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Experimental Investigations on the Coolability of Stratified Debris Beds

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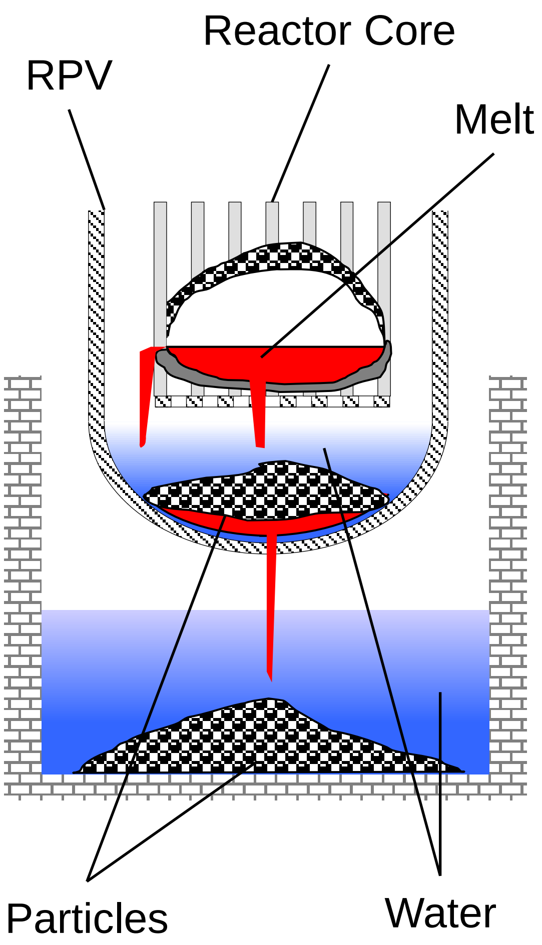
Outline

- Motivation
- Aim of Work
- DEBRIS Facility
- Determination of Heat Input
- Boiling Experiments
- Dryout Experiments
- Conclusion

Motivation

Loss of coolant scenario:

- Over heating of fuel elements due to emerging decay heat
- Melting of the core and relocation to the lower plenum
- Fragmentation and formation of a particle bed due to the presence of water
- Remelting due to insufficient heat removal
- Possible melting of the RPV
- Relocation of core material to the reactor pit and again formation of a particle bed

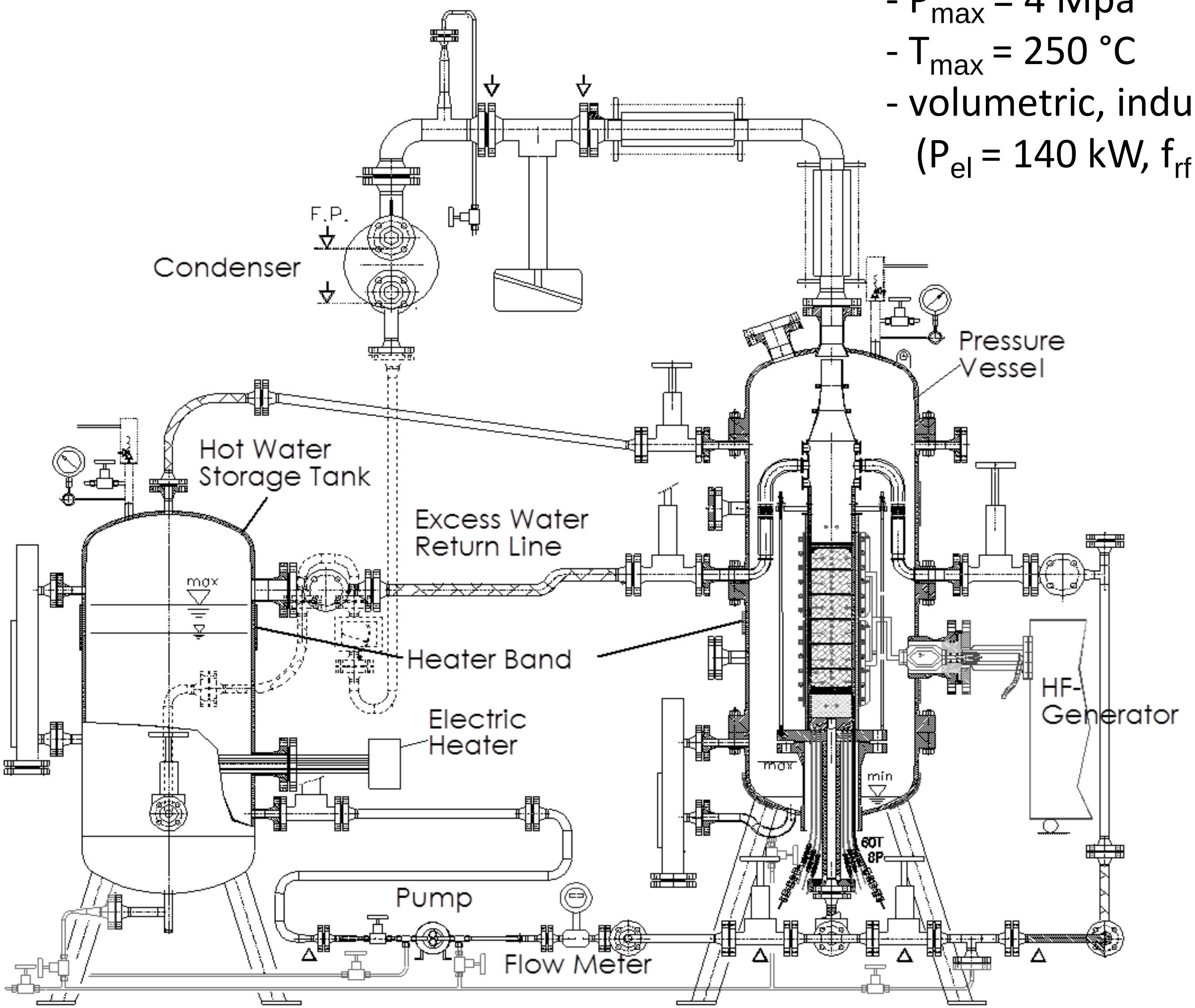


Aim of Work

- In general: Providing data for numerical model development and validation
- In specific: Effect of a stratification in terms of heat input and permeability on the coolability

DEBRIS Facility

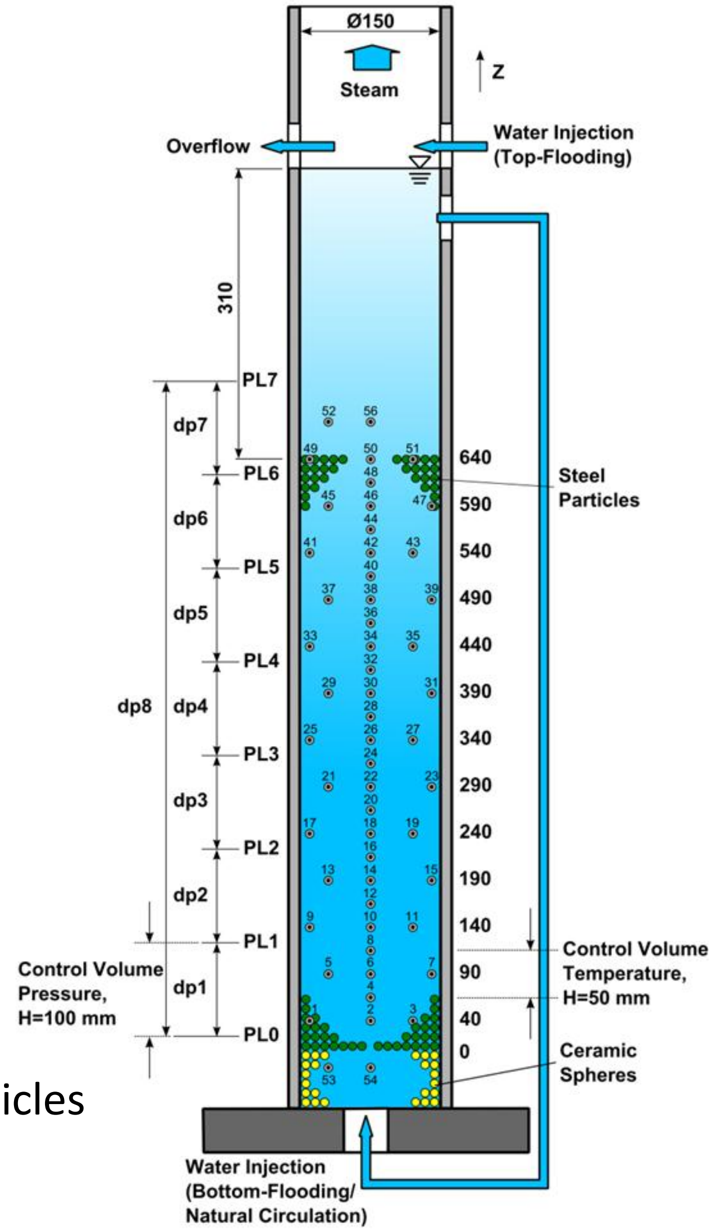
Design parameters:
- P_{max} = 4 Mpa
- T_{max} = 250 °C
- volumetric, inductive heating
  (P_{el} = 140 kW, f_{rf} = 300 kHz



DEBRIS Facility

Cylinders 3x5.75 mm
Stainless steel
$d_{p,eff}$ = 2.5 mm
ε = 0.38

Screws M3x10, ISO 1207
Standard steel
$d_{p,eff}$ = 2.8 mm
ε = 0.58



Influence of non-spherical (well-defined geometry) particles on debris coolability ↔ spherical particles?

Determination of Heat Input

Determination of heat input in a range of 30 - 40 °C for different generator levels:

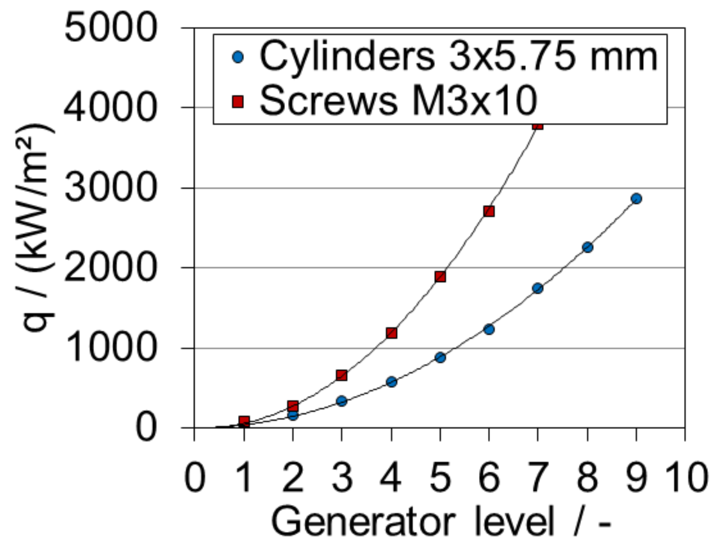
$$Q = \left[\varepsilon \cdot \rho_w \cdot c_p^w + (1-\varepsilon) \cdot \rho_s \cdot c_p^s\right] \frac{dT}{dt} \qquad q = Q \cdot h$$

Calculation of gas superficial velocity J_g:

$$J_g = \frac{q \cdot A - (T_s - T_{in}) \cdot \dot{m} \cdot c_p^w}{A \cdot \Delta h_v \cdot \rho_g}$$

Screws are made of standard steel to have a better coupling to the electro-magnetic field

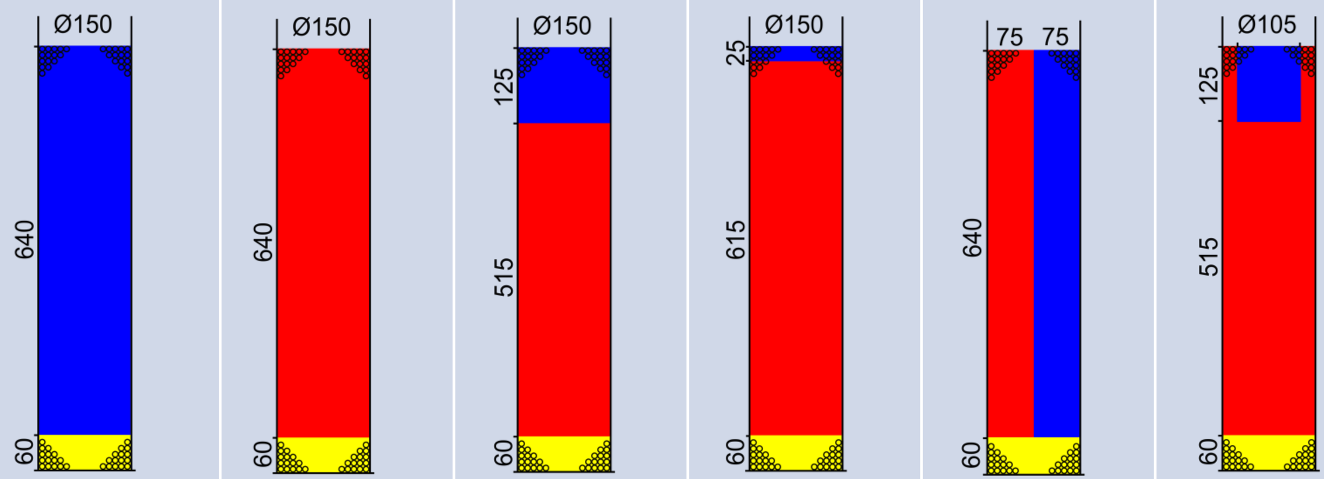
Different particle materials
→ different heat input curves



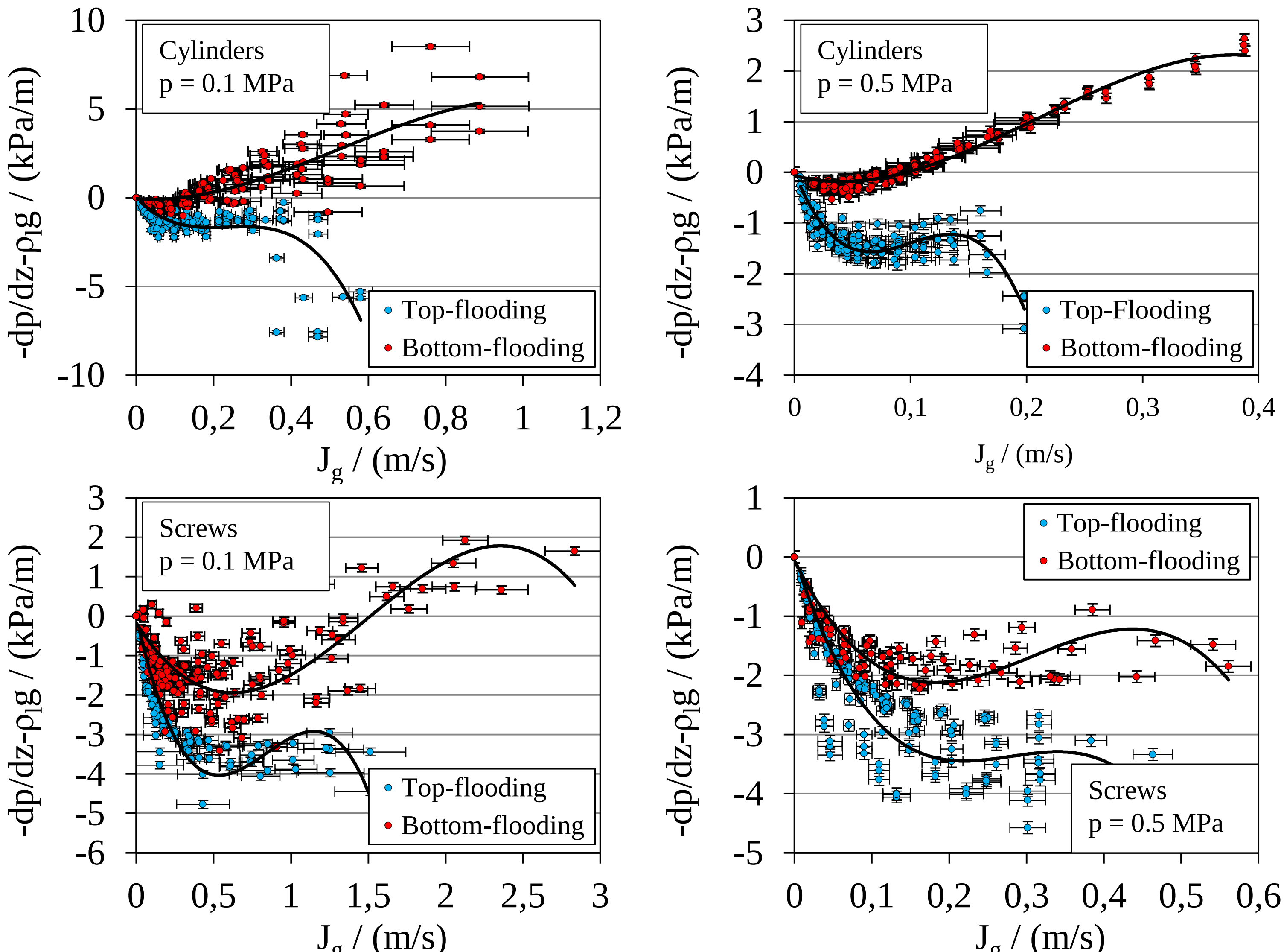
Bed Configurations

Homogeneous and stratified beds

Bed no.	1	2	3	4	5	6
Stratification	no (homogeneous beds)		axial		azimuthal	radial
Geometry Ceramic particles Cylinders Screws						
Composition (Vol. %)	Cylinders (100 %)	Screws (100 %)	Screws (80 %), Cylinders (20 %)	Screws (96 %), Cylinders (4 %)	Screws (50 %), Cylinders (50 %)	Screws (90 %), Cylinders (10 %)



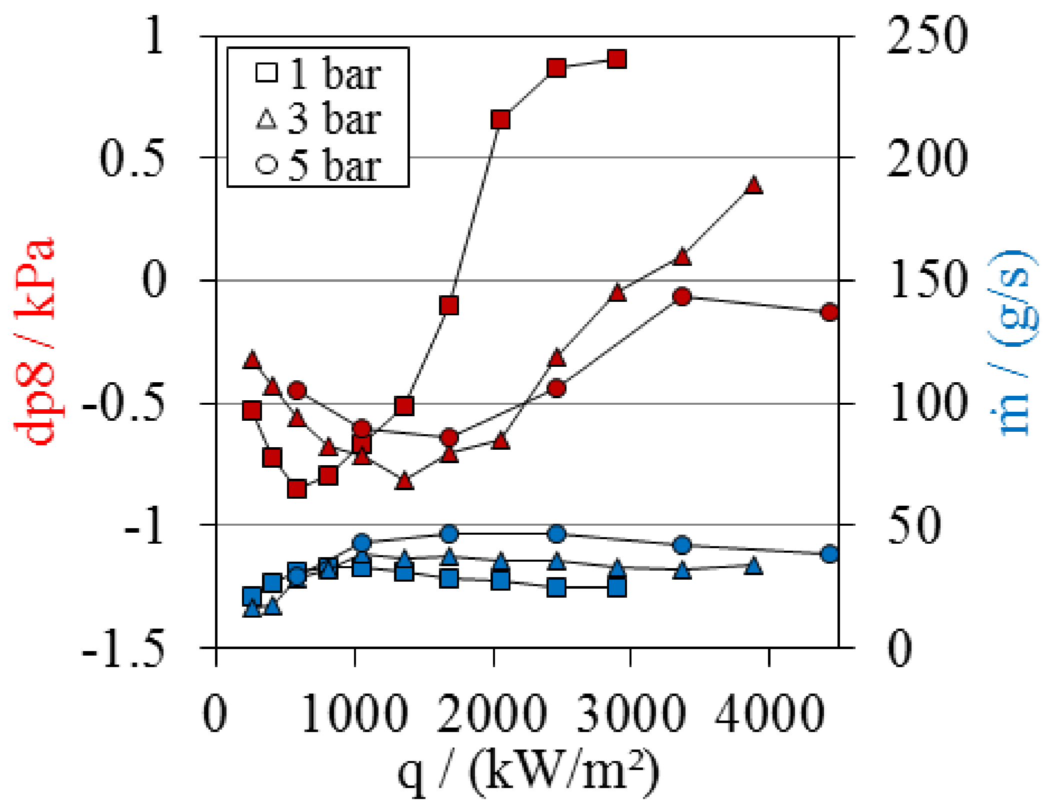
Boiling behaviour of homogeneous beds



Flow rate in the natural circulation loop

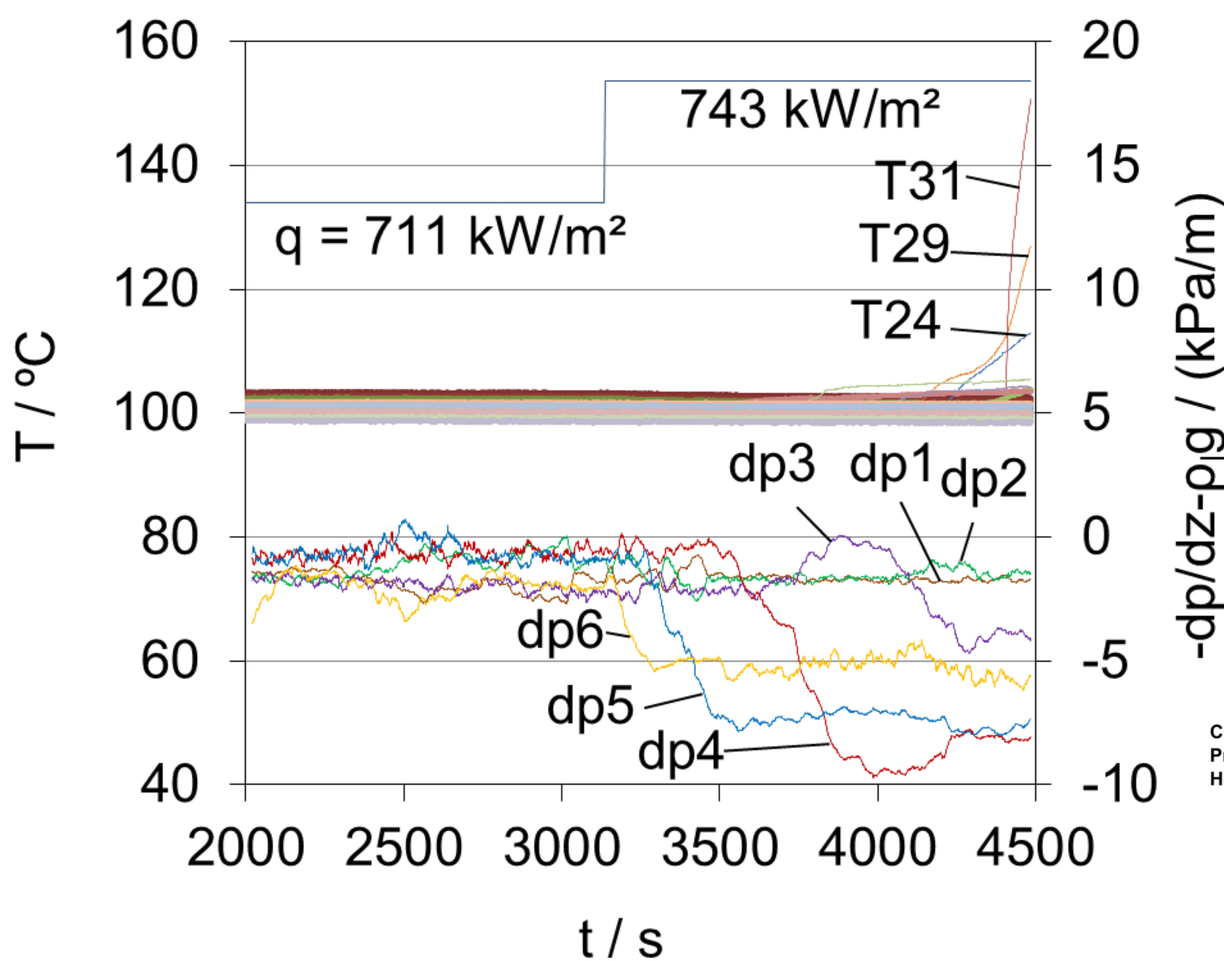
Axial Stratification 80/20

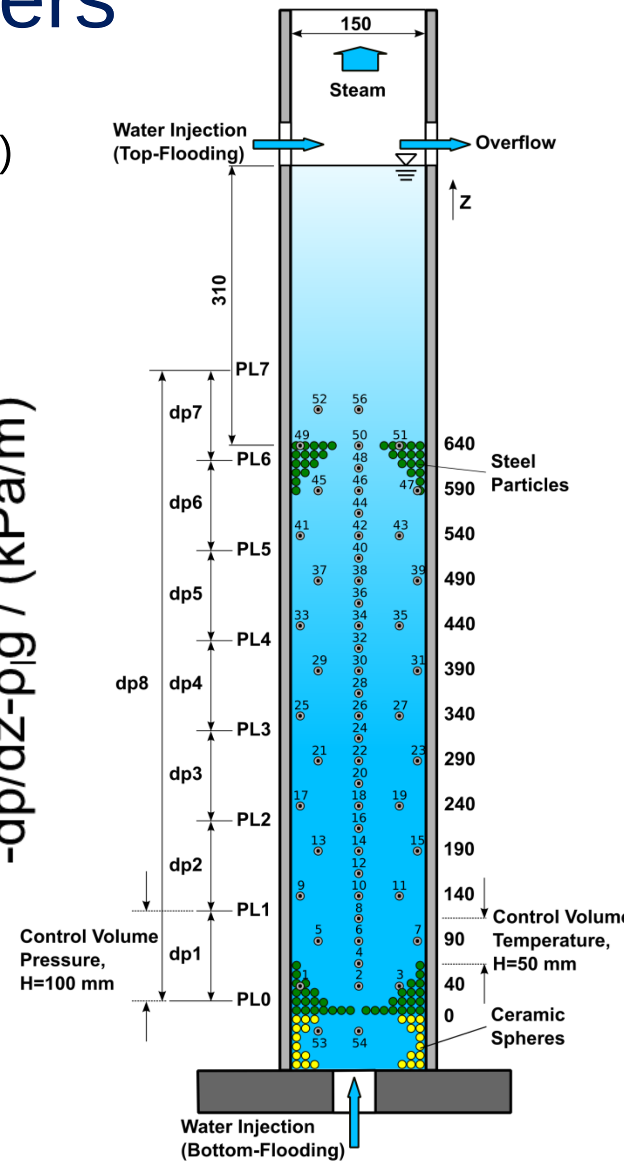
- Strong dependence of flow rate in the natural circulation loop on the total axial pressure difference dp8
- High pressure → high steam density → low friction → high flow rate → better coolability
- Turning points are moving to higher q with increasing pressure



Dryout Experiments – Cylinders

Cylinders, 0.1 MPa, J_l^0 = 0 mm/s (Top-Flooding)

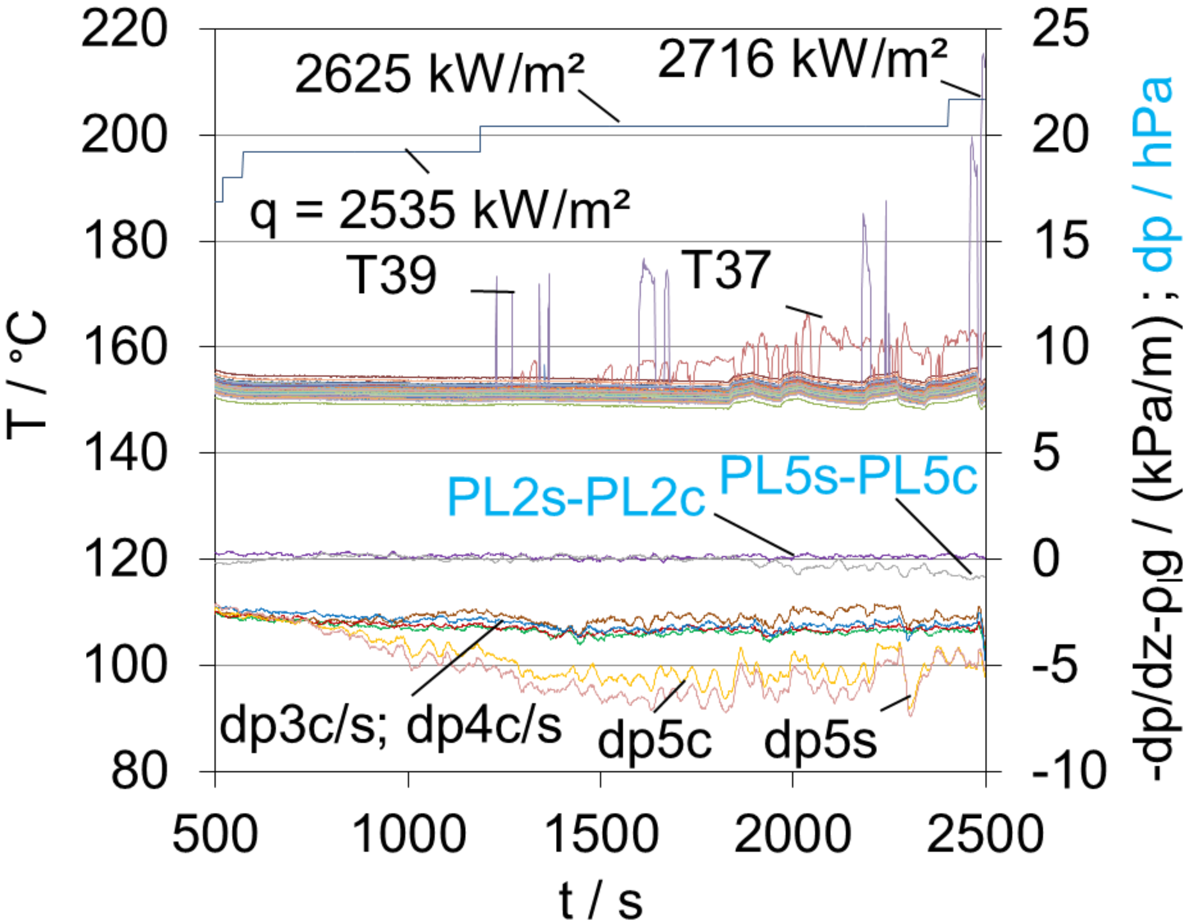


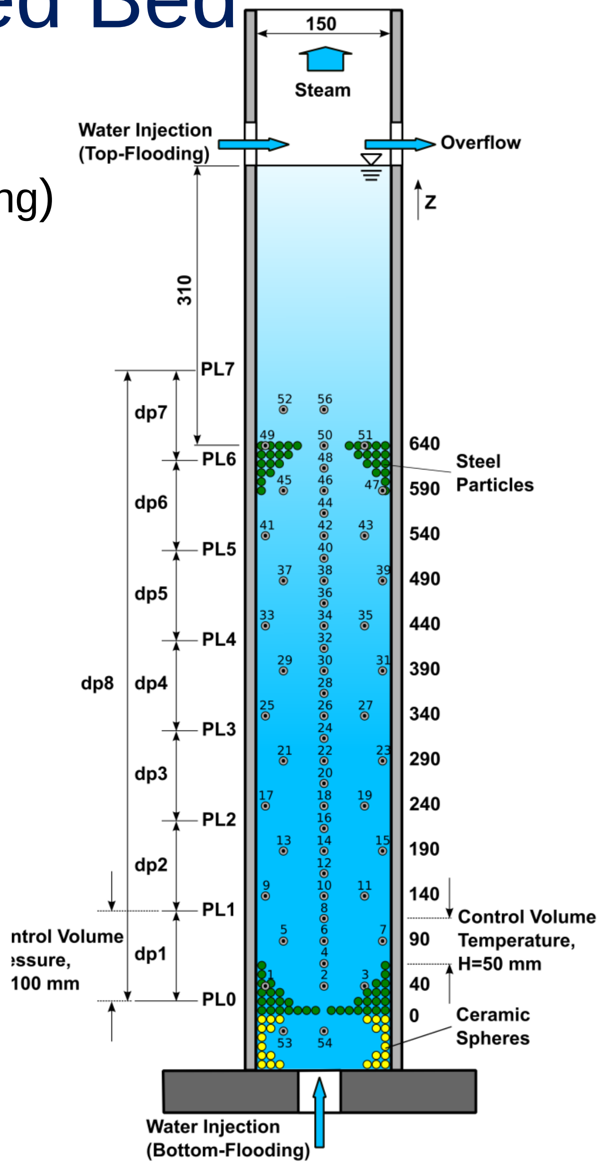


Dryout Experiments – Stratified Bed

Azimuthal Stratified Bed, 0.5 MPa,

J_l^0 = 0 mm/s (Top-Flooding)

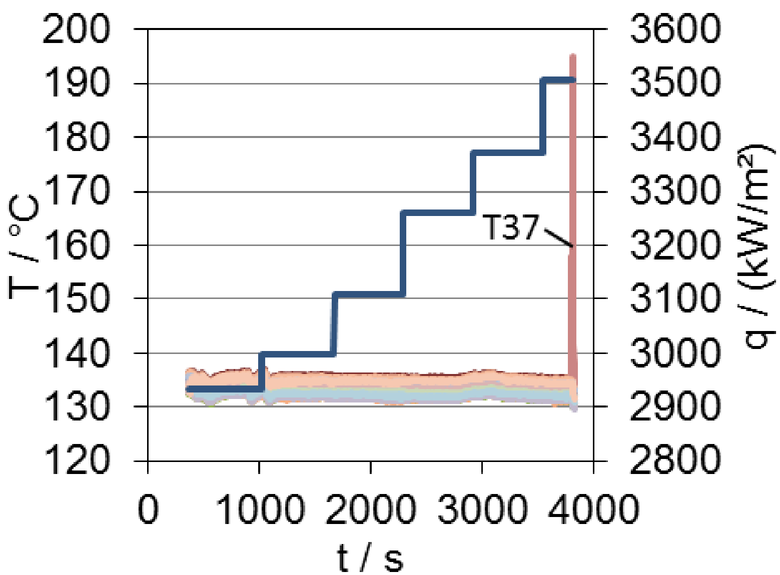




“Plateau“ Behaviour

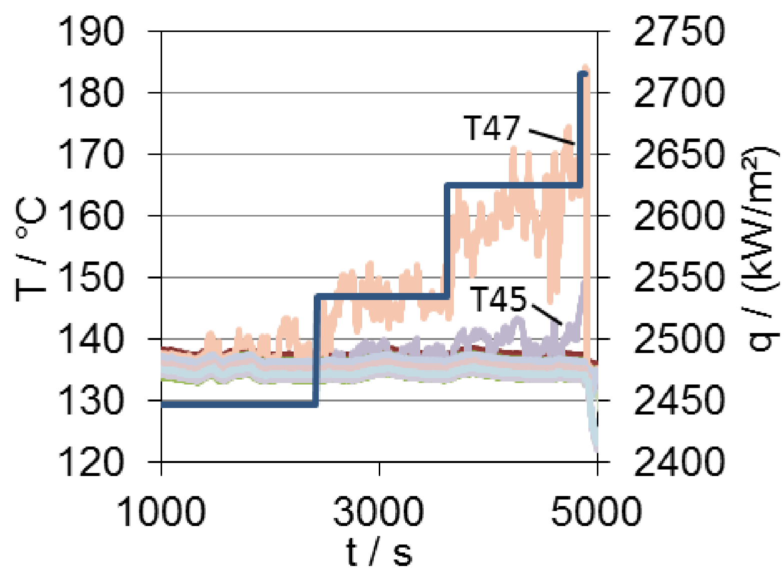
“Normal“ Behaviour

- Rapid temperature increase at DHF, e. g. for bed 2, screws, top-flooding, 3 bar

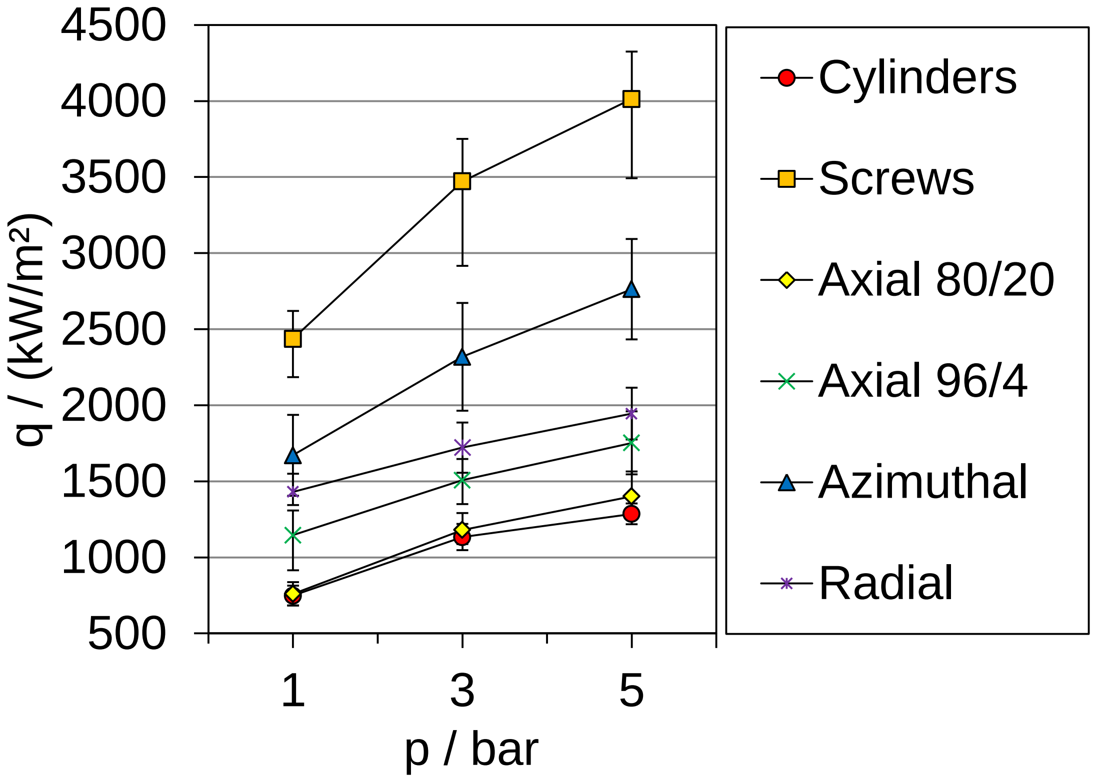


“Plateau“ Behaviour

- No rapid temperature excursion, coolable at a higher temperature level, e. g. for bed 5, azimuthal stratification, top-flooding, 3 bar

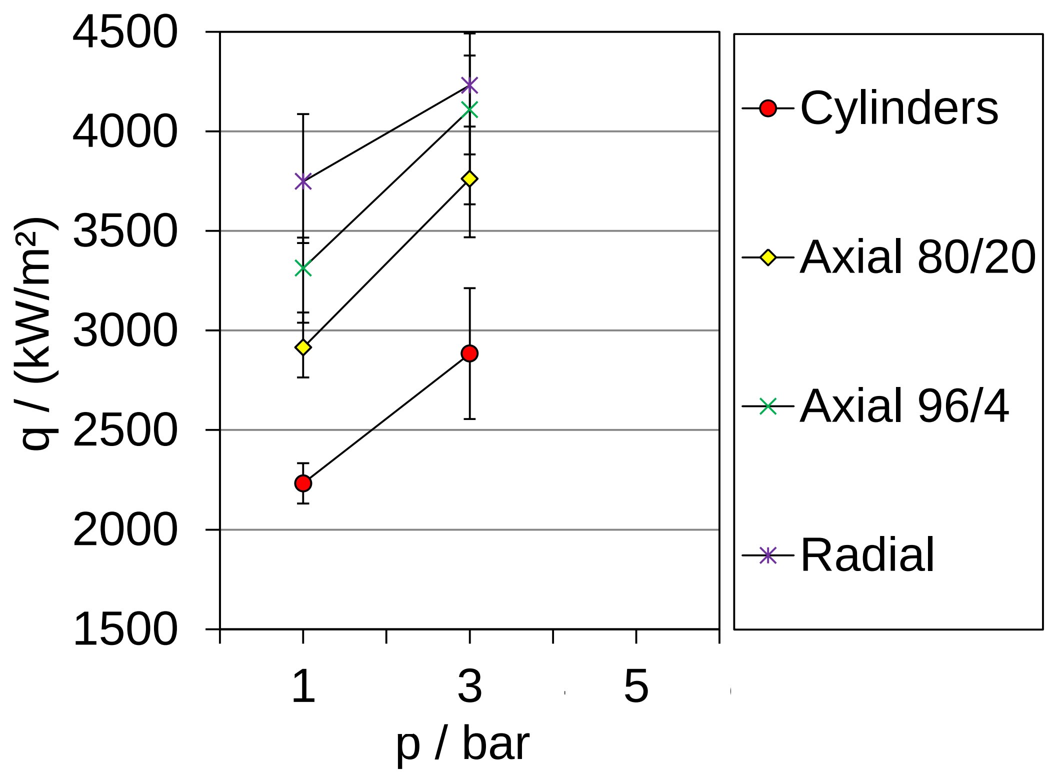


Dryout Experiments – Top-Flooding



- Highest DHF for screws (high porosity, $\varepsilon = 0.58$), lowest DHF for cylinders (low porosity, $\varepsilon = 0.38$)
- Strong reduction of DHF due to axial stratification
- Plateau behaviour for azimuthally stratified bed (remaining at temperature level above saturation temperature instead of rapid temperature increase)

Dryout Experiments – Bottom-Flooding (Natural Circulation Loop)



- Flow rate in the downcomer limited by strong fluctuations of the water level for bed 2 (screws) and bed 5 (azimuthal), thus no DHF can be determined
- For some experiments not sufficient heat input to reach dryout at 5 bar

Conclusions

- Boiling and dryout experiments carried out for two homogeneous beds and four stratified beds with strongly different porosity (ε = 0.38 vs. 0.58)
- Good qualitative agreement of flow rate in the natural circulation loop with measured axial pressure difference
- No significant cross flow detected for the azimuthally stratified bed
- Plateau behaviour in dryout experiments for stratified bed
- Strong increase of DHF by bottom-flooding compared to top-flooding
- Strong decrease of DHF even by a thin layer with low permeability on top of the bed

Acknowledgement

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