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Old and new Findings on Boundary Zone Segregation of Fresh Concrete in Pipe Conveying

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31. Conference „Rheology of Building Materials“ , 03.-04. March 2022, OTH Regensburg, Germany

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What prompts a machine builder to research the properties of fresh concrete in pipe conveying?

As early as 1969 - 1972, two questions arose in research on road construction machinery:

1. What effect do the tools of the construction machine in the still plastic building material, e.g. in fresh concrete or in hot asphalt mix?
2. What effect do the reactions of the building material have on the tools of the construction machine?

Building materials research at the time had no answers.
For them, they were only building materials when they solidified.
The still plastic properties were only of interest with regard to their influence on this later state of use!

Meanwhile, concrete technology is established as part of building materials research.

Nevertheless, even today, some of the approaches of concrete technologists differ from those of mechanical engineers.

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What is Boundary Zone Segregation (BZS)?

- an inevitable room filling problem
- the boundary zone passes steadily and not abruptly into the core zone

What is Boundary Zone Segregation (BZS) not?

- shear-induced particle migration

What does Boundary Zone Segregation (BZS) do?

- radius-dependent sieve line change
- radius-dependent Viscosity change
- plug flow *(also without Bingham-behavior)*
- Self-cleaning of the inner pipe wall with reduction of the residence time

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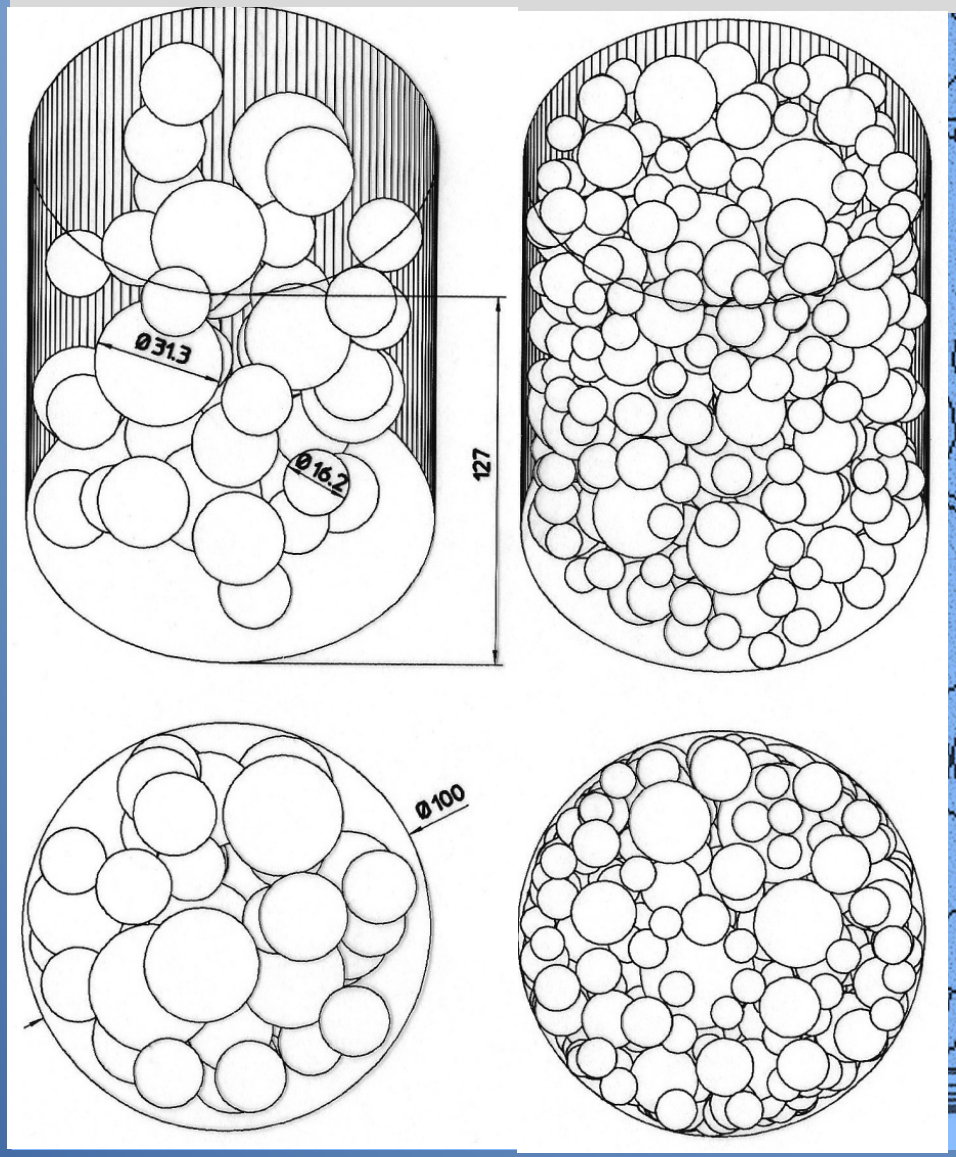
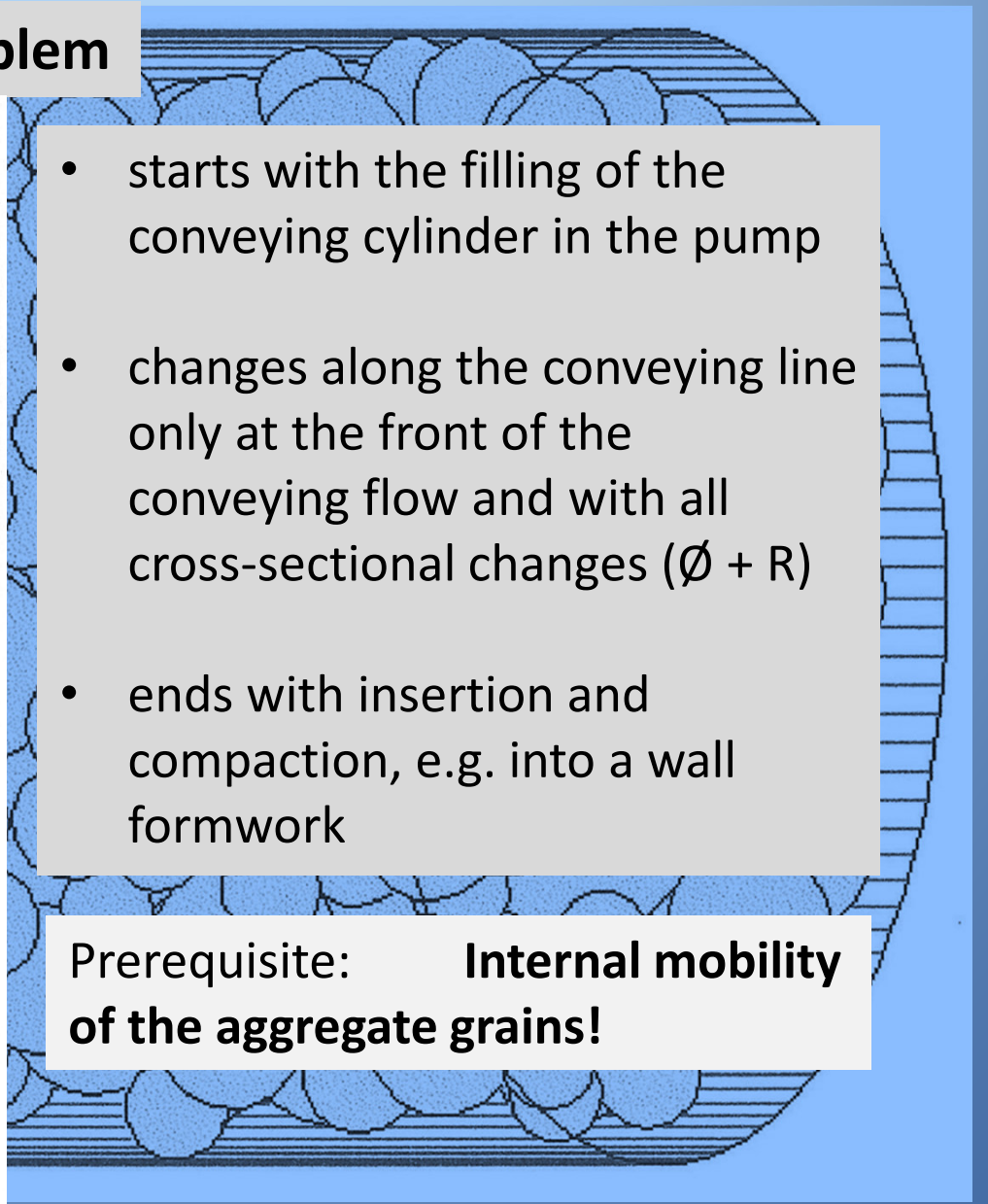
BZS - an inevitable room filling problem





- starts with the filling of the conveying cylinder in the pump
- changes along the conveying line only at the front of the conveying flow and with all cross-sectional changes (Ø + R)
- ends with insertion and compaction, e.g. into a wall formwork

Prerequisite: **Internal mobility of the aggregate grains!**

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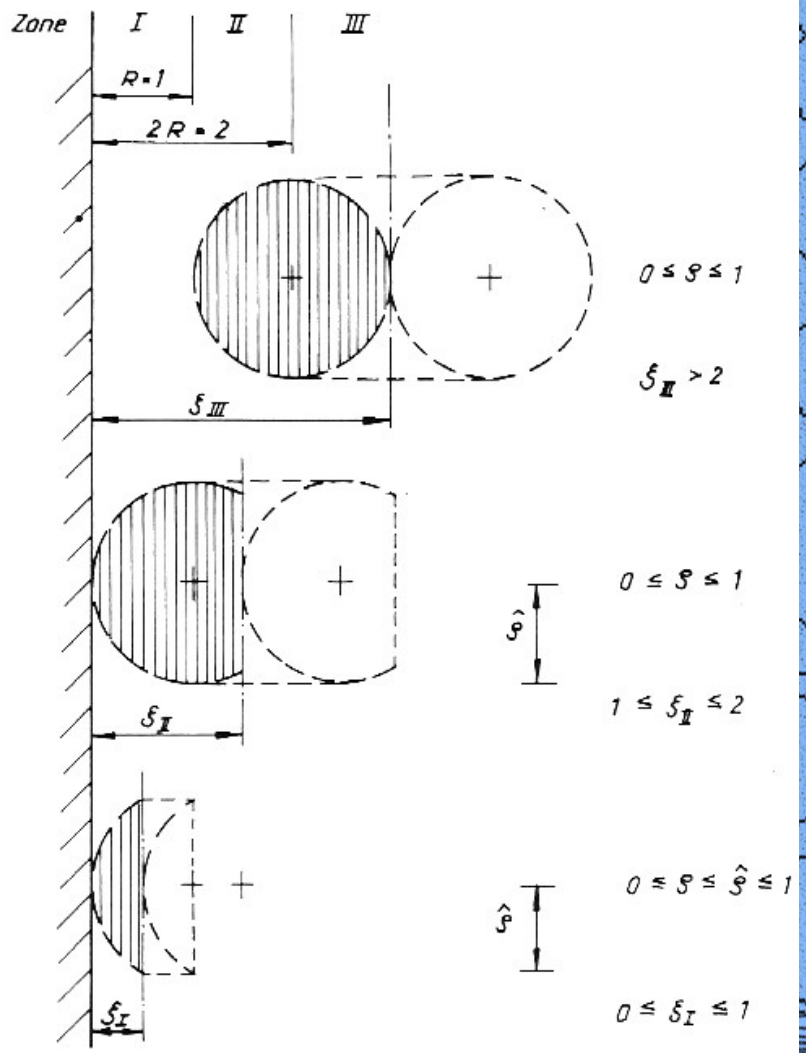
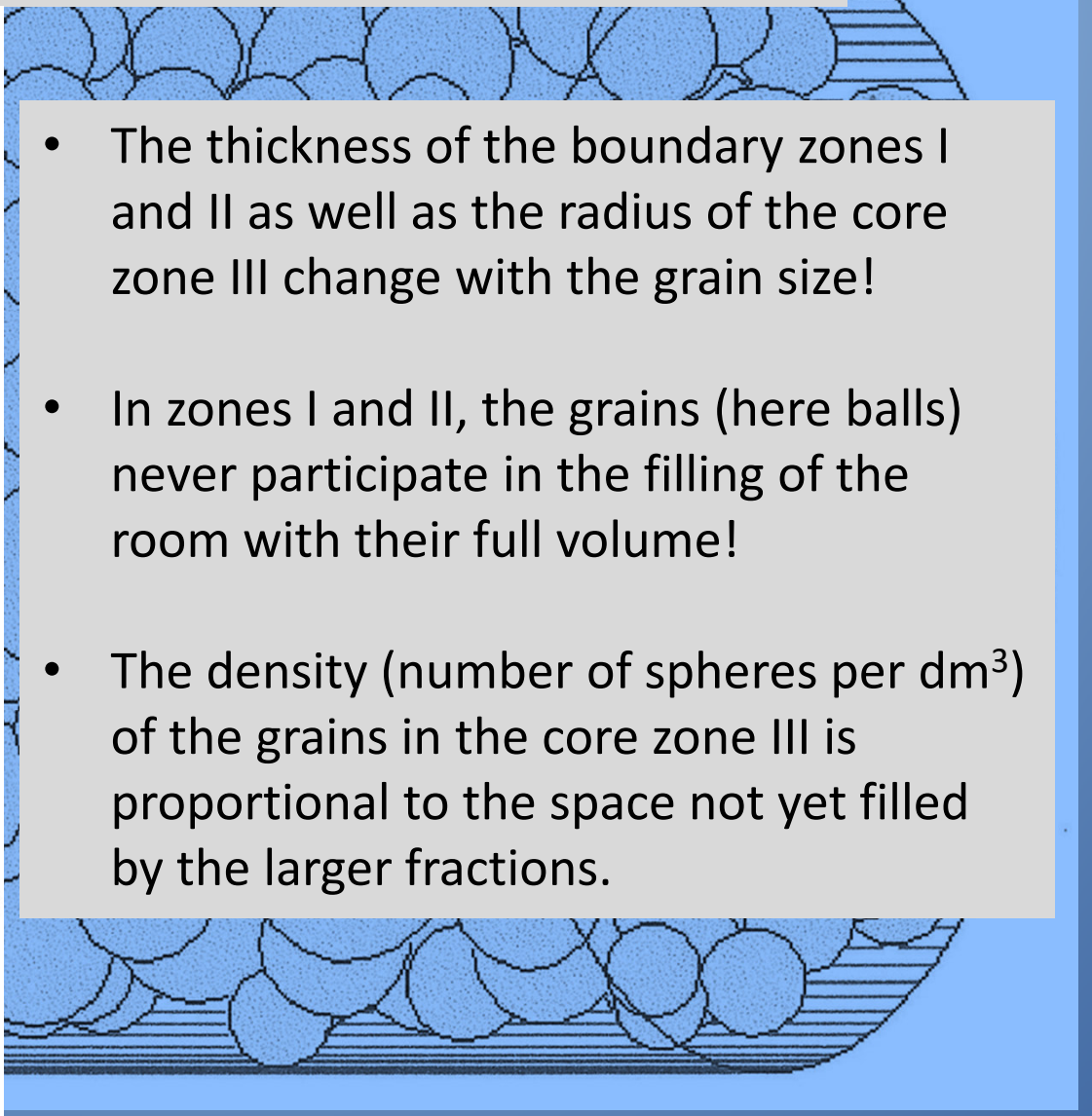
Continuous transition from the boundary zone to the core zone





- The thickness of the boundary zones I and II as well as the radius of the core zone III change with the grain size!
- In zones I and II, the grains (here balls) never participate in the filling of the room with their full volume!
- The density (number of spheres per dm^3) of the grains in the core zone III is proportional to the space not yet filled by the larger fractions.

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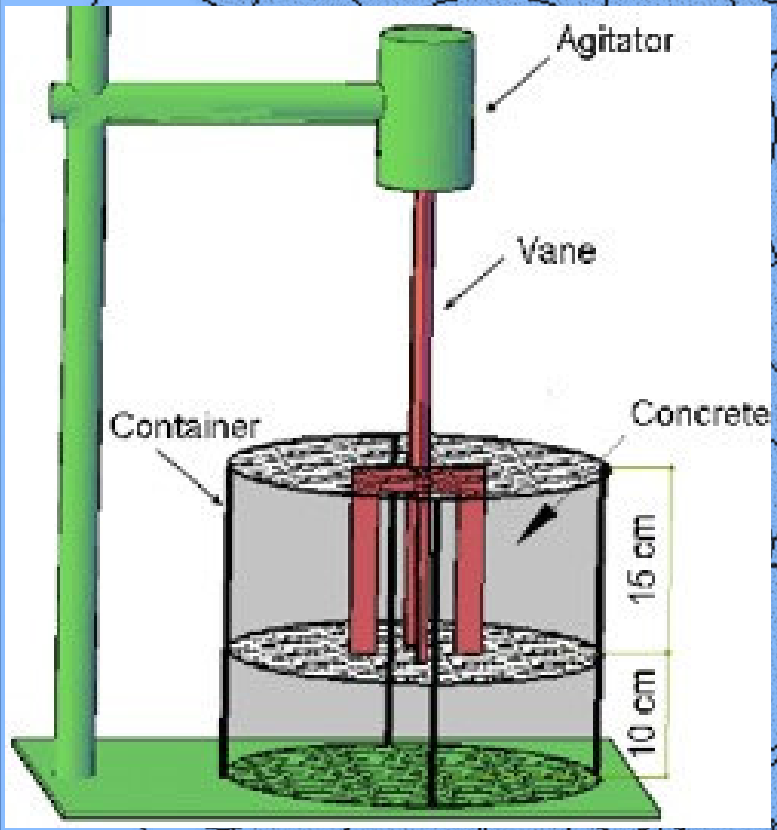
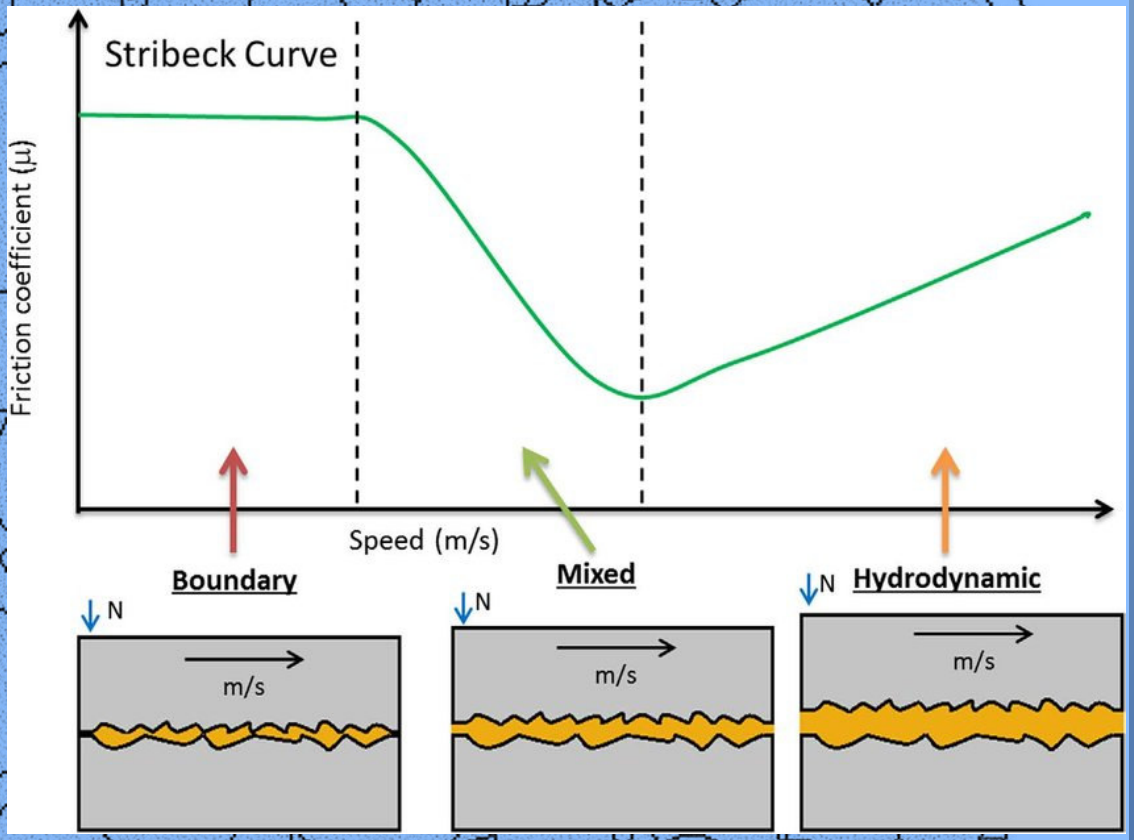
BZS no shear-induced particle migration!



but:
„ Mixed friction with hydrodyn. component“



Side effects: Self-cleaning and reduced residence time of the boundary zone

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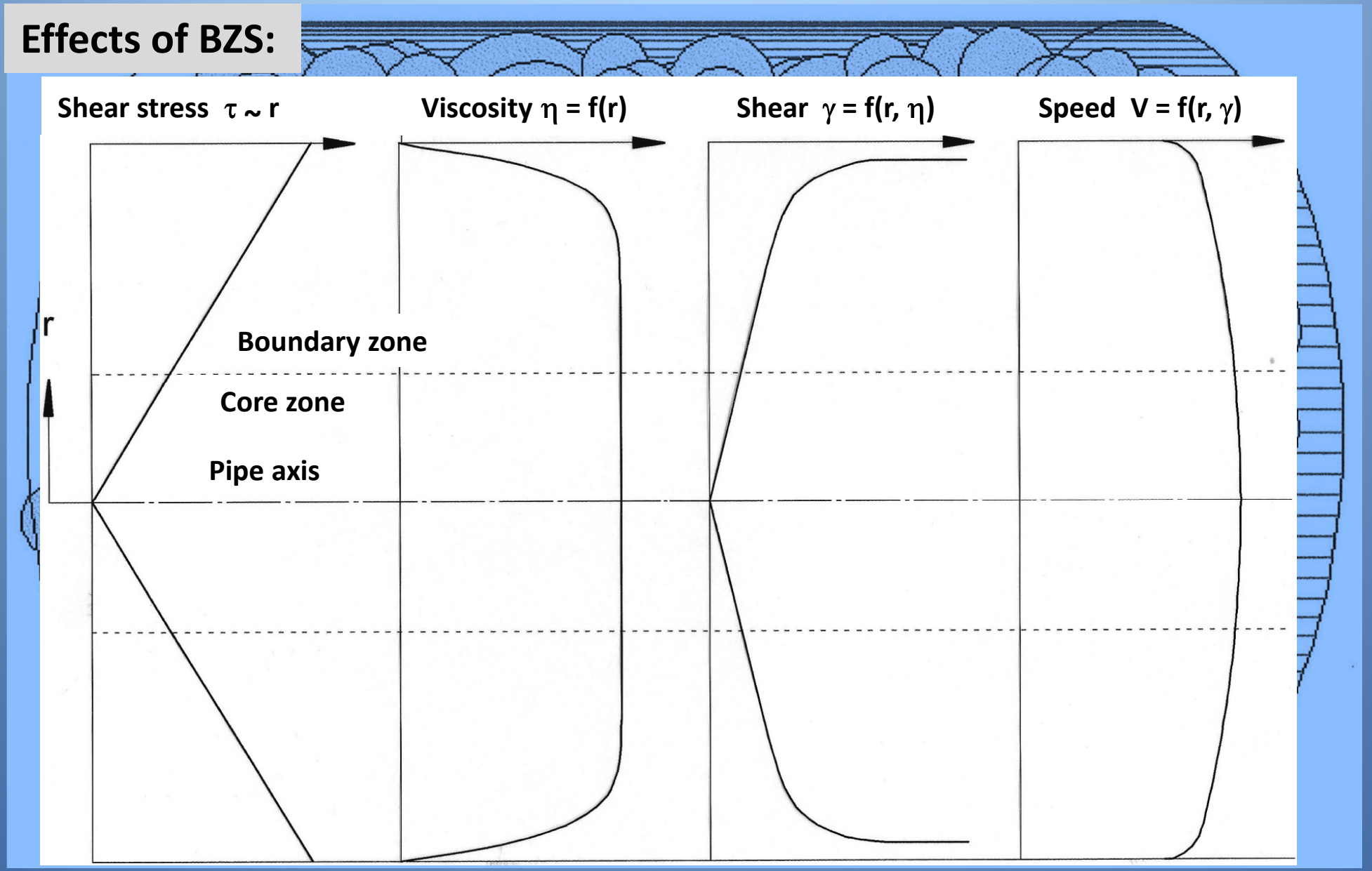
Effects of BZS:



Calculation of BZS:

- Input
- Calculation of the average grain diameters per fraction
- 3D CAD model for preliminary examination
- Proximity polynomial of room filling in boundary zones
- Fractionally numerical calculation in 87 steps
  - Normalized filling level
  - Correction factor
  - Radius-dependent room filling according to recipe
  - Cumulation of all previously calculated fractions
- Calculation and graphic of the radius-dependent screen line change
- Assumptions for deriving the radius-dependent viscosity and the speed profile

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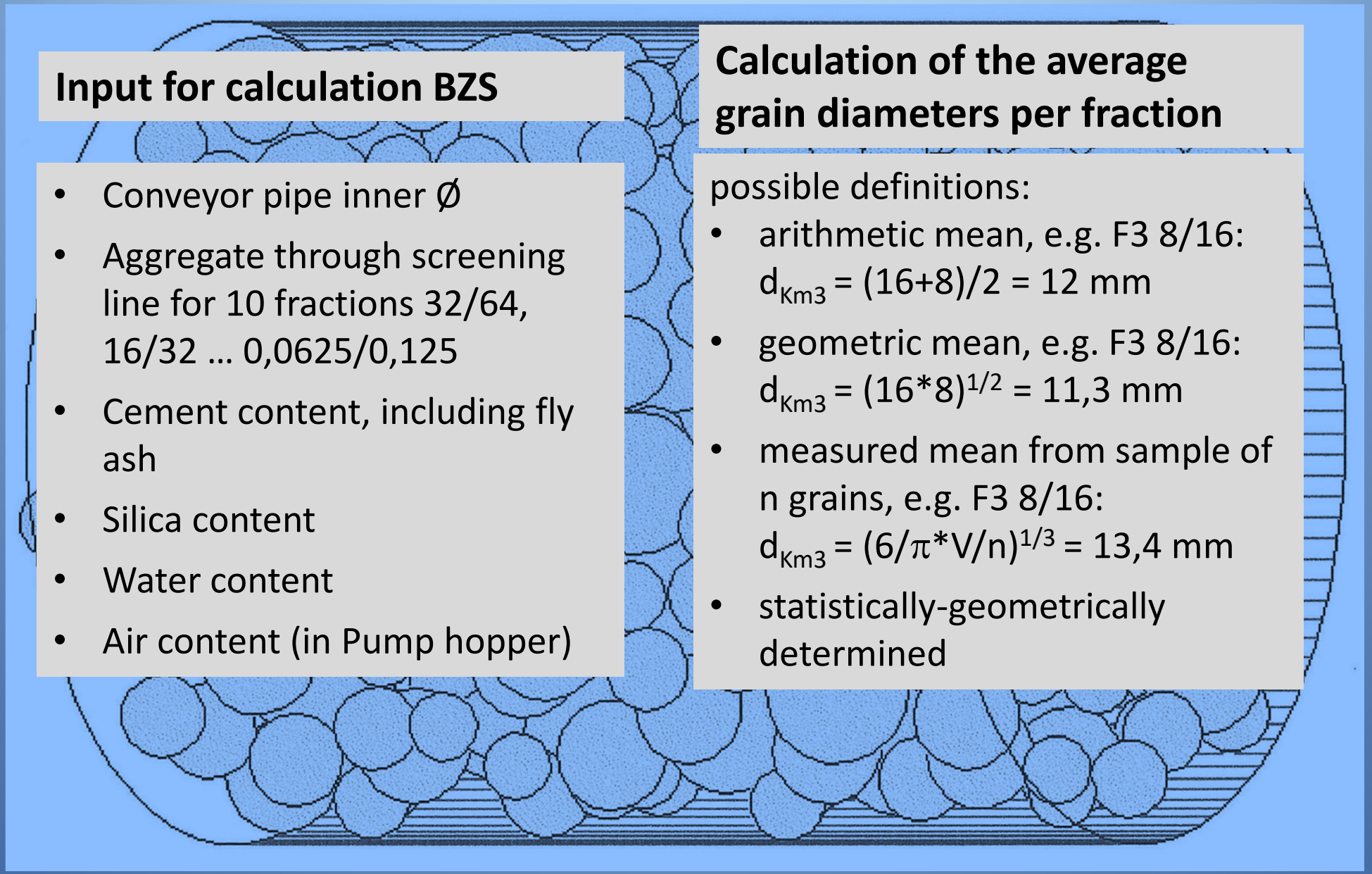

Input for calculation BZS

- Conveyor pipe inner Ø
- Aggregate through screening line for 10 fractions 32/64, 16/32 … 0,0625/0,125
- Cement content, including fly ash
- Silica content
- Water content
- Air content (in Pump hopper)

Calculation of the average grain diameters per fraction

possible definitions:

- arithmetic mean, e.g. F3 8/16: $d_{Km3} = (16+8)/2 = 12$ mm
- geometric mean, e.g. F3 8/16: $d_{Km3} = (16*8)^{1/2} = 11{,}3$ mm
- measured mean from sample of n grains, e.g. F3 8/16: $d_{Km3} = (6/\pi*V/n)^{1/3} = 13{,}4$ mm
- statistically-geometrically determined

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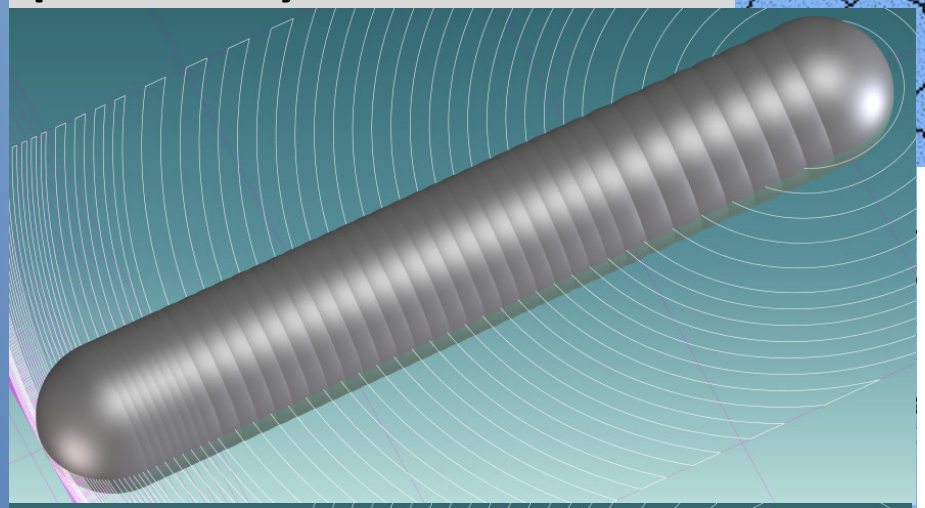
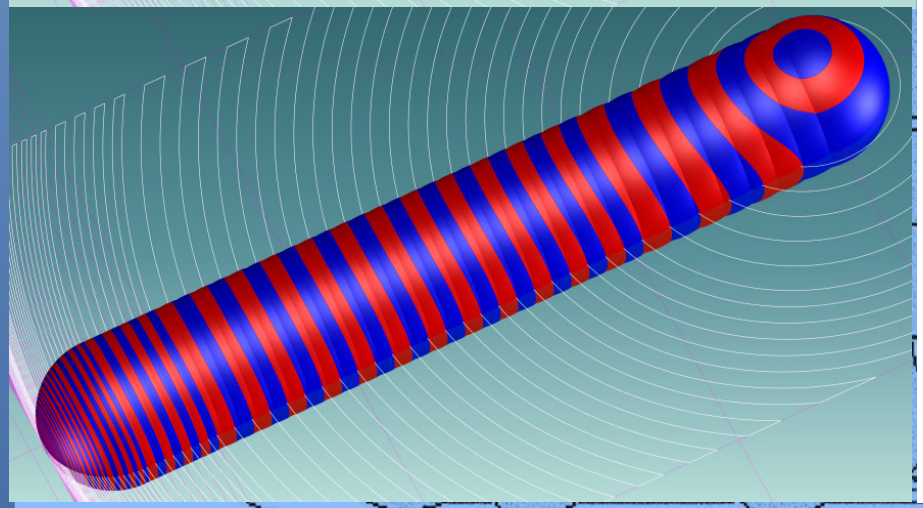
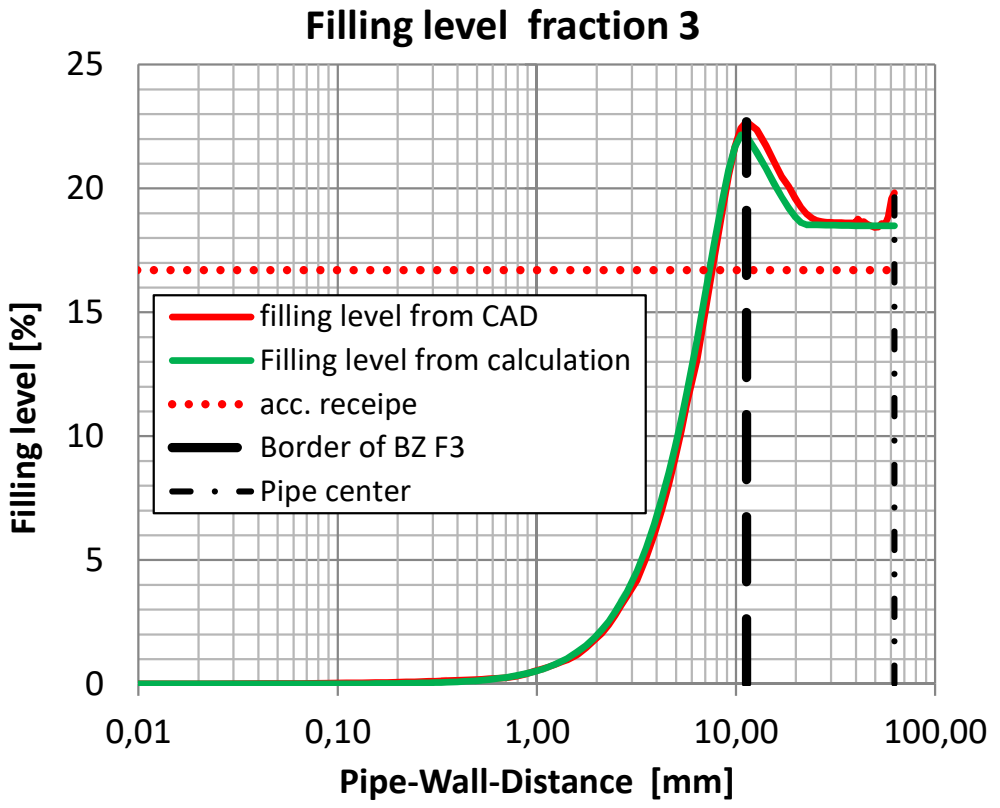
3D CAD model for preliminary examination





Proximity polynomial for boundary zone

$$\varphi_{n_i} = [3 - \varphi'(d_{Kmi})] * \left(\frac{x}{d_{Kmi}}\right)^2 - [2 - \varphi'(d_{Kmi})] * \left(\frac{x}{d_{Kmi}}\right)^3$$



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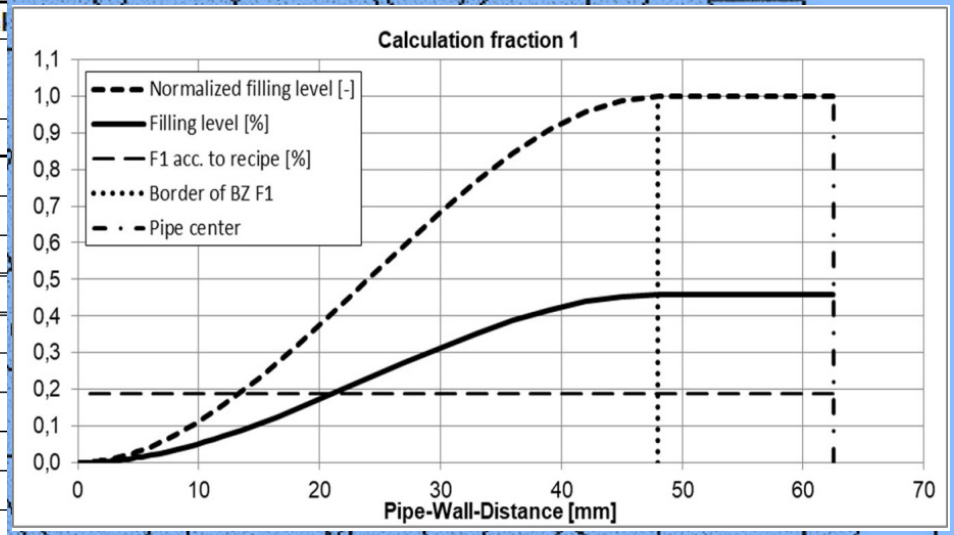
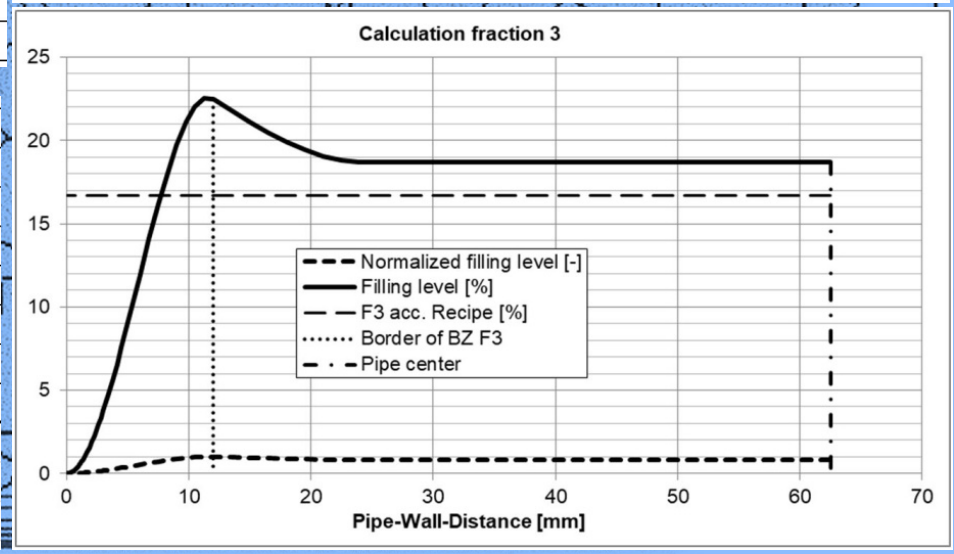
Fractionally numerical calculation in 87 radial steps

Lfd Nr	Wand-abstand	Fraktion 1; 64 … 32			Fraktion 2; 32 … 16 mm				Raum-füllung F1+F2	Fral
		norm. Raum-füllung	Inte-gration	Raum-füllung	freie Höhe	norm. Raum-füllung	Inte-gration	Raum-füllung	freie Höhe	
-	mm	-	-	%	%	%	-	%	%	%
0	**62,5**	**1**	-	0,46	99,541	0,998	-	28,28	28,74	71,258
1	**48**	**1**	210,25	0,46	99,541	0,998	210,250	28,28	28,74	71,258
2	45	0,989	95,46	0,45	99,546	0,998	95,782	28,28	28,74	71,262
3	42	0,957	110,91	0,44	99,561	0,998	113,752	28,29	28,73	71,272
4	39	0,908	123,07	0,42	99,584	0,998	131,738	28,30	28,71	71,289
5	36	0,844	131,36	0,39	99,613	0,998	149,741	28,30	28,69	71,310
6	33	0,768	135,39	0,35	99,648	0,999	167,764	28,31	28,67	71,334
7	30	0,684	135,00	0,31	99,686	0,999	185,807	28,32	28,64	71,362
8	27	0,593	130,24	0,27	99,728	1,000	203,870	28,34	28,61	71,392
9	**24**	0,500	121,35	0,23	99,771	**1**	221,952	28,35	28,58	71,422
10	23	0,453	56,119	0,21	99,792	0,989	117,100	28,04	28,24	71,757
…										
81	**0,0469**	0,000	0,000	0,00	100,00	0,000	0,000	0,00	0,00	100,00
82	0,0234	0,000	0,000	0,00	100,00	0,000	0,000	0,00	0,00	100,00
83	0,0117	0,000	0,000	0,00	100,00	0,000	0,000	0,00	0,00	100,00
84	0,0059	0,000	0,000	0,00	100,00	0,000	0,000	0,00	0,00	100,00
85	0,0029	0,000	0,000	0,00	100,00	0,000	0,000	0,00	0,00	100,00
86	0,0015	0,000	0,000	0,00	100,00	0,000	0,000	0,00	0,00	100,00
87	0,00073	0,000	0,000	0,00	100,00	0,000	0,000	0,00	0,00	100,00
88	**0**	**0**	**0**	**0**	**100**	**0**	**0**	**0**	**0**	**100**
gem. Rezeptu		**$\Delta V'_1$=**	**0,188**	%		**$\Delta V'_2$=**	**18,705**	%		
Grenzanstieg KZ/RZ:			**0,000**				**-0,003**			
Korrekturwert:			**0,459**				**28,348**			





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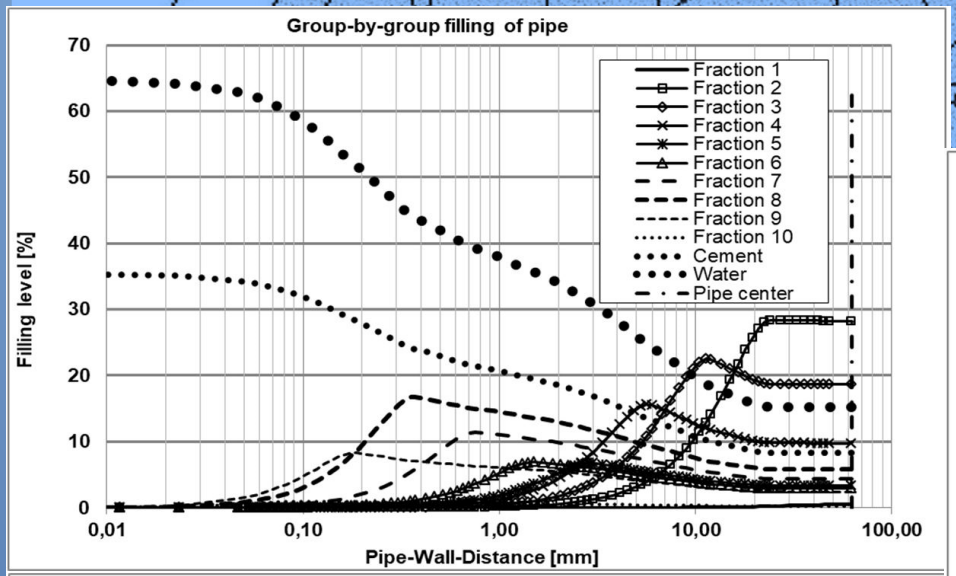

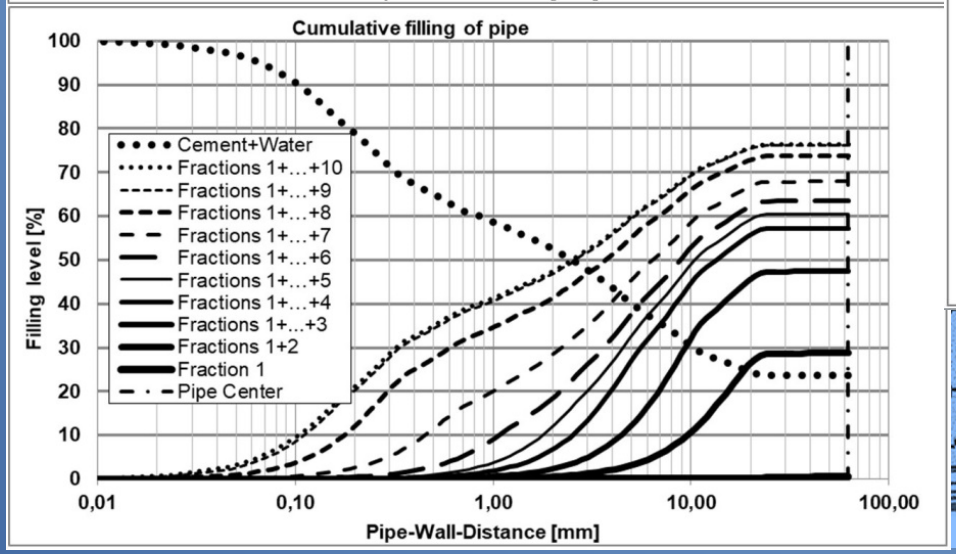

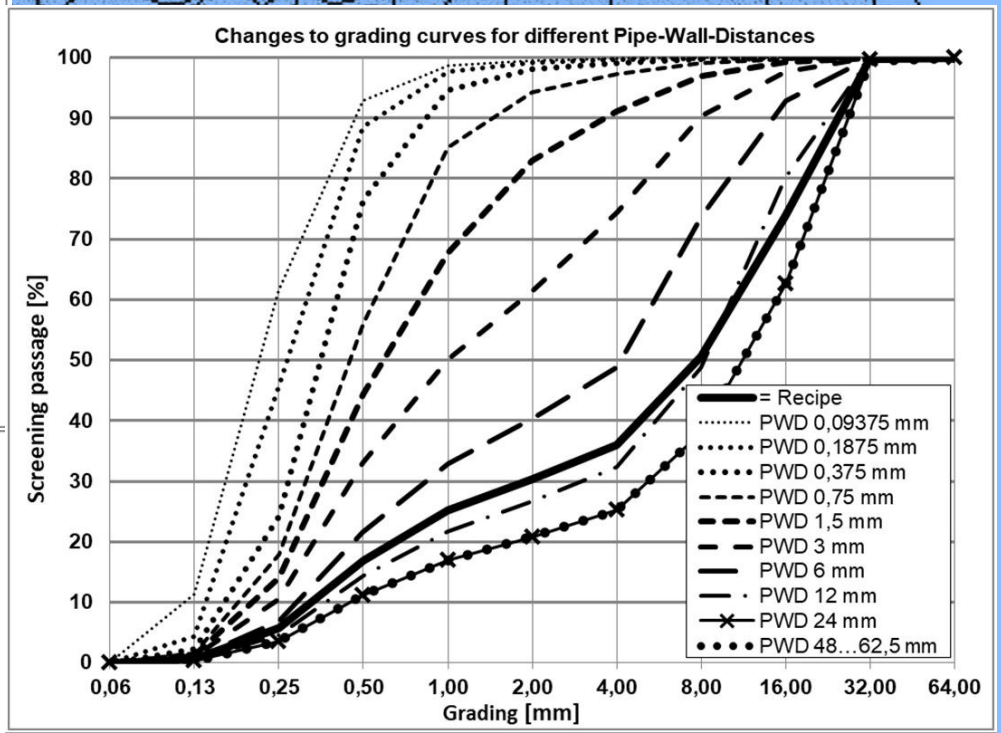

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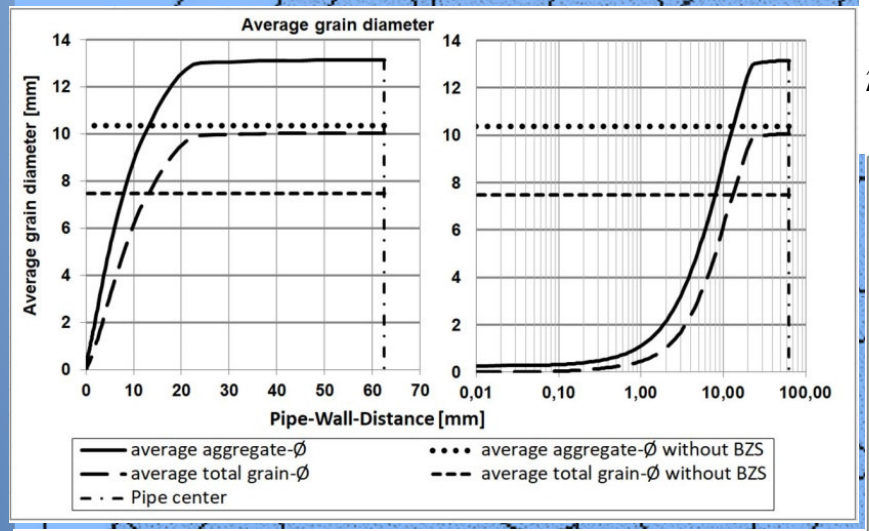
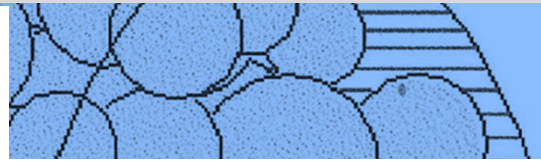
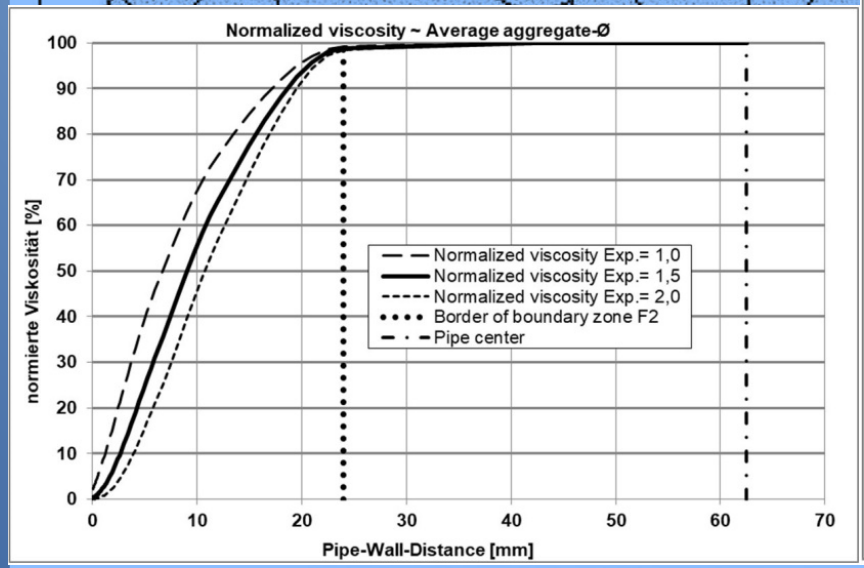
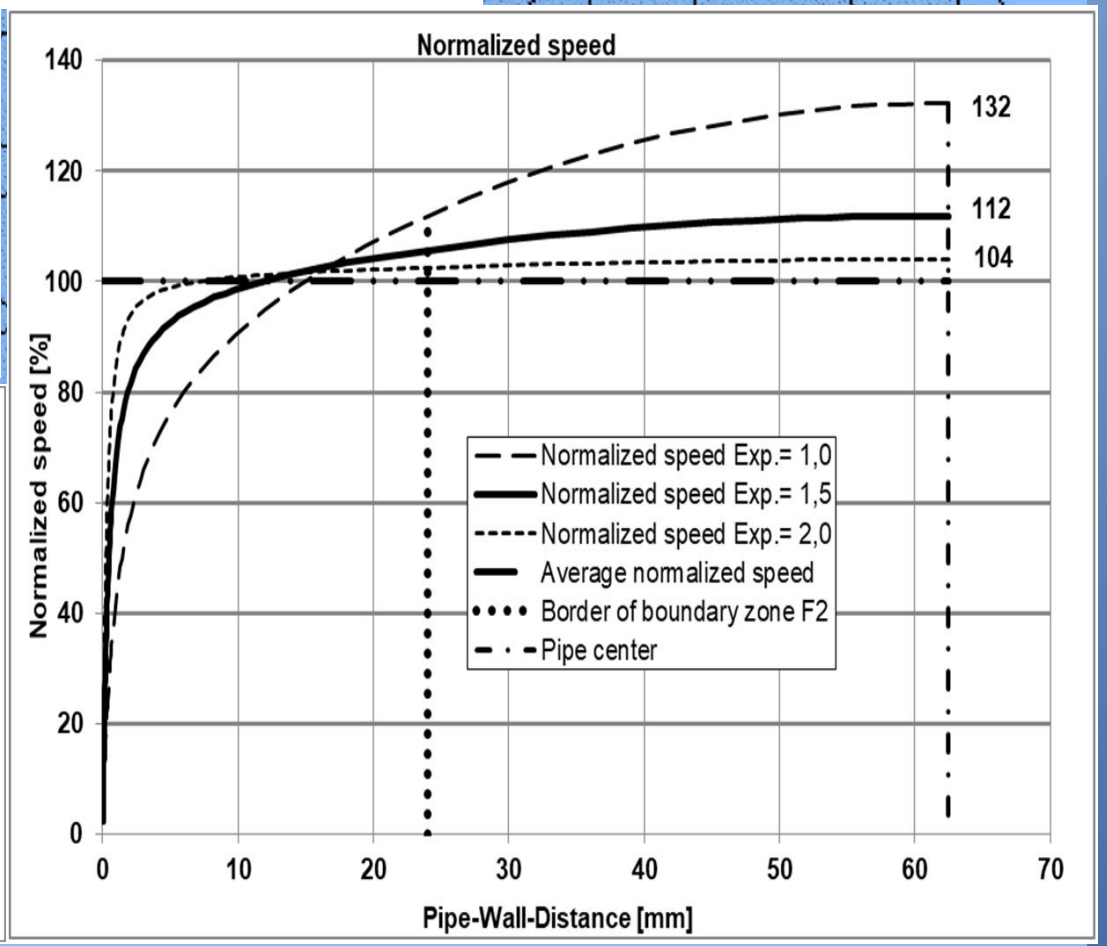
Assumption for the dependence of viscosity on the averaged grain diameter



$$\eta_n = \left(\frac{d_{Km}(x)}{d_{Km}(x_{PC})} \right)^{\varepsilon} * 100\%$$







Outlook for further investigations on BZS :

- Studies on statistical geometry, i.e.
  - Definition of the most suitable averaged grain Ø,
  - Consideration of irregular grain shape
- Verification of the assumptions made about the dependence of the viscosity as well as measurement of the actual velocity profiles with a rotational viscometer (e.g. Feys tribometer) with two smooth cylinders rotating against each other, which do not prevent sliding
- Validation of hydrodynamic mixed spelling as a cause of
  - the strong increase in the flow rate in the lower speed range and
  - the self-cleaning effect as well as the prevention of too long residence time of the edge zone material in the conveying pipe
- Extension of the investigations to pipe bends, reductions and the like


Thank you!