Fluid Dynamic Modeling Of An Industrial Wet Chemical Process Bath For The Production Of Silicon Solar Cells

L. Mohr[1], M. Zimmer[1], A. Moldovan[1], M. Menschick[2], B. Mandlmeier[2], C. Müller[3]

[1]Fraunhofer ISE
[2]Singulus Technology AG
[3]Albert-Ludwigs-Universität, Freiburg

Comsol Conference

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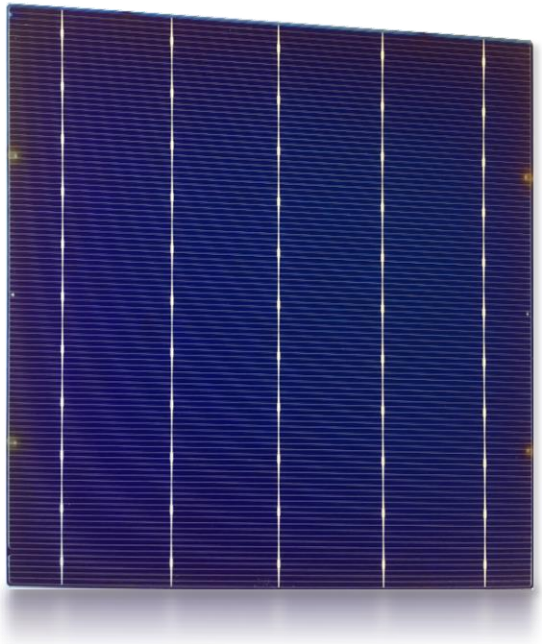
Introduction

- Silicon solar cell process



Saw damage removal & Texture

Diffusion

Rear emitter removal & Surface cleaning

Rear & Front passivation

Metallization

Firing & Annealing

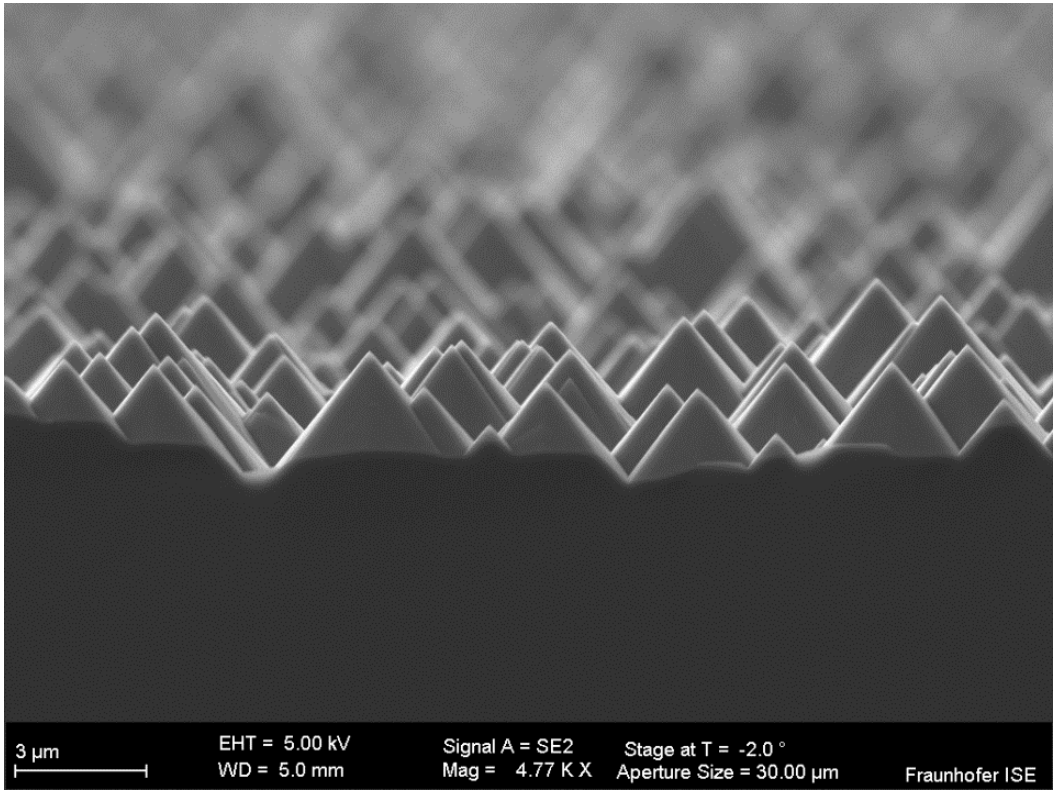
Introduction

- Silicon solar cell process
- Chemical process steps
  - Surface structuring
    - ➢ Reduction of reflection
  - Intended etch back
    - ➢ Modification of emitter sheet resistance

Introduction

- Silicon solar cell process
- Chemical process steps
  - Surface structuring
    - ➢ Reduction of reflection
- Texture process
  - KOH 80°C
    - ➢ Surface covered with small micropyramids

Saw damage removal & Texture



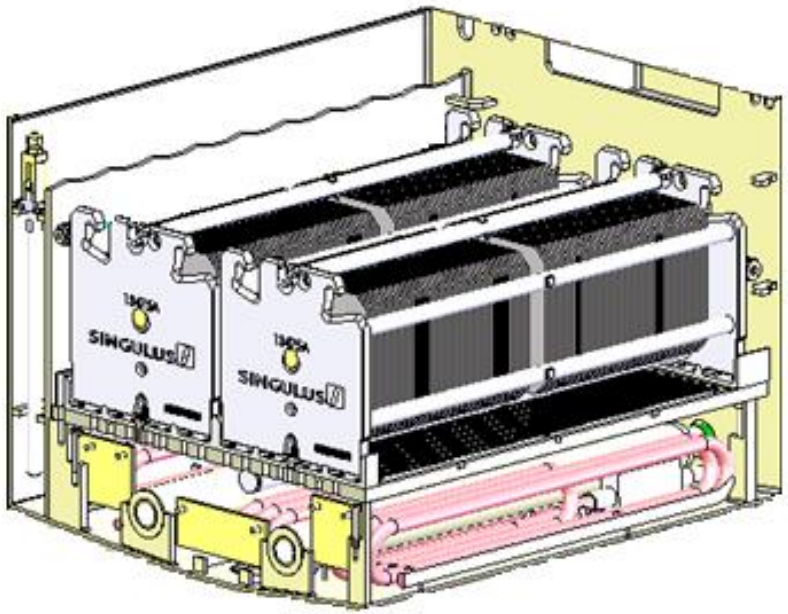
Introduction

- Silicon solar cell process
- Chemical process steps
  - Surface structuring
    - ➢ Reduction of reflection
- Texture process
  - KOH 80°C
    - ➢ Surface covered with small micropyramids
- Process steps in automated batch etching and cleaning tool

Saw damage removal & Texture

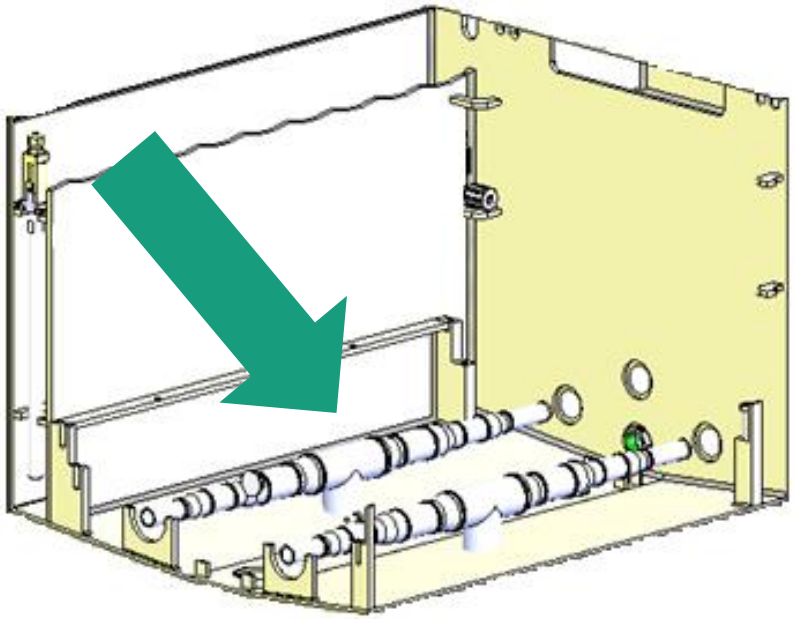
Motivation

- Goal
  - Homogeneous texture on wafer surface
  - Deeper understanding of processes in the basin
  - Investigate flow-induced etching patterns
  - Optimizing basin or pipe geometry



Simulation Approach

Components	Module
Inlet pipe	**CFD**
Basin without fittings	CFD
Basin with perforated plate	CFD



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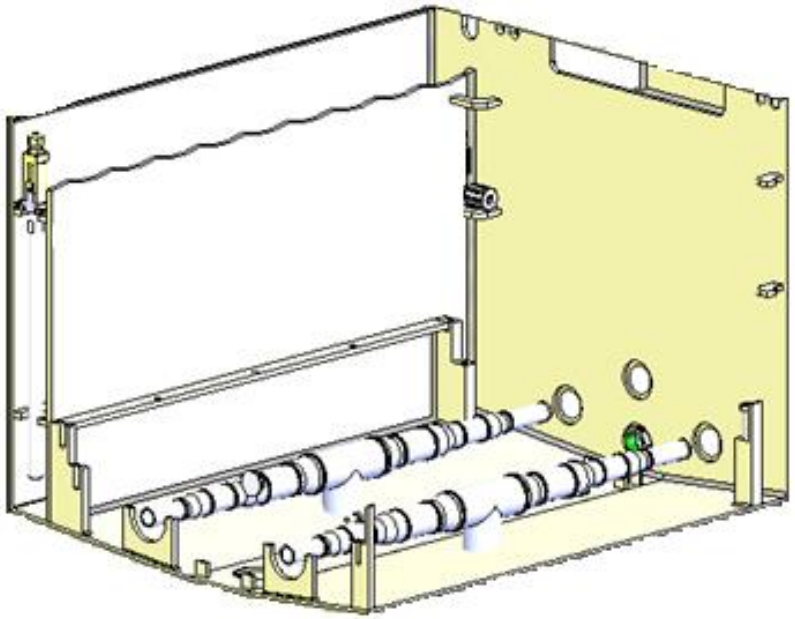

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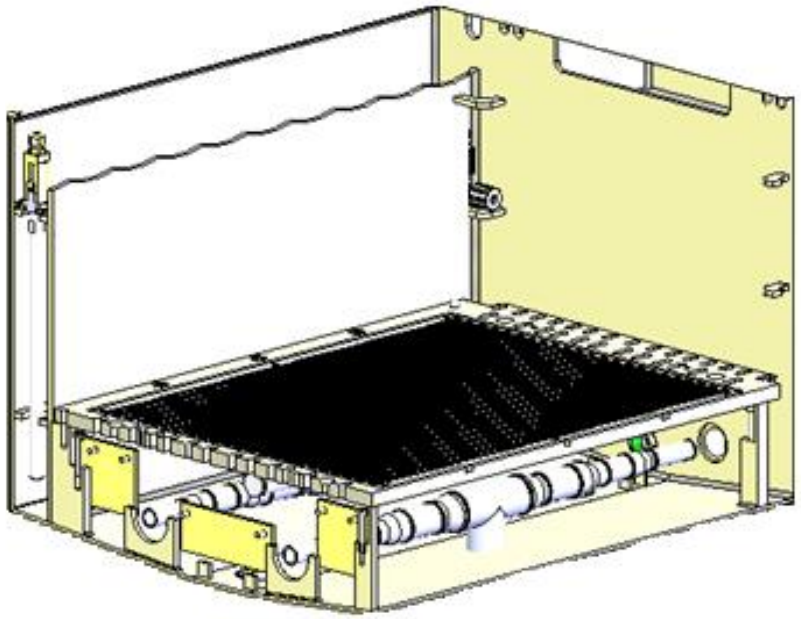
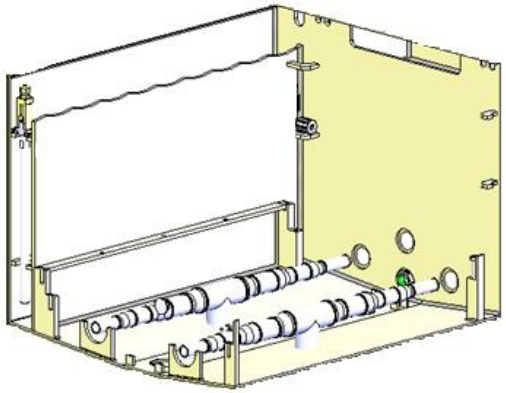
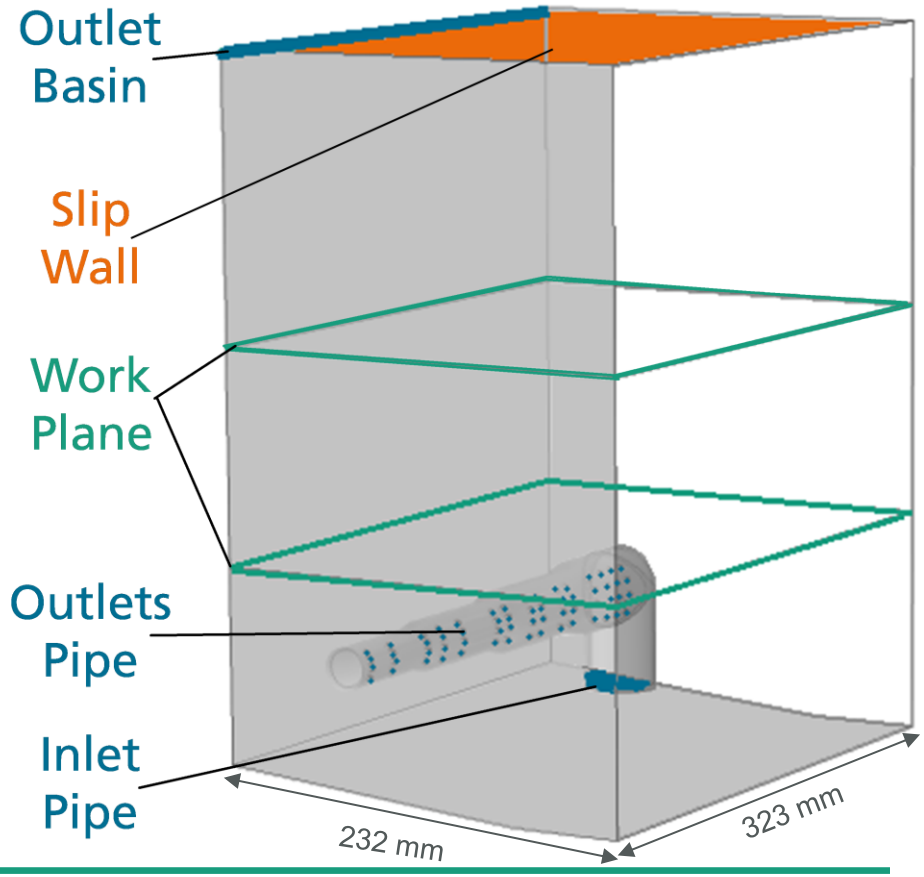


- COMSOL Multiphysics 5.21 on two AMD Opteron Processor 6128 with 8 cores each, 2 GHz, 72 Gb Ram

Separation of Geometry
Investigation Approach

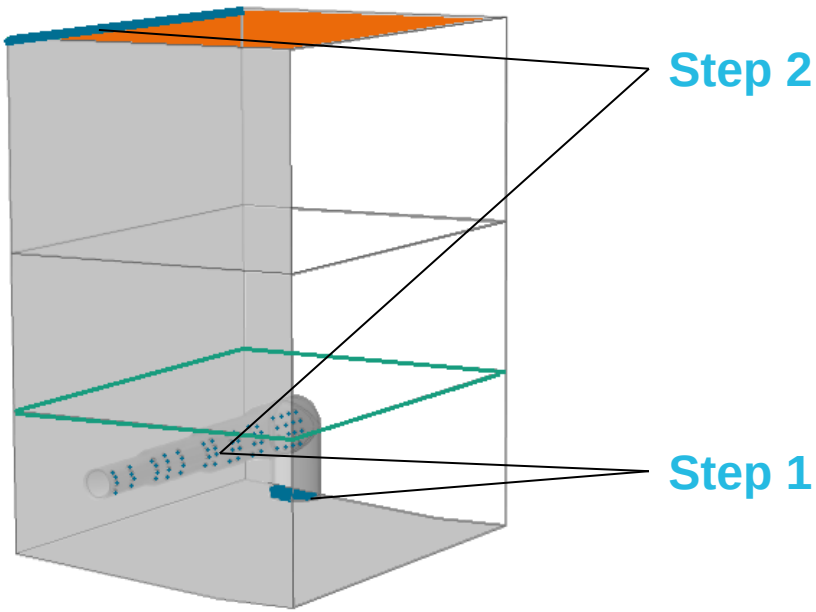


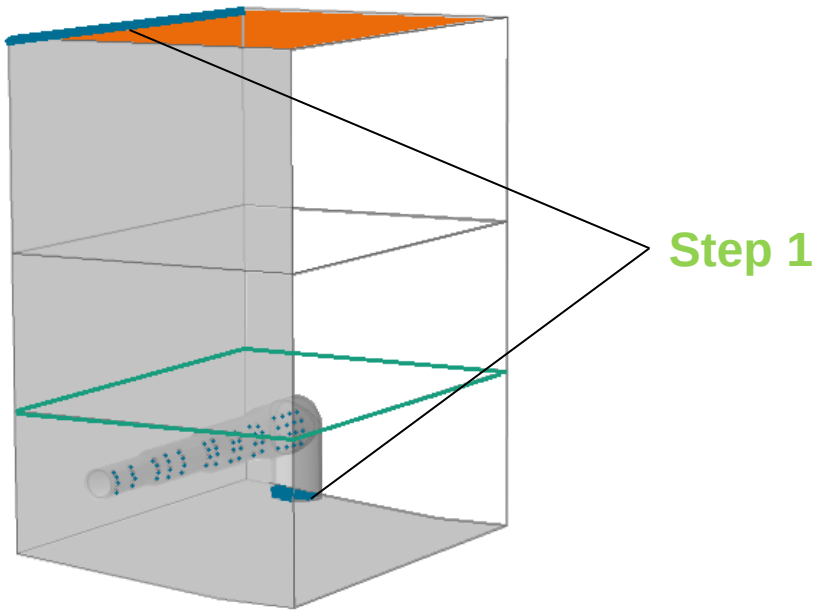
- Simulation setup
  - Geometry: quarter of basin
  - Initial Material:
    Water, Comsol library
  - Study: Stationary
  - Pipe: κ-ε turbulence model
  - Basin: Algebraic *y*Plus



Separation of Geometry
Investigation Approach

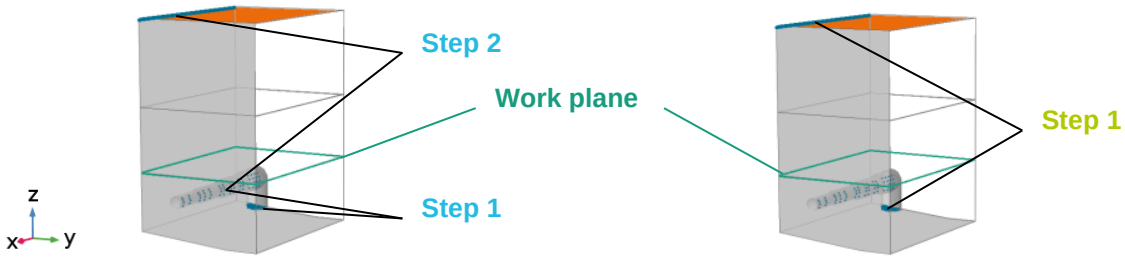
- Separation to save computational time in later changes of geometry
- Comparing **two step** study with **one step** study





Separation of Geometry
Results

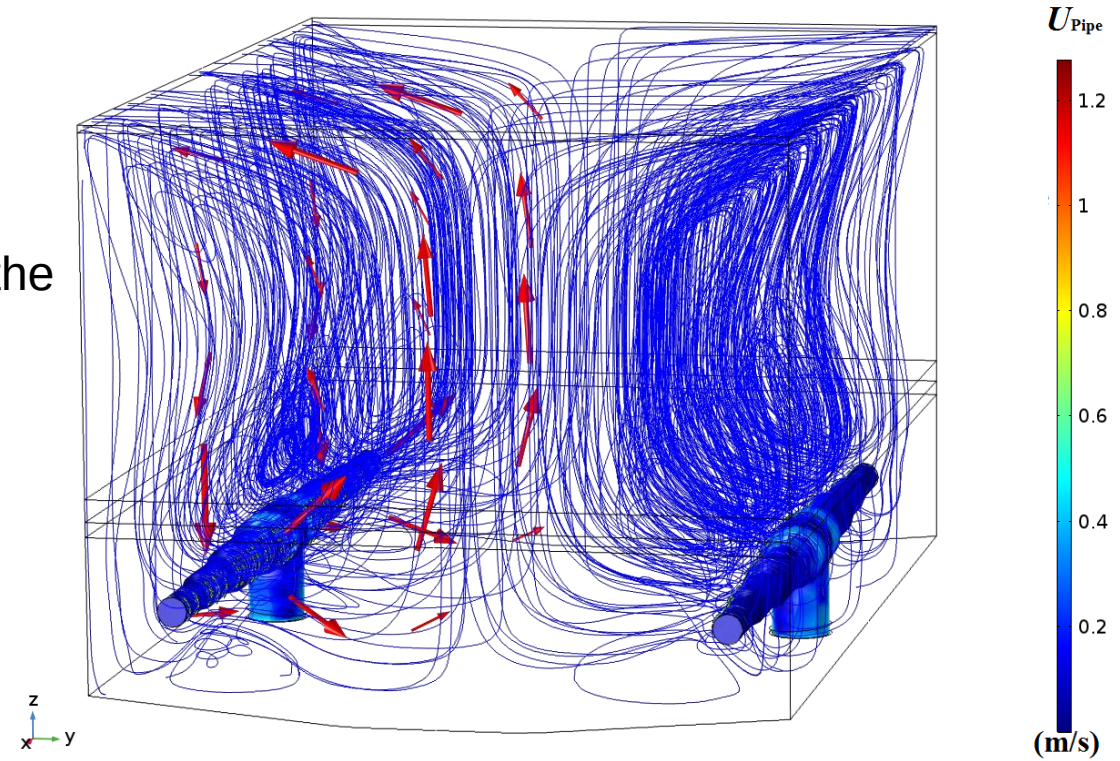
- **Two Step** and **One step** study results compared on work plane



Study	Two step		One step	Relative difference
Velocity magnitude U (m/s)	$7.93 \cdot 10^{-3}$		$7.75 \cdot 10^{-3}$	2%
Velocity in z-direction u_z (m/s)	$1.98 \cdot 10^{-3}$		$1.84 \cdot 10^{-3}$	7%
Number Mesh Element [N]	$8.7 \cdot 10^{4}$	$3.0 \cdot 10^{5}$	$3.9 \cdot 10^{5}$	
Time [min]	22	49	254	

Results Two Step Study
Simulation

- Turbulence around supply pipes
- One part flows through overflow collar
- Other part flows along the wall



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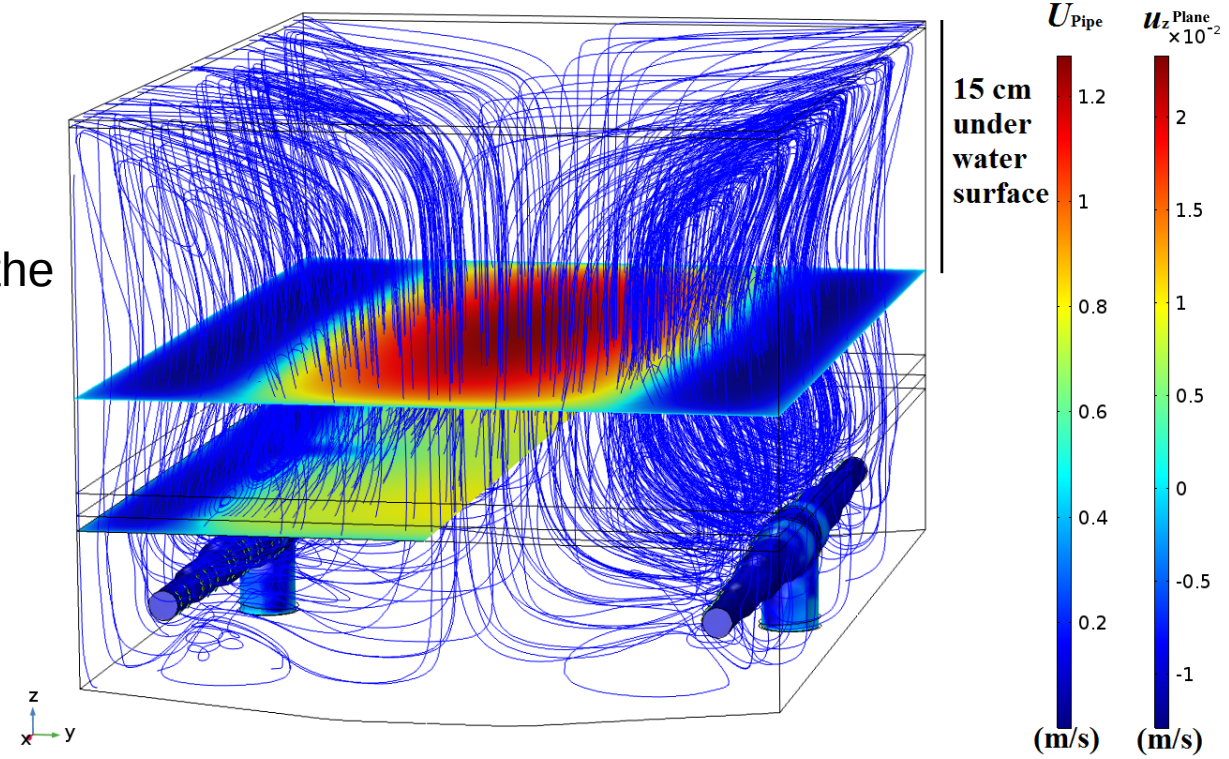
Results Two Step Study
Simulation

- Turbulence around supply pipes
- One part flows through overflow collar
- Other part flows along the wall
- Turquoise, area of less flow
- ➢ Upper work plane to validate



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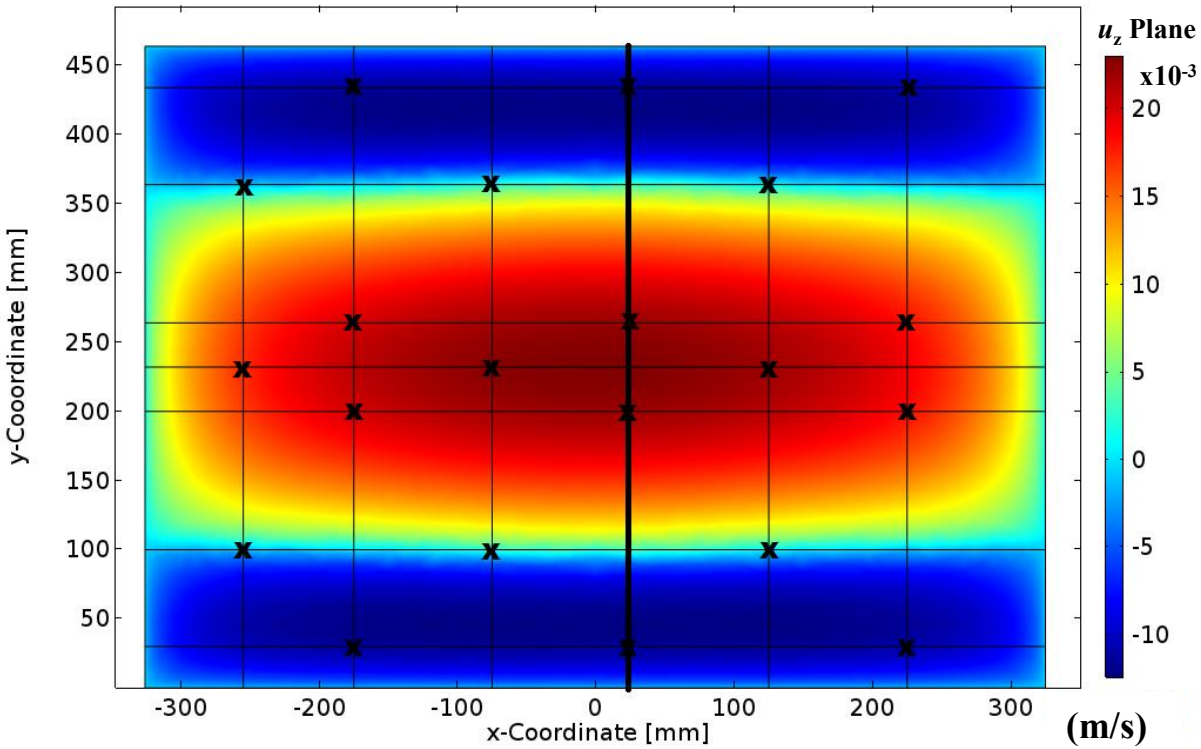
Results Two Step Study
Validation

- 21 measuring points, based on simulation
- Velocity profile along row 3
- Ultrasonic flow sensor
  - Highly accurate point velocity
  - between -0.2 m/s and 2.4 m/s ± 1%
  - Resolution of 0.001 m/s



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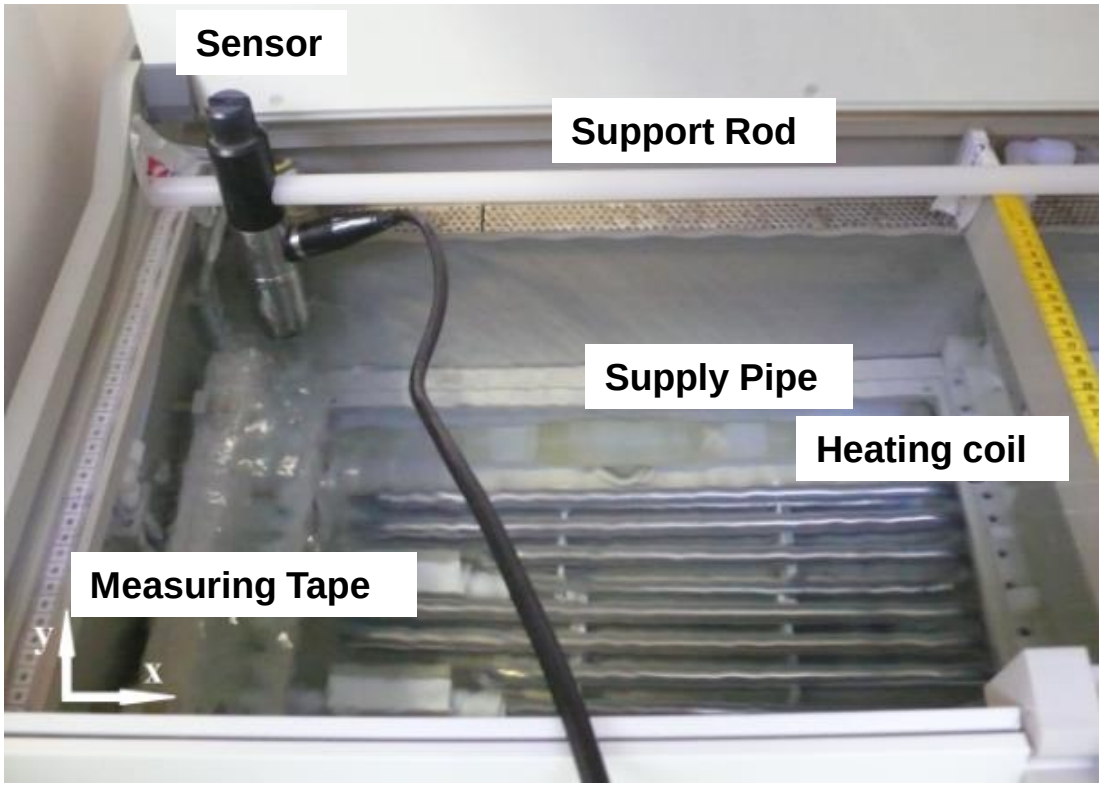

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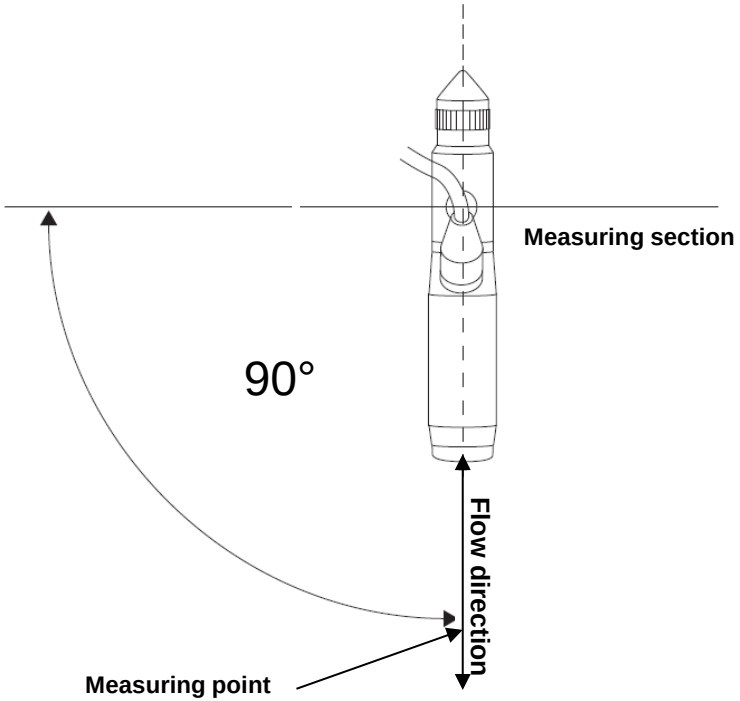
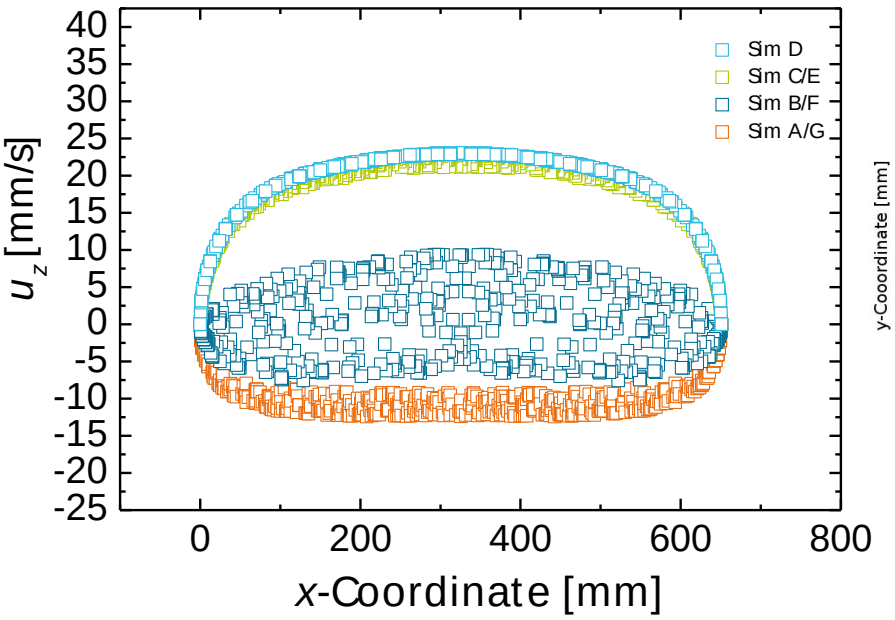
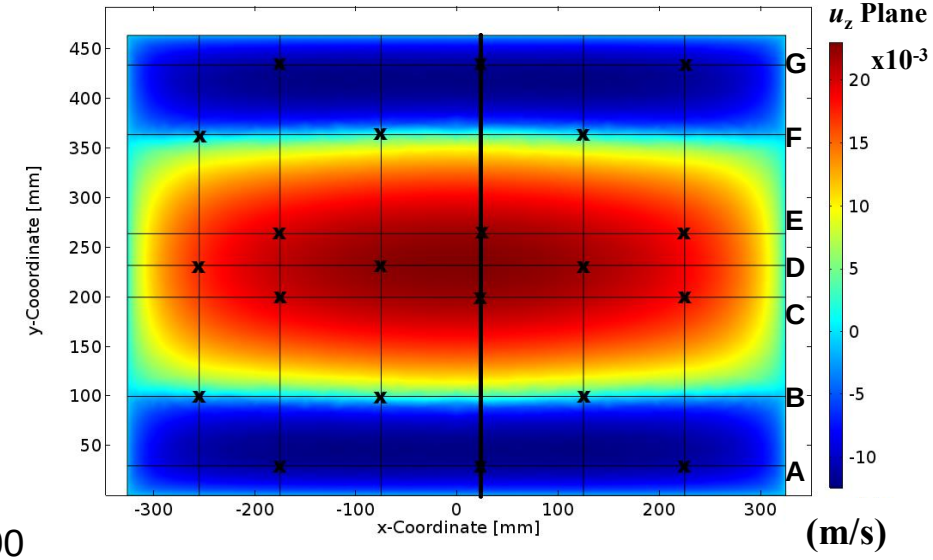


Results Two Step Study

Simulation and Experimental Results





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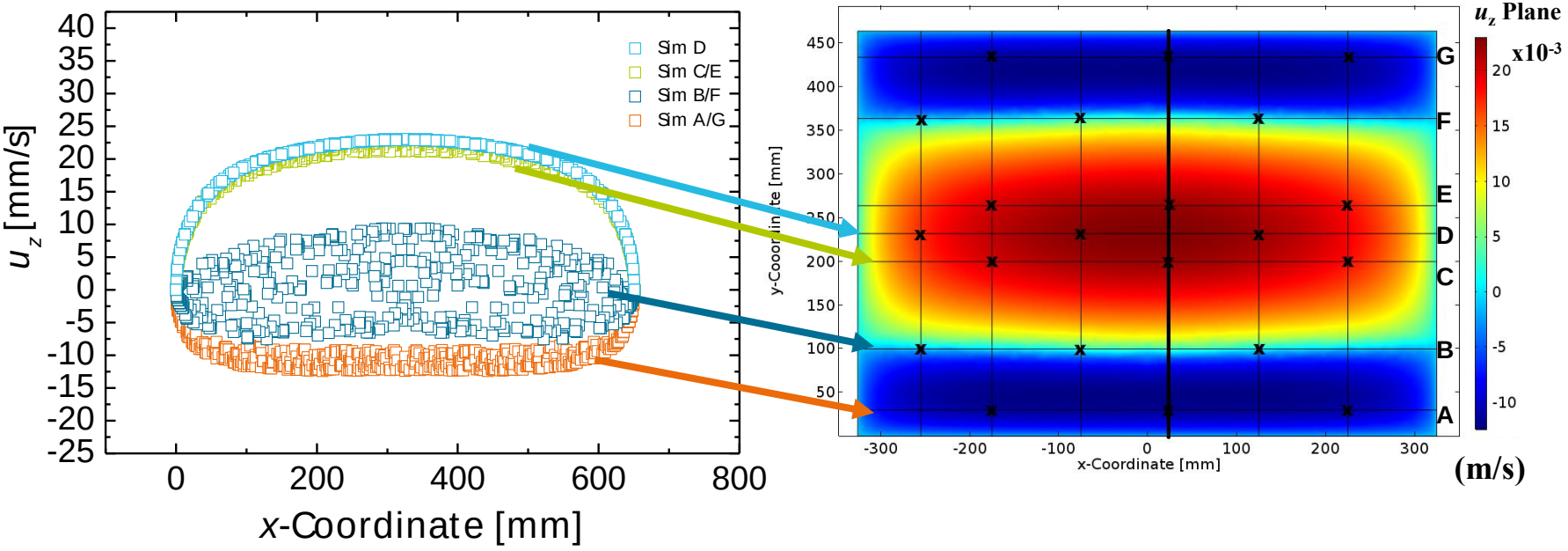
Results Two Step Study

Simulation and Experimental Results



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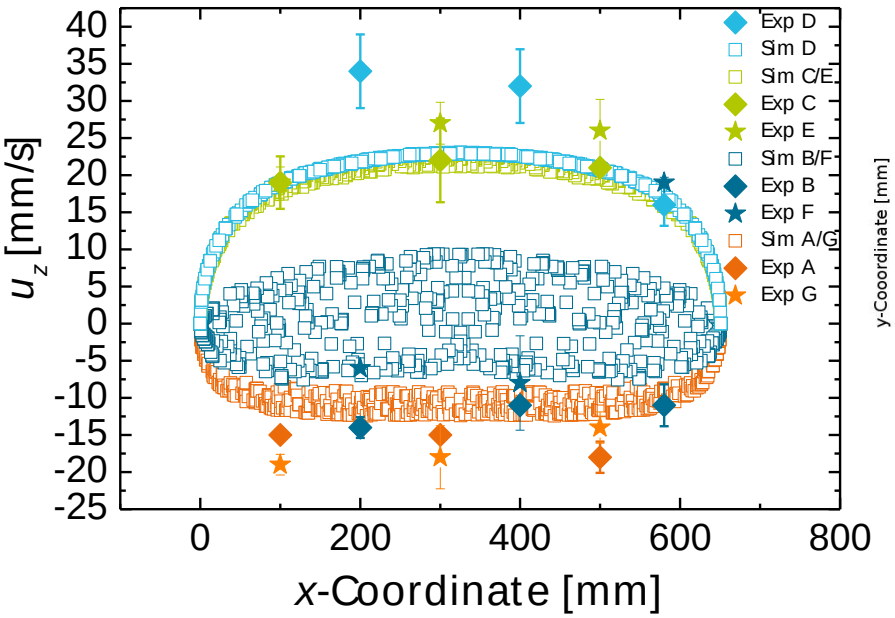
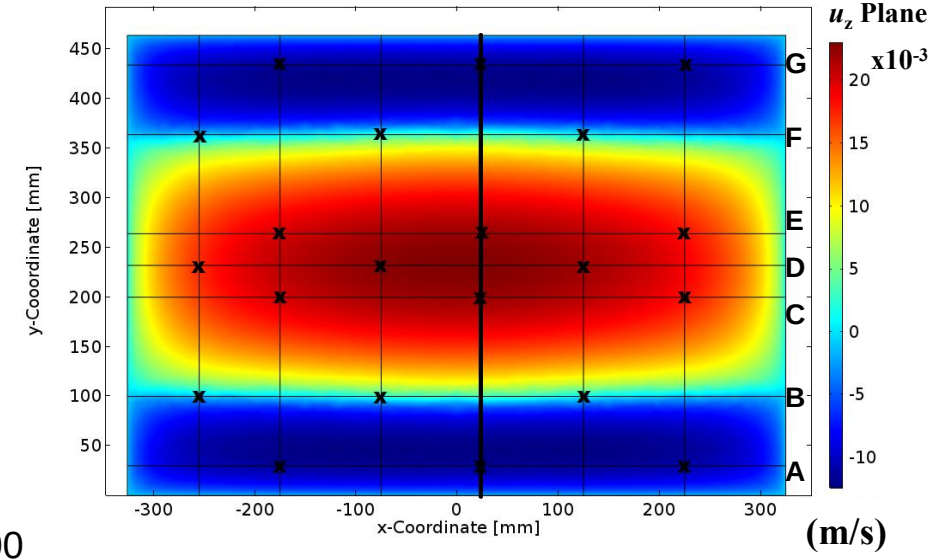
Results Two Step Study
Simulation and Experimental Results

- Flow direction verified
- Positive and negative velocities detected and measured
- Symmetry in basin recognized





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Results Two Step Study

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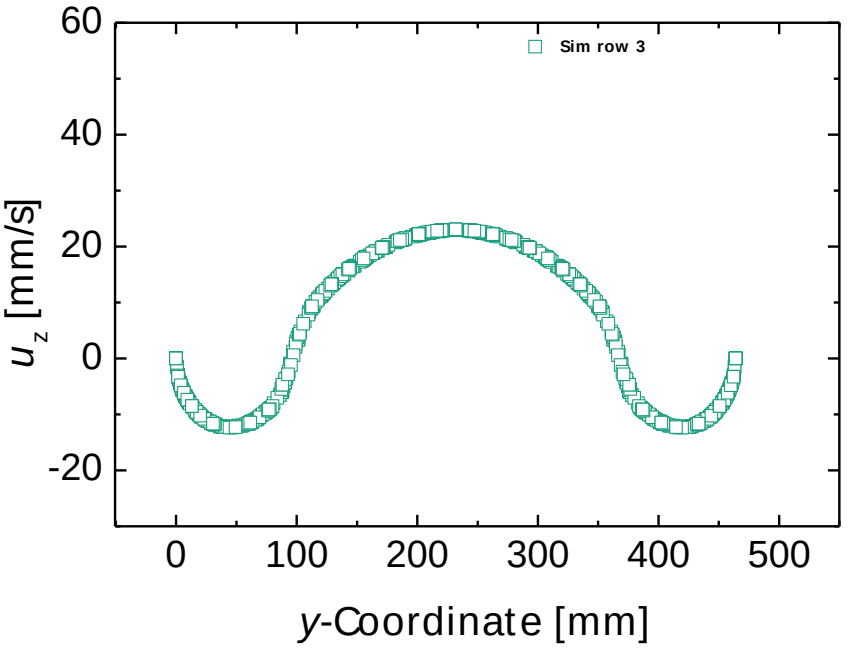

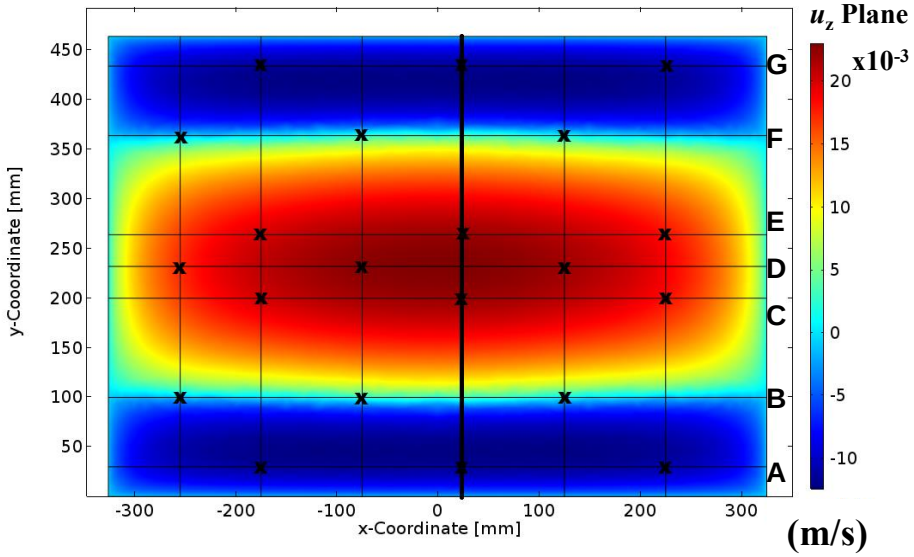

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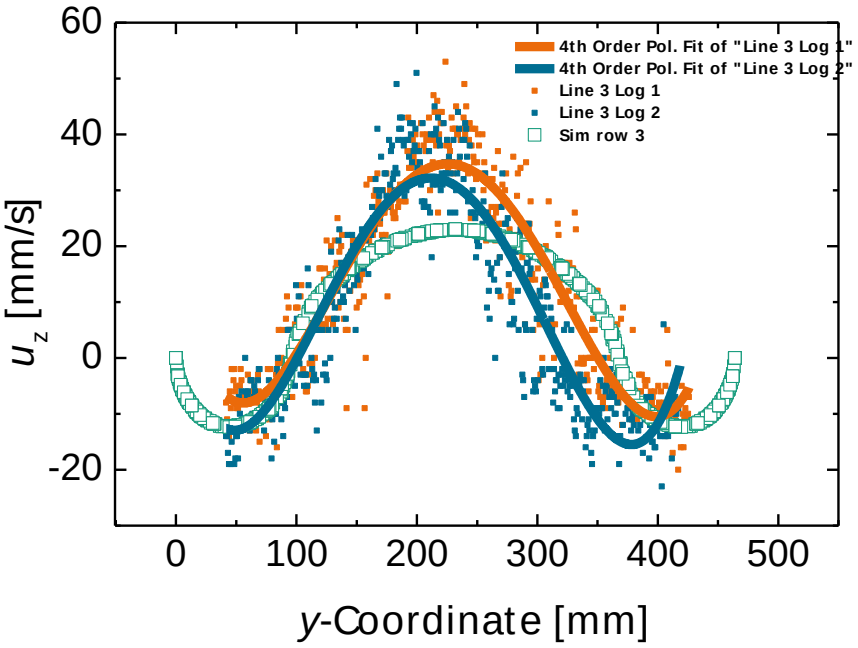
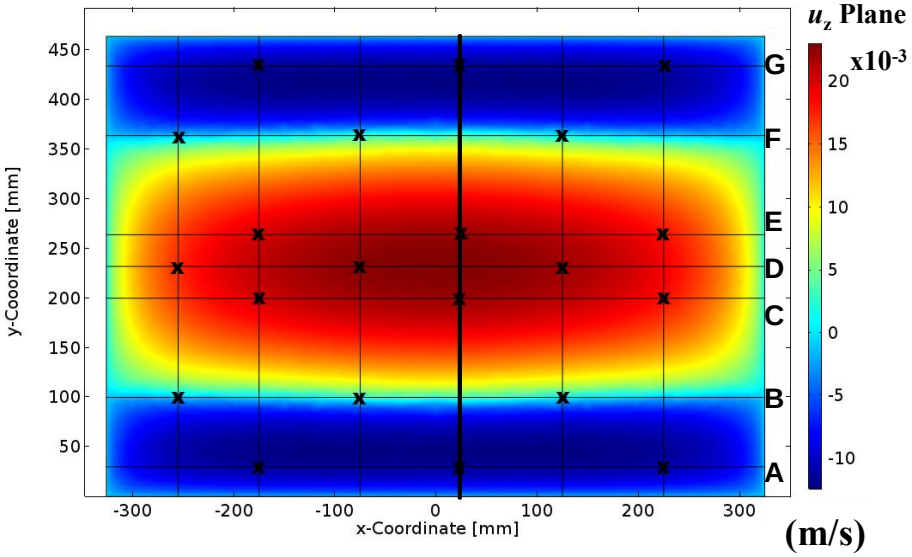
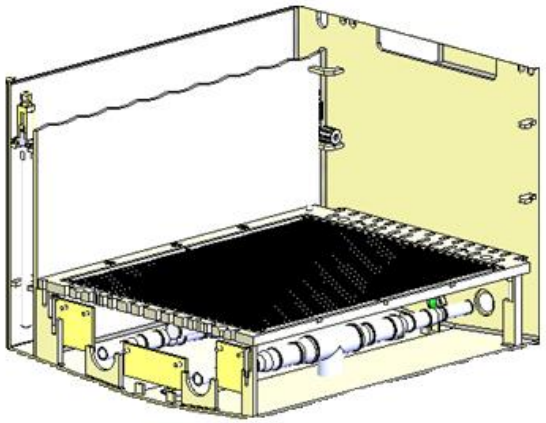
Results Two Step Study
Simulation and Experimental Results

- Flow profile along basin confirmed
- Maxima of curve fittings close to simulated maxima

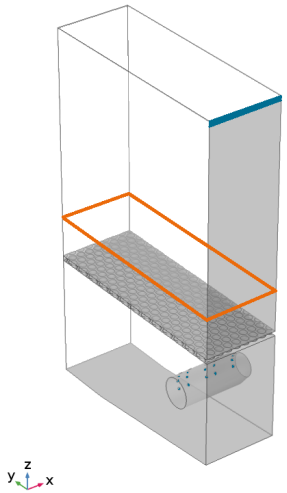




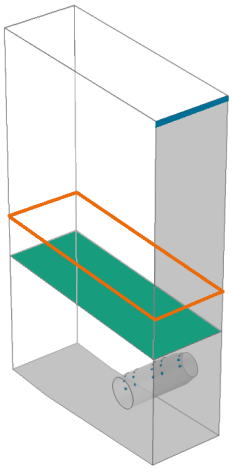
Replacement of Perforated Plate
Investigation Approach



Perforated Plate



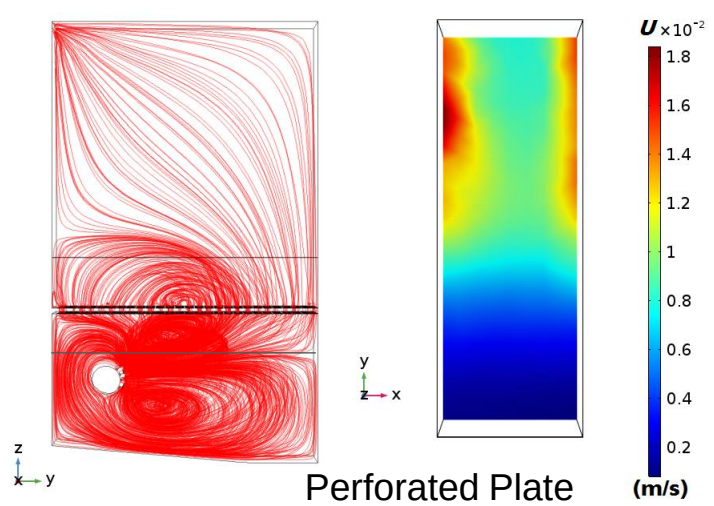
Screen Feature



- Investigate perforated plate
- Simulation setup
  - Initial Material: Water, Comsol library
  - Study: Transient
  - κ-ε turbulence model
- Scale differences
- Replacement by Screen Feature
  - Comsol Screen resistance *K*
  - Solidity σ=0.68
  - Refraction coefficients η= 0.8

Replacement of Perforated Plate
Results

	Velocity magnitude U_{below} (m/s)	Velocity magnitude U_{above} (m/s)	Pressure p_{below} (Pa)	Pressure p_{above} (Pa)	Mesh Elements [N]
Perforated plate	$37.1 \cdot 10^{-3}$	$4.8 \cdot 10^{-3}$	45.93	45.06	$4.5 \cdot 10^{5}$
Screen Feature	$12.1 \cdot 10^{-3}$	$8.1 \cdot 10^{-3}$	16.98	16.99	$3.4 \cdot 10^{4}$



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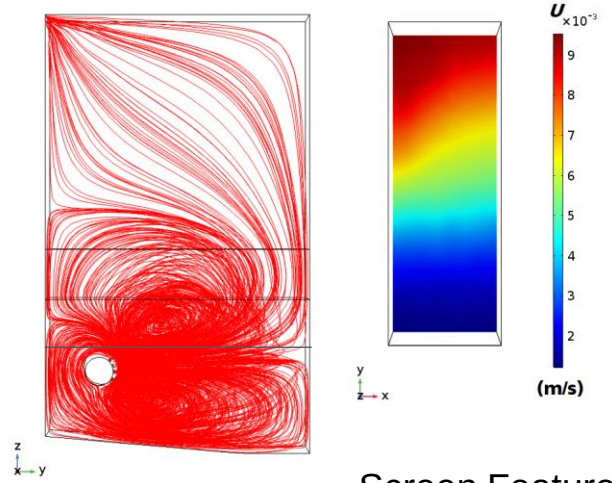

Screen Feature

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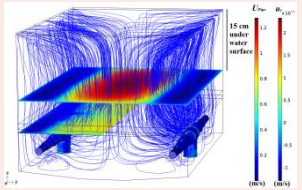
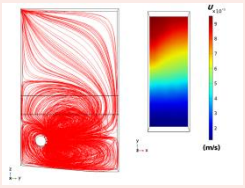
Summary

<table>
<tr><th>Components</th><th colspan="2">Simulation</th><th colspan="2">Experimental Validation</th></tr>
<tr><td rowspan="2">Inlet pipe</td><td colspan="2">Two step study</td><td rowspan="2">√</td><td rowspan="2">  </td></tr>
<tr><td>Step 1 Pipe</td><td>Step 2 Basin</td></tr>
<tr><td rowspan="2">Basin
without fittings</td><td colspan="2">One step study</td></tr>
<tr><td colspan="2">Pipe and basin together</td></tr>
<tr><td rowspan="2">Basin
with perforated
plate</td><td colspan="2">Section of the Basin</td><td rowspan="2">  </td><td rowspan="2">  </td></tr>
<tr><td>Perforated plate</td><td>Screen Feature</td></tr>
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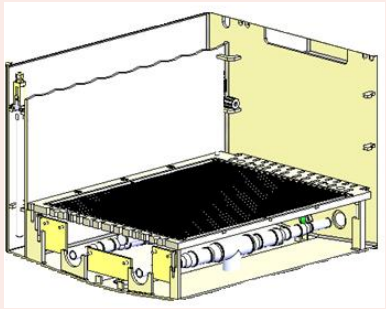
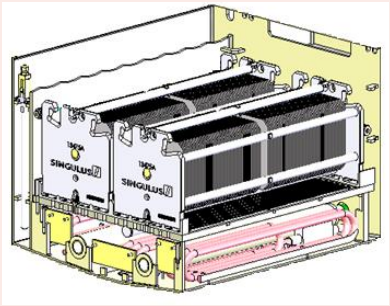
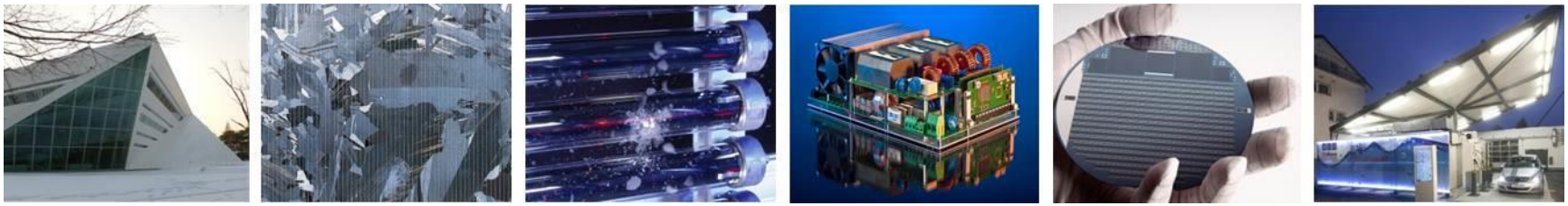
Outlook

	Components	Module	
Concluded	Inlet pipe	CFD	
	Basin without fittings	CFD	
	Basin with perforated plate	CFD	
Future	Basin with carrier	CFD	
	Heater	CFD, Heat Transfer	
	Wafer	CFD, Heat Transfer, Chemical Reaction Engineering	

Thank you for your attention!



Fraunhofer Institute for Solar Energy Systems ISE

Lena Mohr

www.ise.fraunhofer.de

lena.mohr@ise.fraunhofer.de

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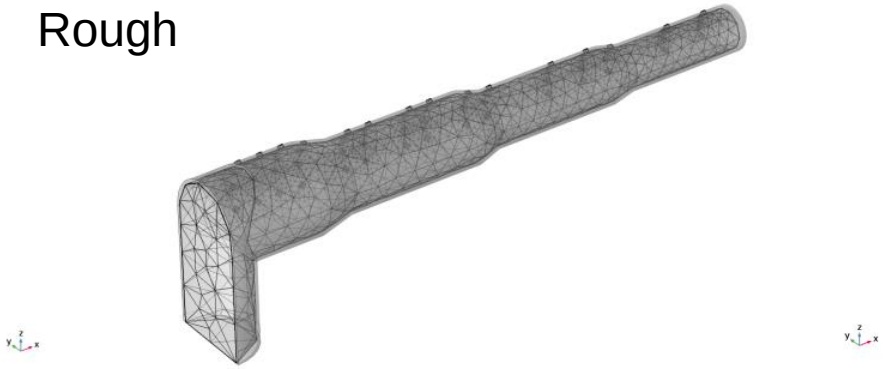
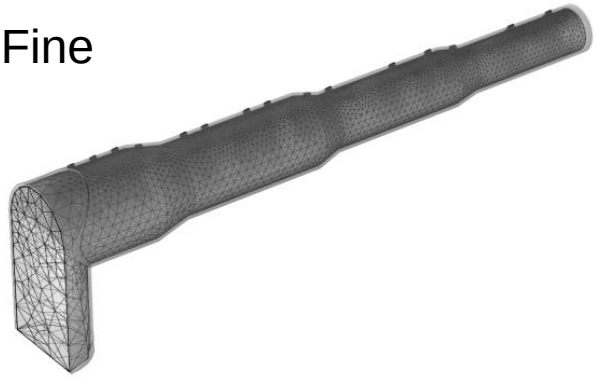
Mesh Convergence Study

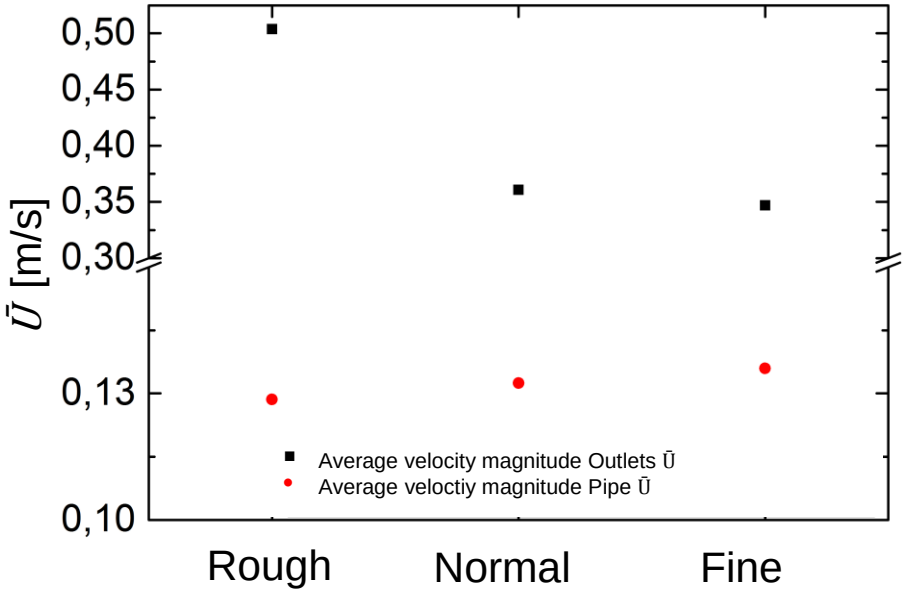
Rough



Fine



Mesh	DoF [N]	Ū Pipe [m/s]	Ū Outlets [m/s]
Rough	$1{,}5 \cdot 10^5$	0,5037	0,1238
Normal	$5{,}5 \cdot 10^5$	0,3608	0,1271
Fine	$2{,}4 \cdot 10^6$	0,3471	0,1299



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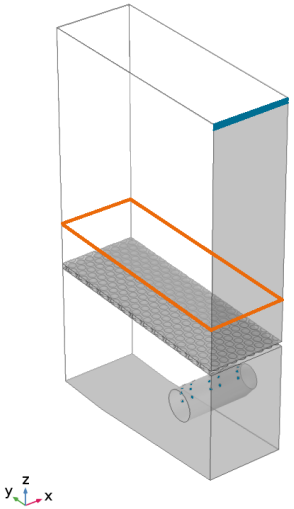
Replacement of Perforated Plate
Investigation Approach

- Perforated plate as interior wall
  - Flow changing according to given parameters
- Screen Feature setup
  - $K = 0.94((1 - \sigma_S)^{-2} - 1)^{1.28}$
  - $\eta_{\text{user defined}} = 0.8$
  - K = Resistance
  - σ_S = blocked area / total area
  - $\eta_{\text{Wire gauze}}$ = refraction coefficient

Perforated Plate



Screen Feature