 2:
Influence of ash content on Burst- and SCT-Index (Case study)



Reference: 100% paper for recycling
Case 1: about 4% inorganics are separated from the pulp
Case 2: about 7.5% inorganics are separated from the pulp
Case 3. about 4% of the recycled pulp is substituted by virgin fibres
Case 4: about 7.5% of the recycled pulp is substituted by virgin fibres

Possible options if *PfR* quality becomes worse

Example 3: Energy for mechanical dewatering

Specific Surface Area

Permeability

$$K = \frac{PO^3}{k \cdot S_W^2 \cdot \rho^2}$$

Kozeny-Carman

Flow rate (Dewatering)

$$Q = K \cdot \frac{\rho}{w} \cdot \frac{\Delta p \cdot A}{\eta}$$

Darcy's law

Energy for Mechanical Dewatering

$$W_{SR} \approx \frac{u}{Q} = v \cdot S_W^{\ 2}$$

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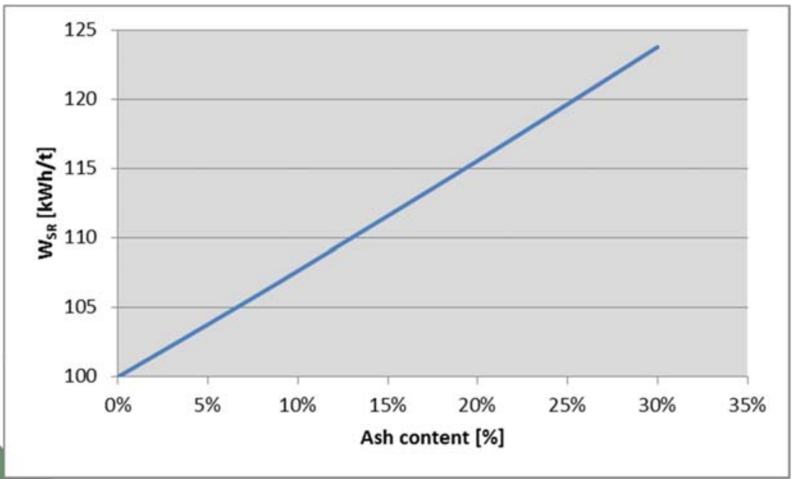
Consequences of higher ash content for mechanical dewatering

Example:

- Specific Surface Area
  Pulp (without ash): $S_W = 4 m^2/g$
  Filler: $S_W = 5.5\ m^2/g$
- Specific energy demand for mechanical dewatering (Pulp without ash): W_{SR}=100 kWh/t

Ash content vs. electrical energy demand for mechanical dewatering



Remark:
A detailed investigation into the influence of fillers on dewatering can be find here:
Springer A., Kuchibhotla S.
An Investigation into the Influence of Filler Components on Specific Filtration
Proc. TAPPI Papermakers Conference 1992, Nashville

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5. Summary

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Summary

- A tool set for numerical prediction of paper properties (structural, mechanical, optical) based on a “standardized” pulp vector is available
- The tool set allows a virtual eco-design of paper
- The full power of the tool set will be unfolded in combination with stock preparation process models and proper calculations of eco indicators
- Handling the increasing ash content in *PfR* will be one of the biggest challenges for *PfR* using paper mills in the next futures
  → A special value was set in modelling activities on considering the influence of fillers on paper properties

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Many thanks for your attention!

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