JOHANNES KEPLER
UNIVERSITY LINZ

voestalpine
ONE STEP AHEAD.

K1 MET
metallurgical competence center

Validation of continuous casting mold flow simulations by water model experiments

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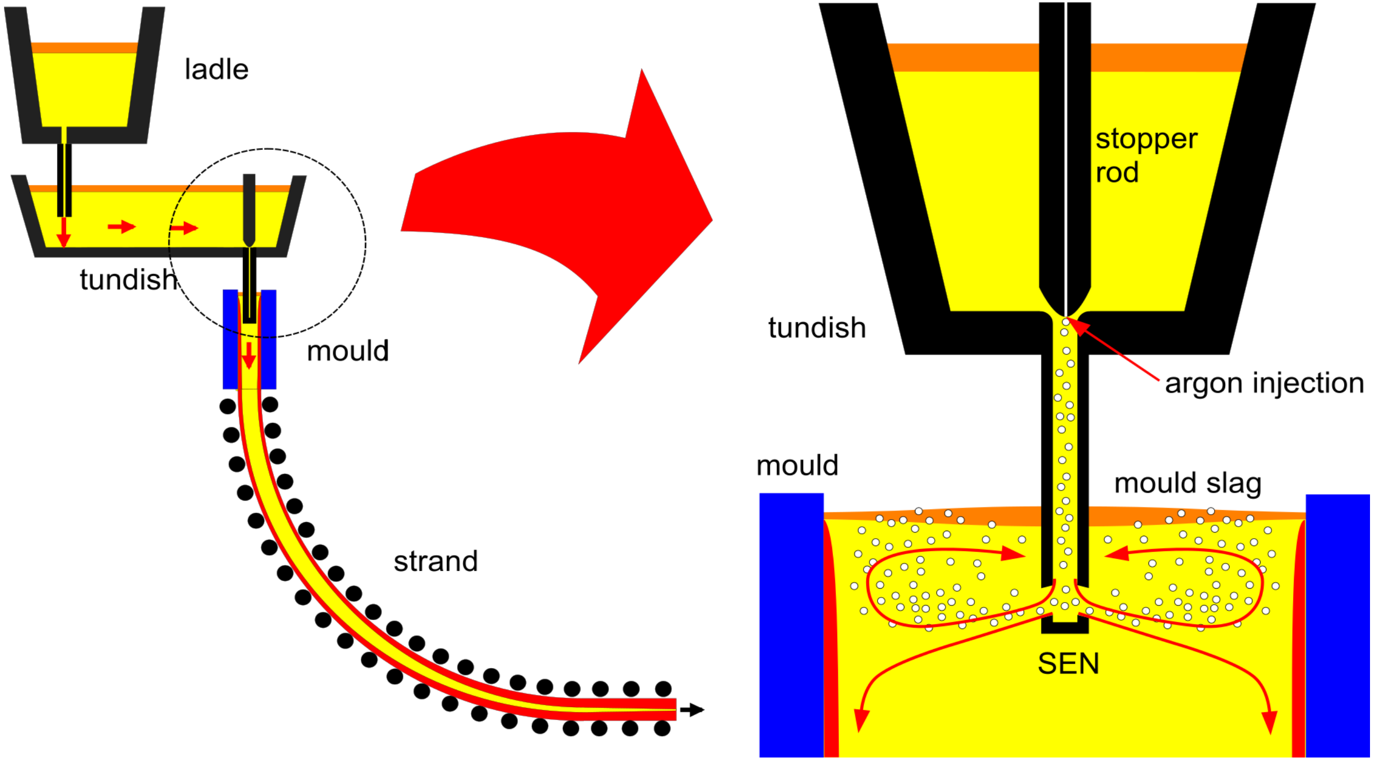
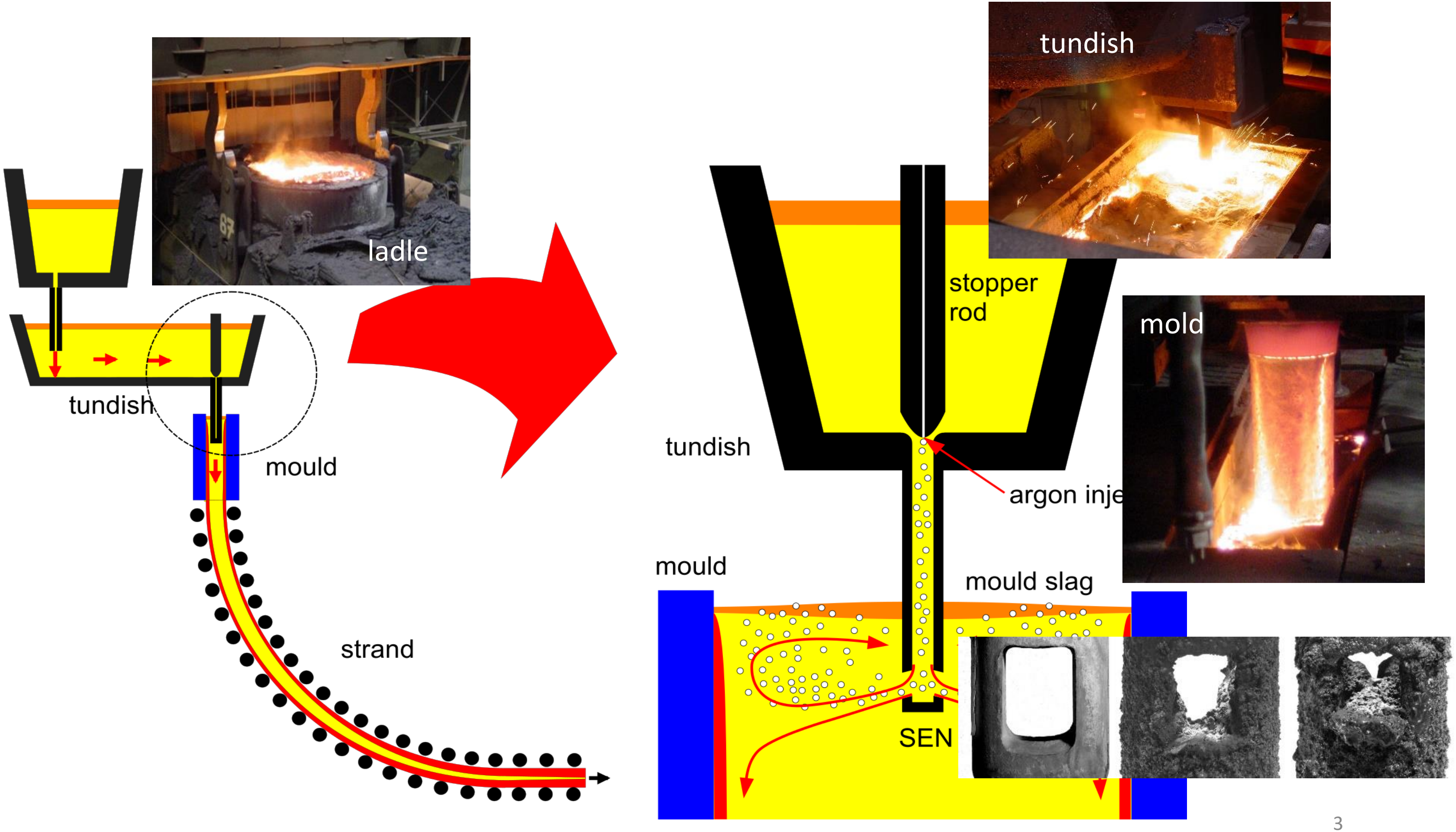
Continuous Casting of Steel




ladle
tundish
mould
strand
tundish
stopper rod
argon inje
mold
tundish
mould
mould slag
SEN

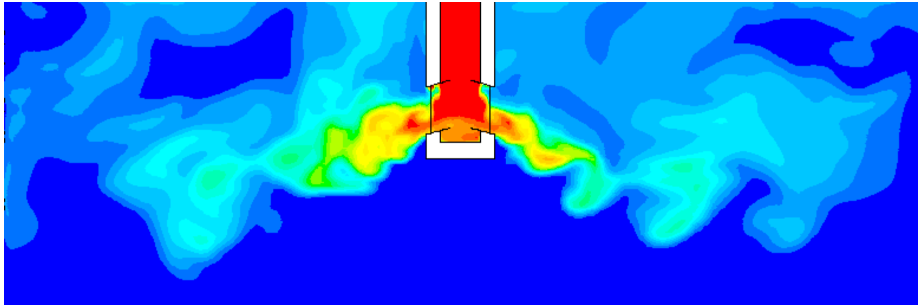
Mathematical and Physical Simulation

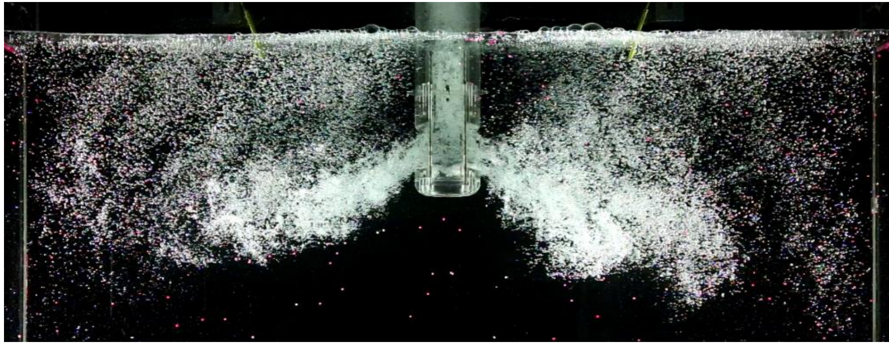
Mathematical Simulation (CFD)

- only empirical turbulence modelling
- complex interaction of gas bubbles and turbulence
- Validation/verification required

Physical Simulation: 1:1 Water Model

- similarity: Reynolds, Froude
- lower surface tension
- lower absolute pressure: $\frac{1}{2}\rho u^2 + \rho g h$
- measurement methods required

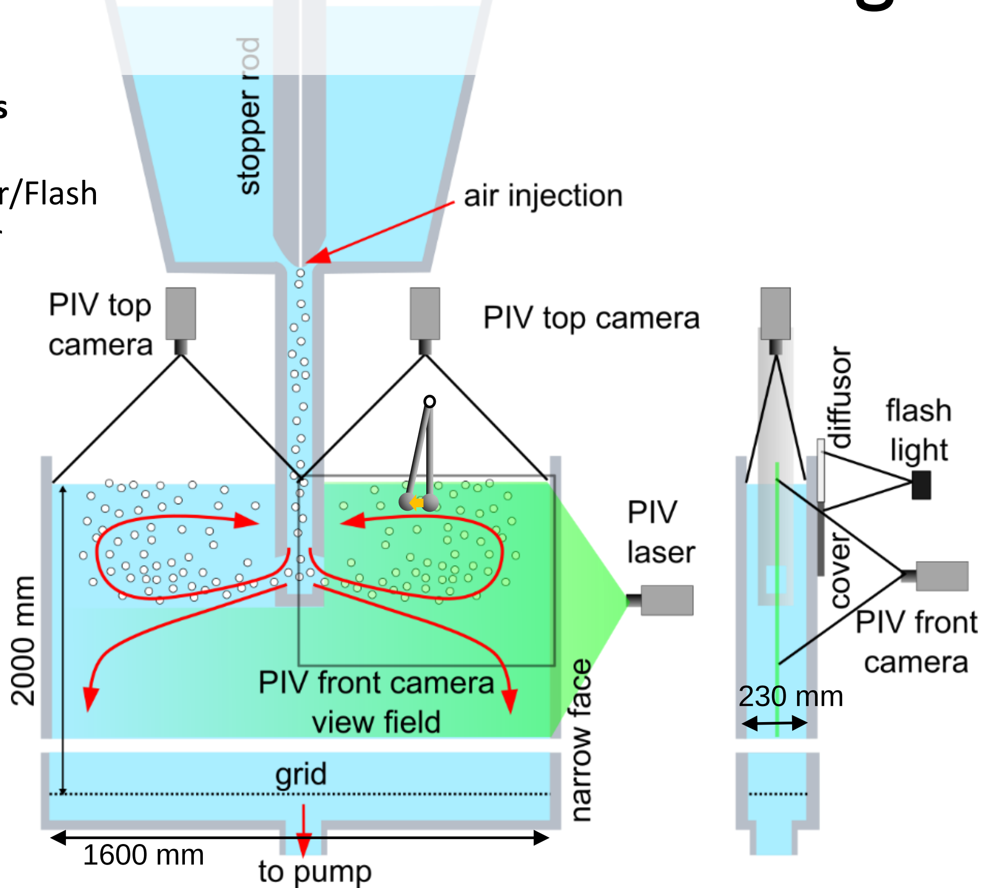




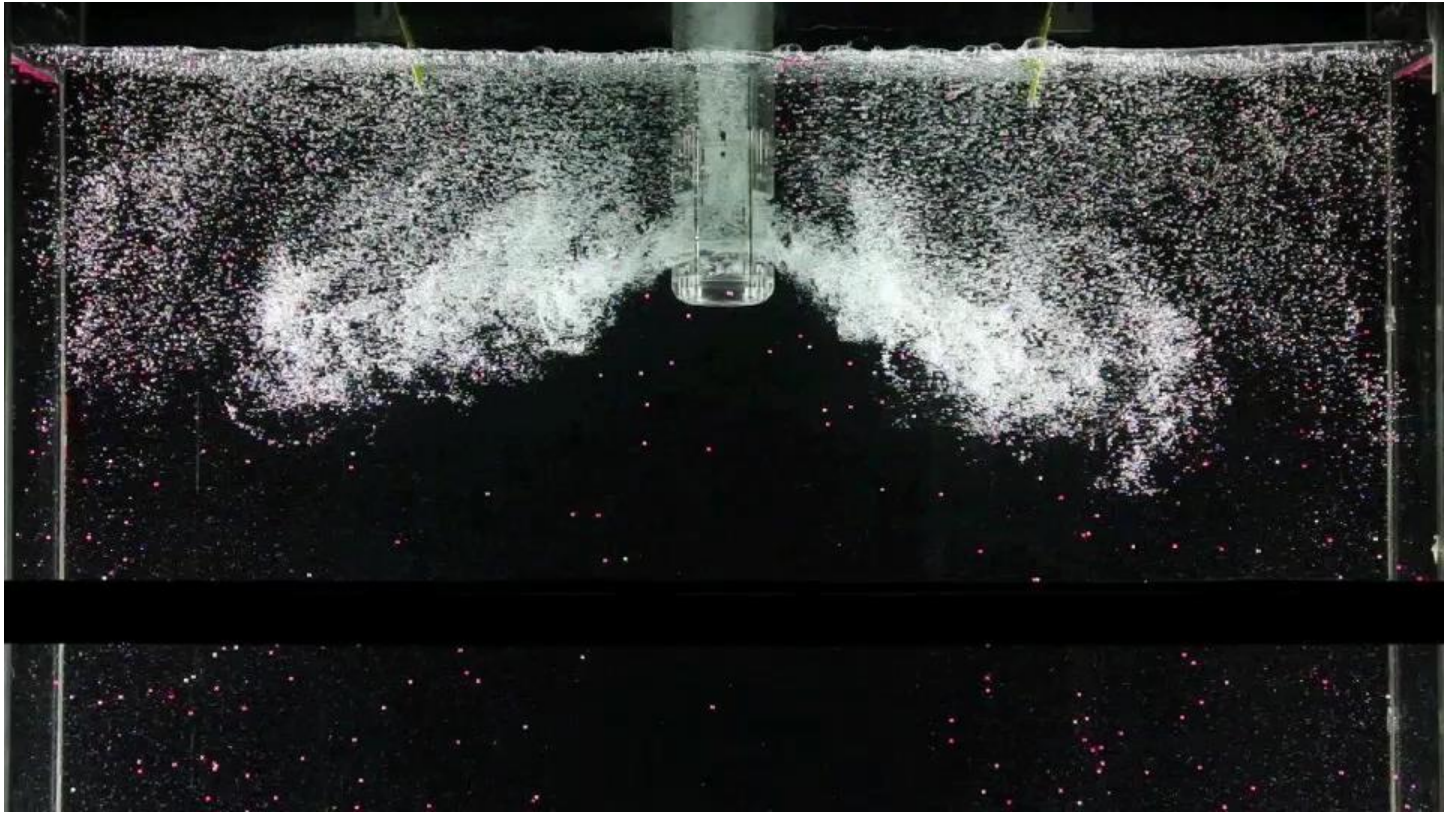
Water Model of Continuous Casting Mold

measurement methods

- video cameras
- PIV cameras + Laser/Flash
- paddle velocimeter



Water Model of Continuous Casting Mold



voestalpine Mold Water Model

- 1:1 scale
- same velocities & throughput like in reality

Similarity

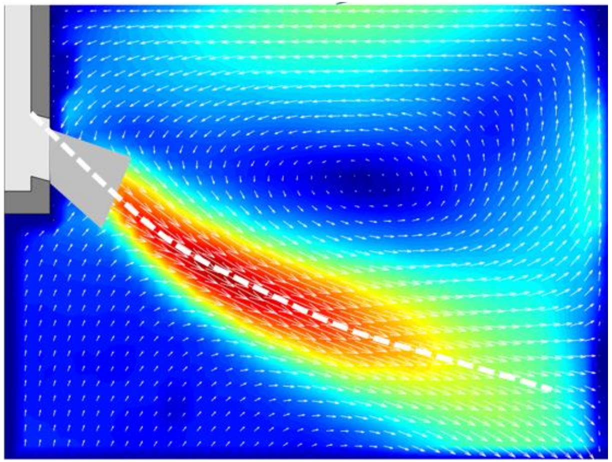
- Reynolds
- Froude
- surface tension
- temperature: gas expansion 1:6
- absolute pressure [Steel Res. Int. 2015]

Video

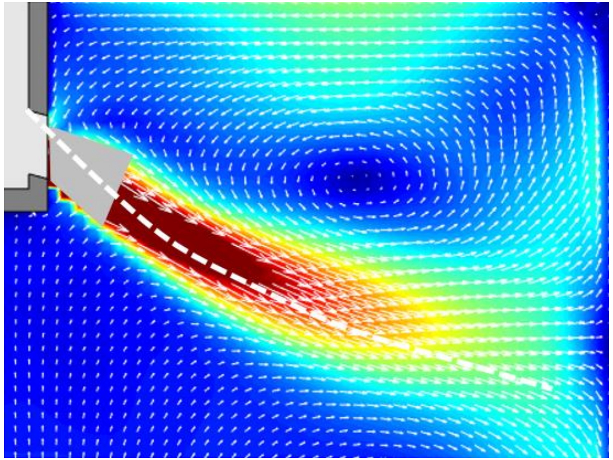
- 8 % gas volume in SEN at 1,2 m/min
- playback speed 2.5 x slowed down

PIV velocity measurements: single phase flow

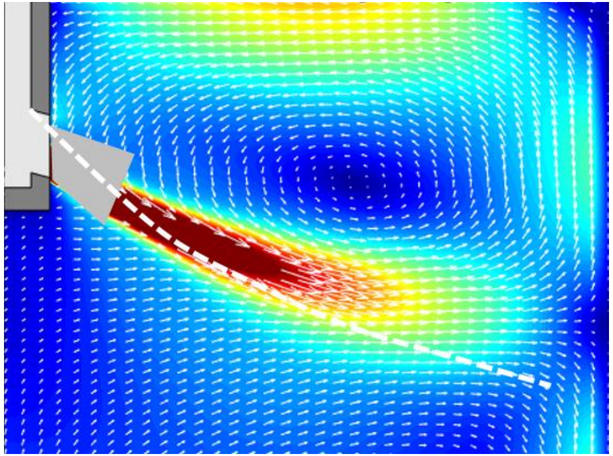
time averaged PIV



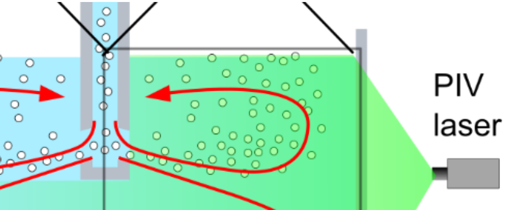
time averaged flow simulations



scale resolving turbulence model (SAS)



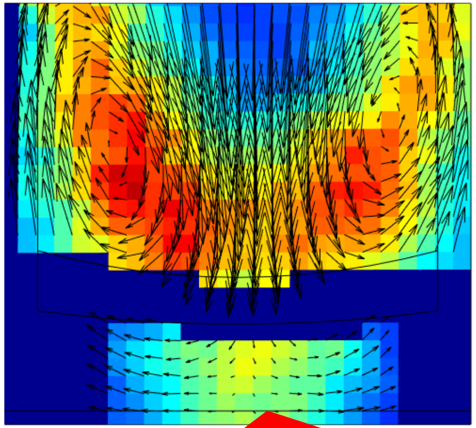
Reynolds averaging turbulence model (realizable k - ϵ)

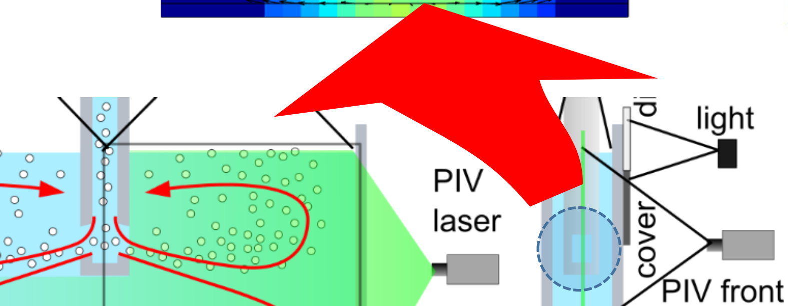


center plane color: velocity magnitude

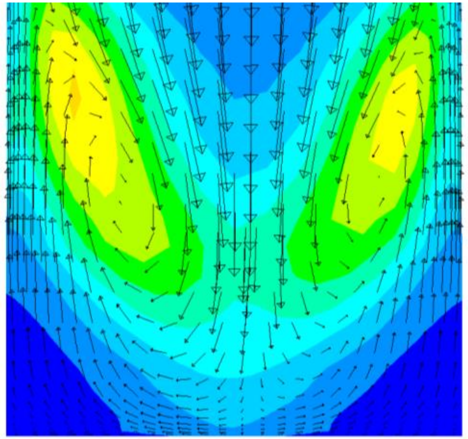
PIV velocity measurements: single phase flow

time averaged PIV

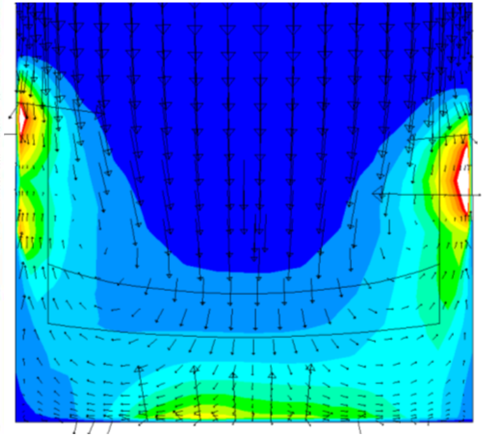




time averaged flow simulations



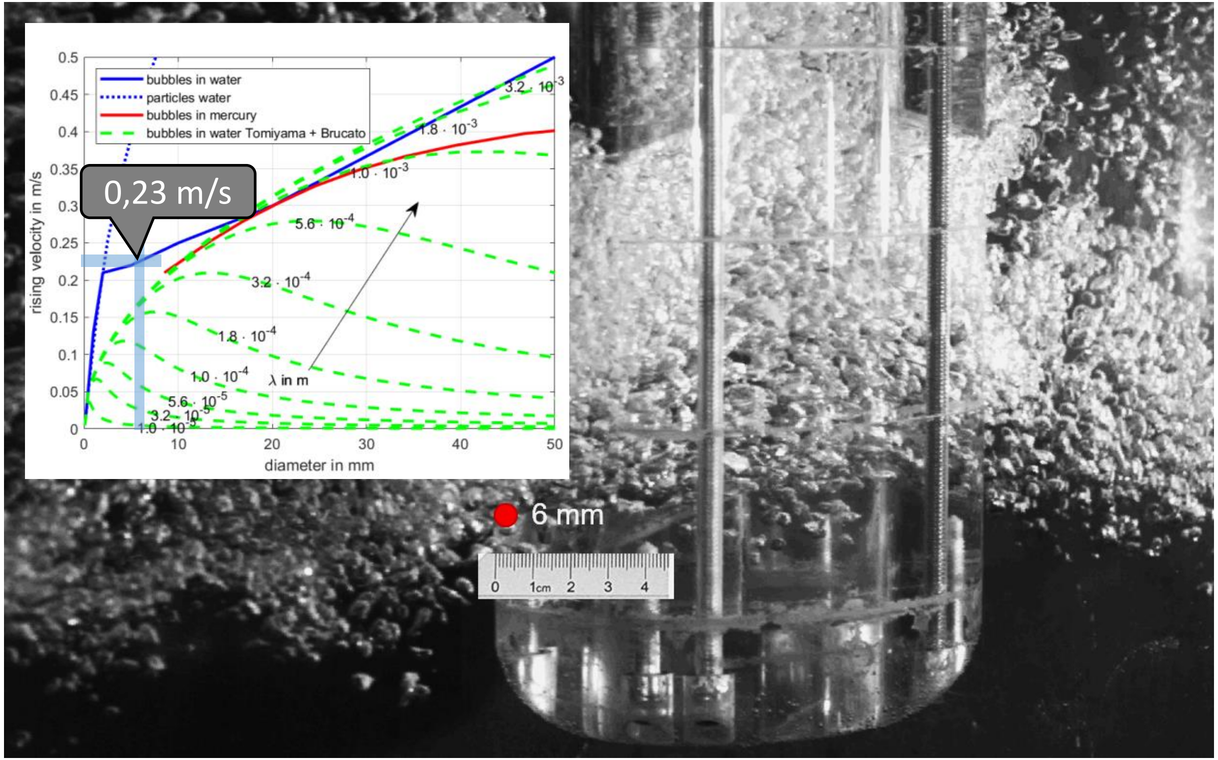
scale resolving
turbulence model (SAS)



Reynolds averaging turbulence
model (realizable k - ϵ)

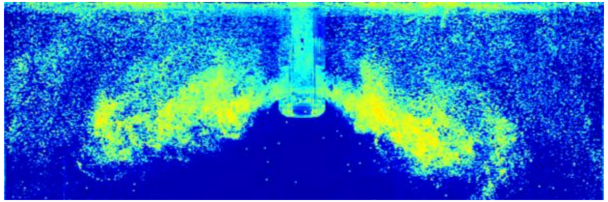
color: turbulent kinetic energy

Video Camera Images: Bubble Size

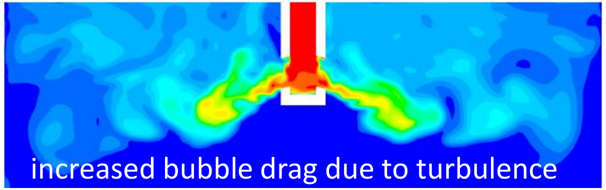


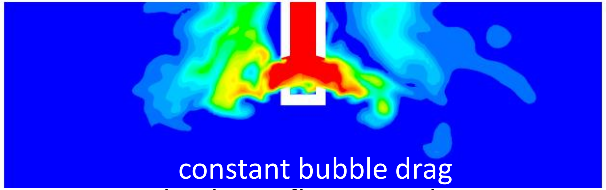
Video Camera Images: Bubble Distribution

snapshot



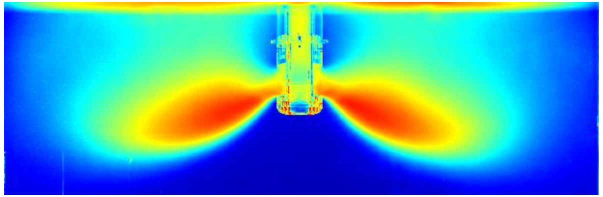
video image



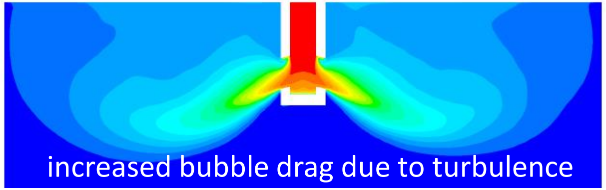


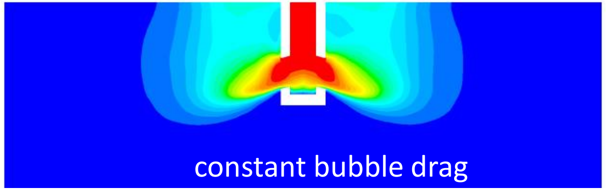
multiphase flow simulations

time averaged



video image



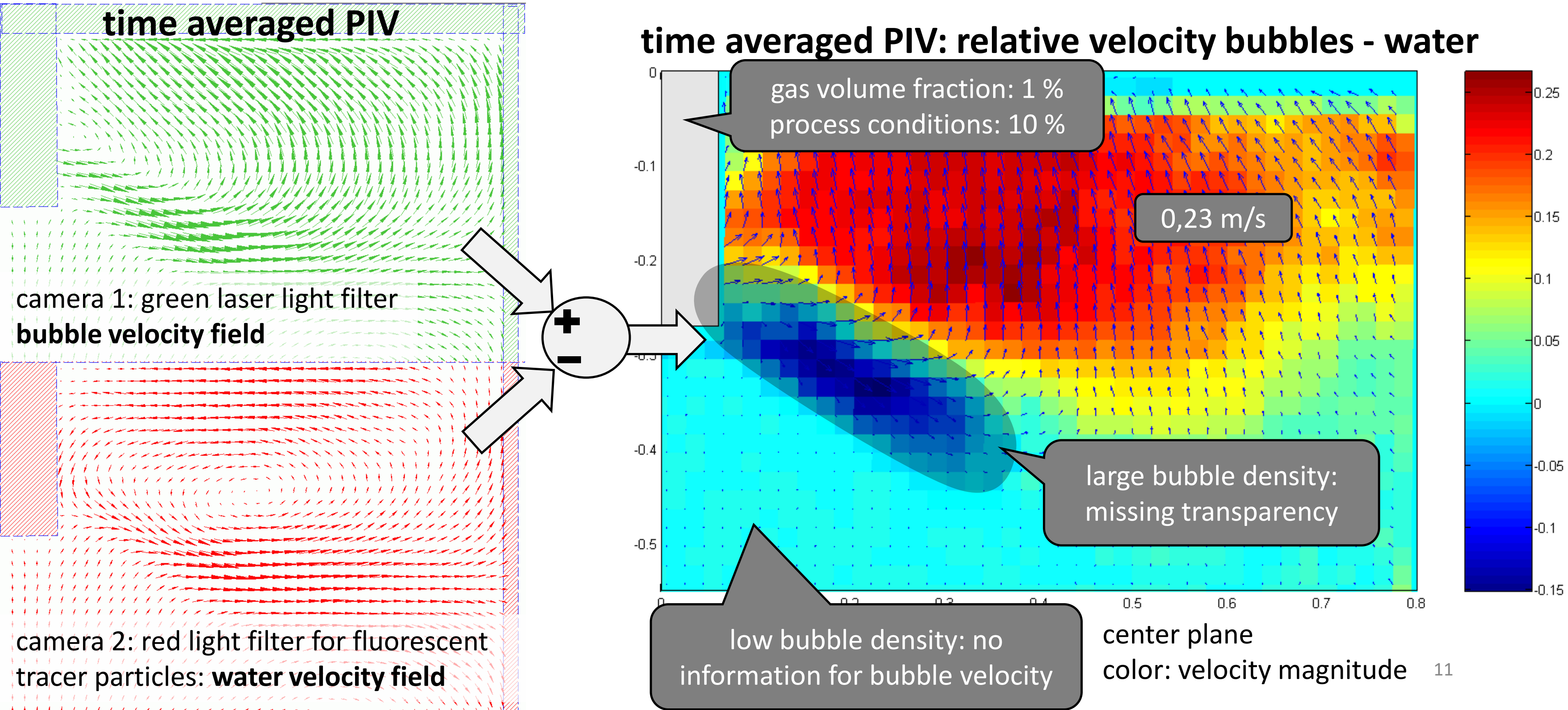


multiphase flow simulations

color: image brightness

color: gas bubble volume fraction

PIV velocity measurements: two-phase flow

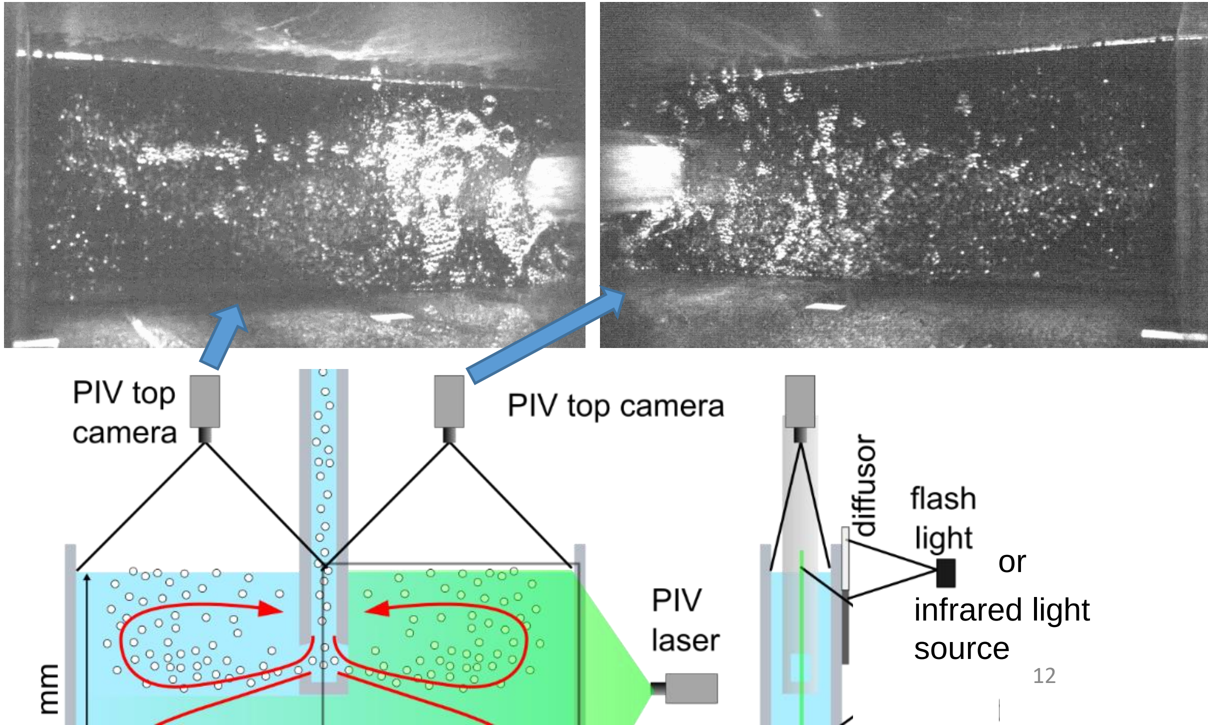


PIV velocity measurements: two-phase flow

- setup 1: PIV cameras + flash illumination
- setup 2: infrared cameras with 60 fps + continuous infrared illumination

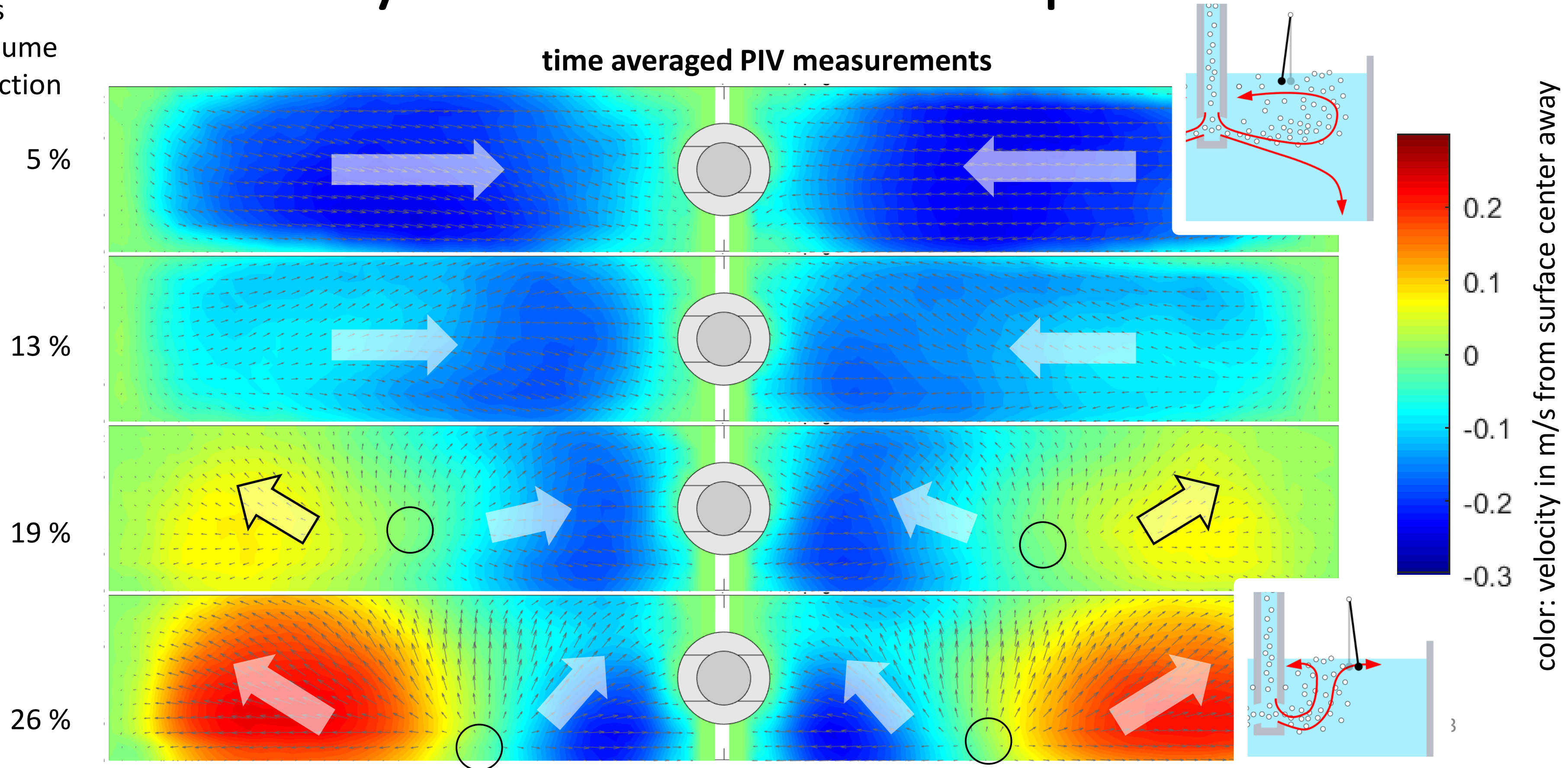
- use bubbles as tracer particles

- PIV cross correlation algorithm
- Optical Flow algorithm

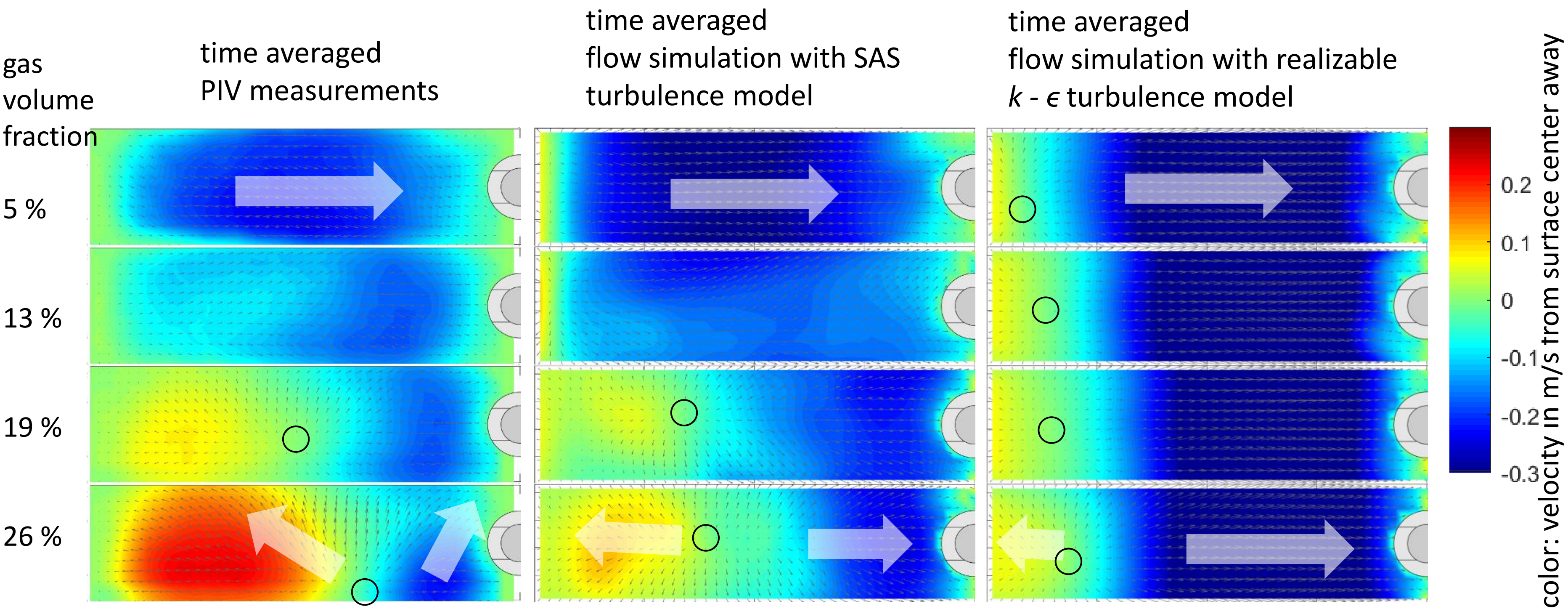


PIV velocity measurements: two-phase flow

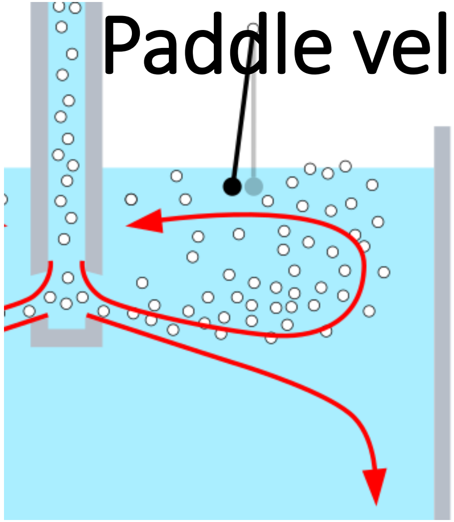
gas volume fraction

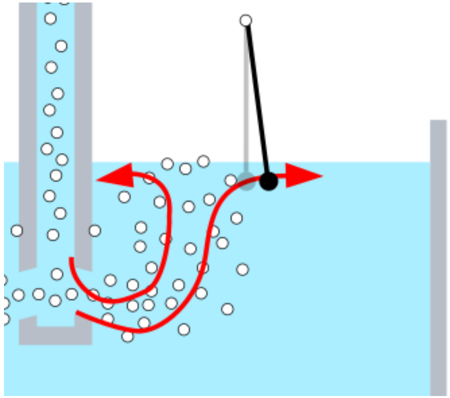


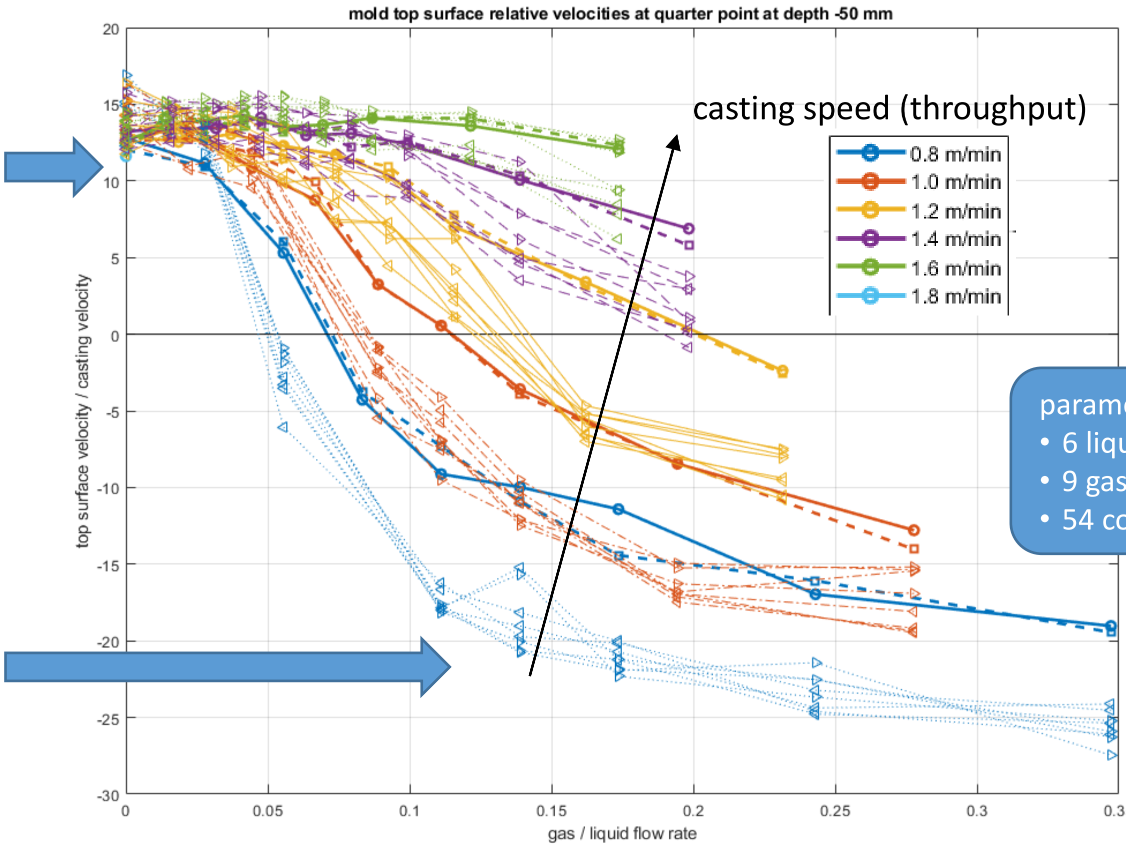
PIV velocity measurements: two-phase flow



Paddle velocimeter vs. Numerical Simulation



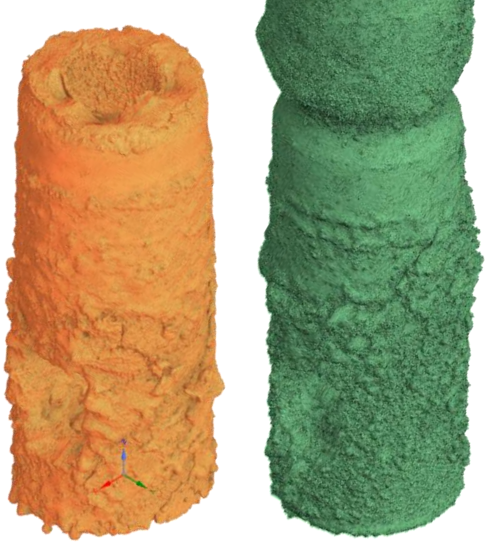




parameter space:
- 6 liquid flow rates
- 9 gas flow rates
- 54 combinations

Outlook

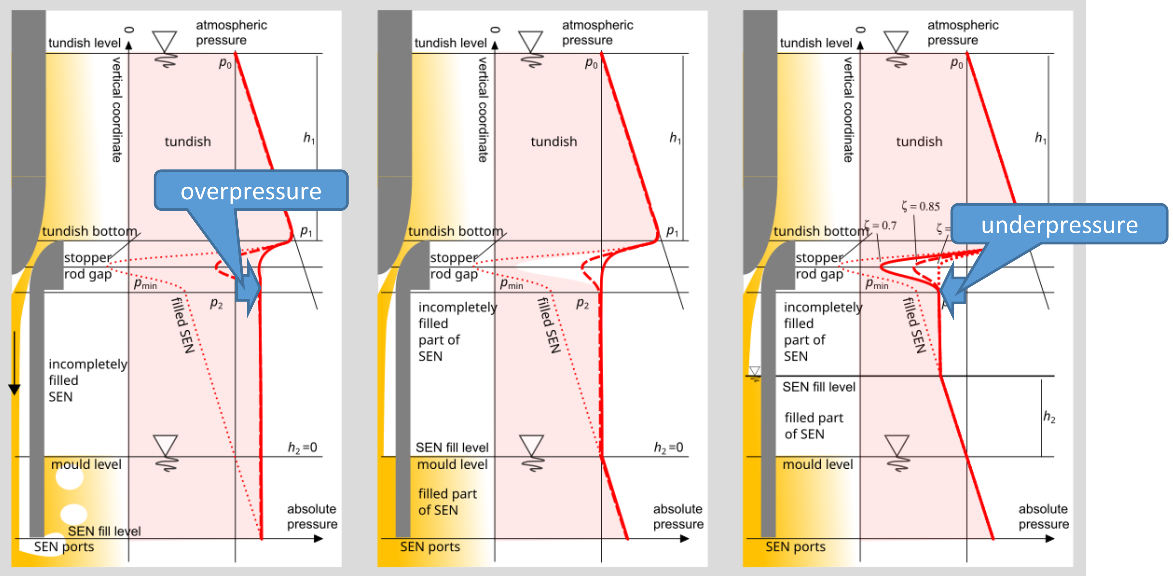
- influence of changes in nozzle surface geometry by deposition of solid material (clogging) and erosion:
  - simulations of 3D scanned nozzles,
  - measurements with 3D printed nozzles

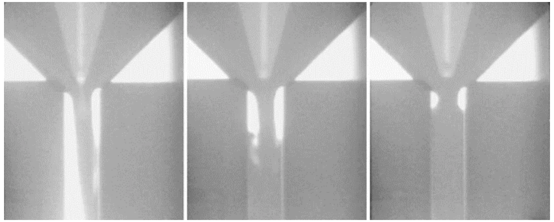


Outlook

- measurements with liquid metal at SWERIM

pressure conditions for liquid metal and different phase distribution patterns





HZDR 2015
liquid metal experiment

First sketches in 2012, Proc. ECCC 2014, *Steel Res. Int.*, 2014, DOI:10.1002/srin.201300448

Conclusions

- validation succeeds or fails? → accurate enough?
  - empirical CFD models: always expect imperfect results
- validation fails (too inaccurate): “debugging”?
  - try and error
  - understand physics
    - use as many measurement techniques as possible: look into details
    - separate complex situations into smaller details