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Towards, Competitive, Reliable, Safe and Sustainable Concentrated Solar Power (CSP) Plants

Midterm meeting REA, 18-19 April 2024

TURBULENT BOILING FLOWS IN DIRECT STEAM GENERATION SOLAR RECEIVER

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Adrien TOUTANT (UPVD, PROMES)
Florent LECAT (eLLO)

CONTENTS

I. INTRODUCTION
- About myself
- Thesis Project

II. NUMERICAL ANALYSIS
- Study case - Actual module of eLLO
- Homogeneous heat flux Results
- Non-homogeneous heat flux Results

III. EXPERIMENTAL ANALYSYS
- Experimental setup
- Preliminary results

IV. CONCLUSION AND PERSPECTIVES
- Perspectives

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ABOUT MYSELF

Academic background:

- Bachelor in **Mechanical Engineering** 2017-2021
  Bachelor thesis: *FEM analysis of ceramic materials*

- Master in **Industrial Mechanics** 2021-2022
  Specialization: *Experimental techniques*
  Master thesis: *Latent phase change modelling*

Work experiences:

- Member of a **Rocketry & FSAE associations** *2020-2022*
  Fluid Mechanics & FEM analysis

- **Teaching** in thermal engineering (30h) *2021-2022*
  100 undergraduate students

- Airframe stress **Engineer** (Toulouse – Fr) *2022-2023*
  FEM analysis of Aircraft structures

- *PhD Candidate at **PROMES-CNRS*** *2023-2026*

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THESIS PROJECT

OBJECTIVES

- Predicting the amount of steam produced and plant production
- Predicting the thermomechanical stresses imposed on the tube materials

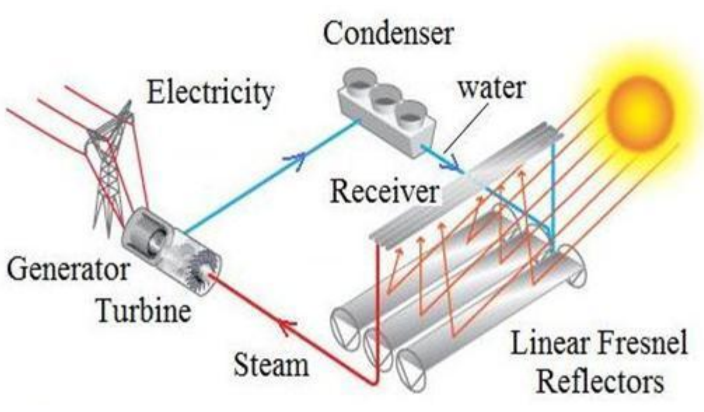
WHY?

Advantages

- ✓ Higher Efficiency
- ✓ Fewer Components
- ✓ No conventional HTF
- ✓ Effective Thermal Storage
- ✓ Low Carbon Footprint

Uses for the produced vapor

- ✓ Electricity production (turbine)
- ✓ Valorization in industrial processes
- ✓ Industrial heat production



DSG powerplant layout

HOW?

Numerical

- Conjugate heat transfer simulations
- Simulations of real eLLO module
- Simulations of experimental setup
- Thermomechanical assessment

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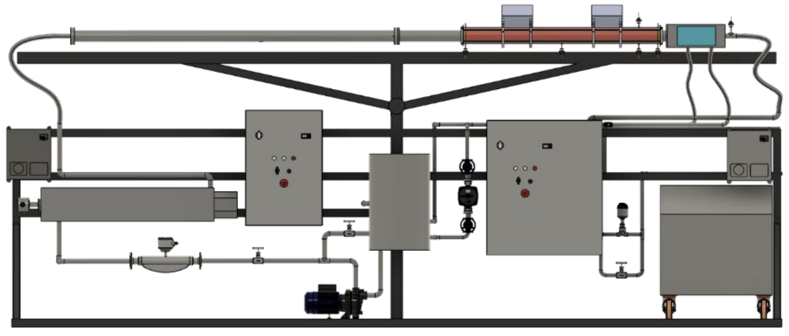
Experimental

- In-house made experimental setup
- Manufactured from the scratch
- Multivariate study



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Turbulent boiling flows in DSG solar receiver

NUMERICAL STUDY

SOLVER FEATURES

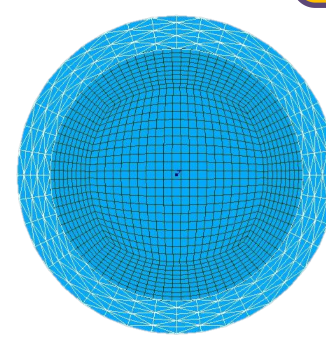
General features

- Euler-Euler approach
- Transient analysis
- Multiregime flow
- Compressible
- Turbulence model → $R_{ij} - \varepsilon$

Closure modelling

- Surface tension model
- Nucleate boiling model
- Wall function model

GEOMETRY & MESH



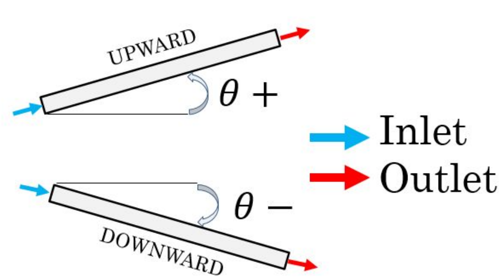
Cross section meshing

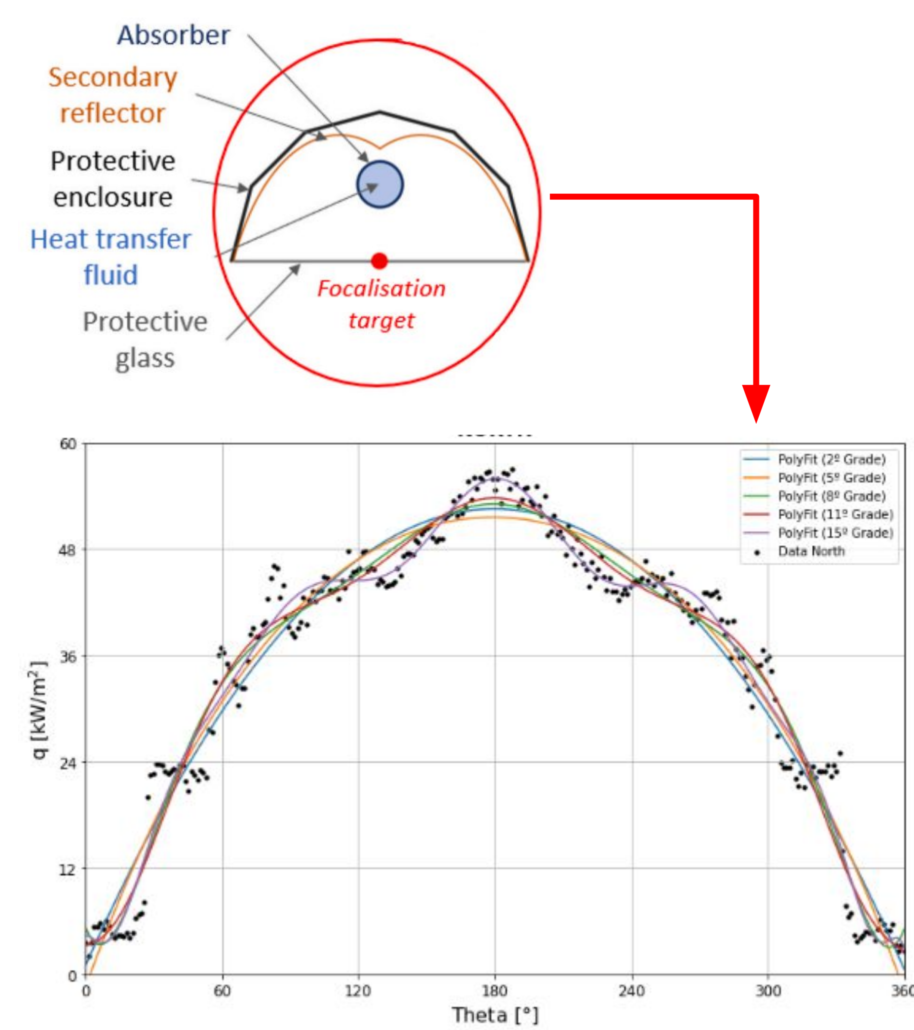
- 67 meters long receptor
- 77.9 mm diameter
- 10 mm tube thickness
- More than 10 M elements in the fluid domain
- 2.5 M elements in the solid domain

STUDY CASES

			NON HOMOGENEOUS	

28 simulations in total





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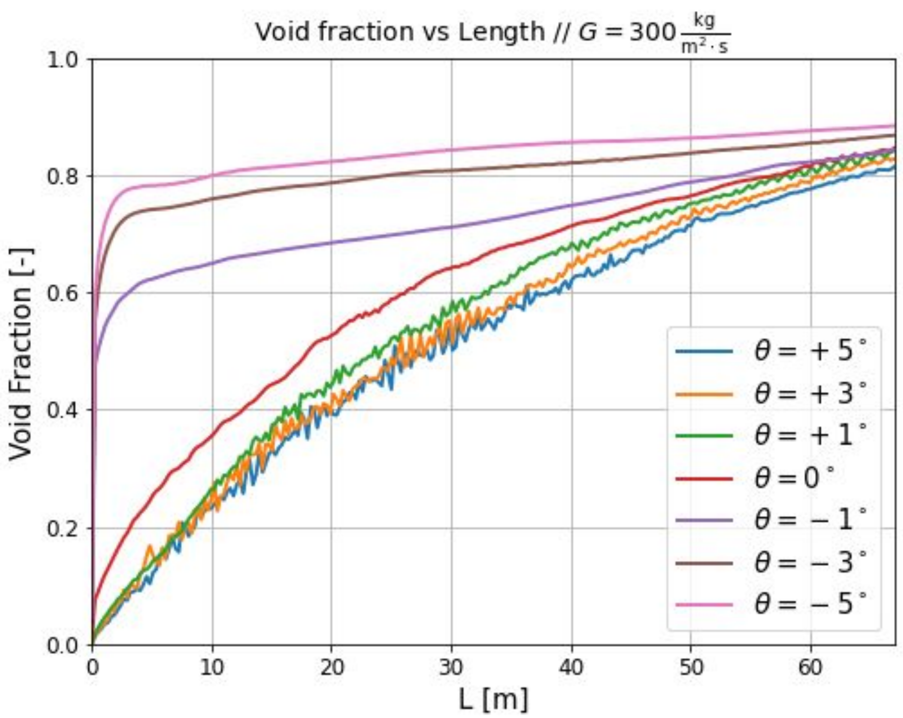
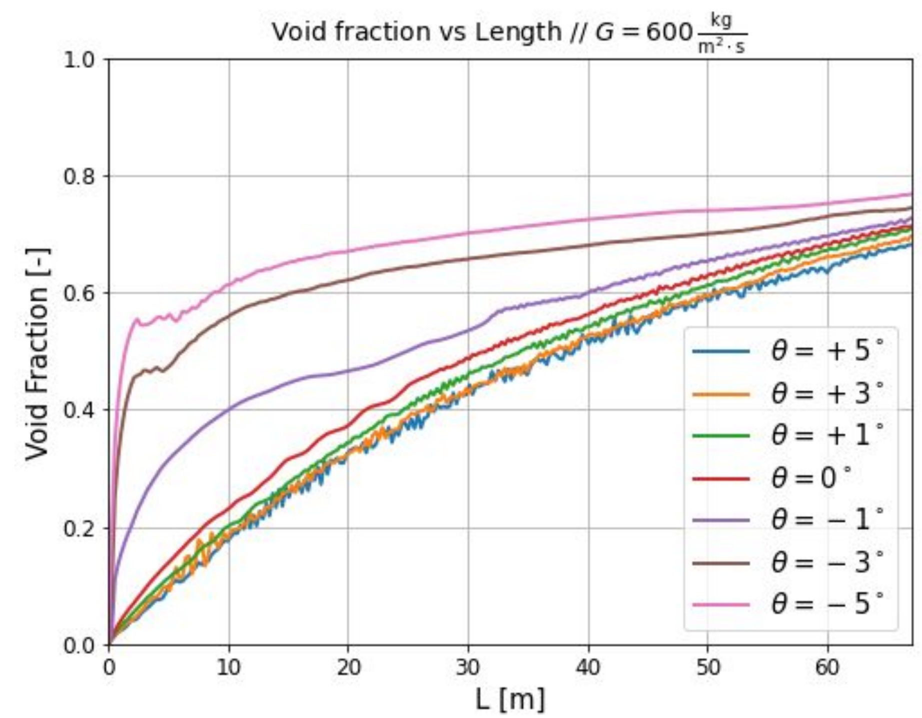
RESULTS – HOMOGENEOUS FLUX

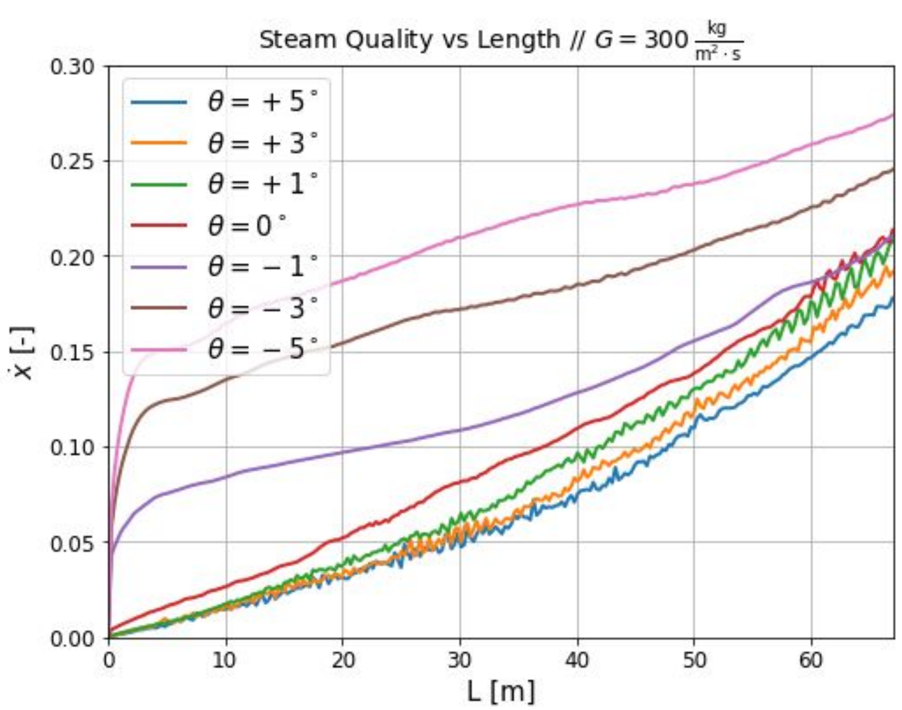
FLUID DOMAIN

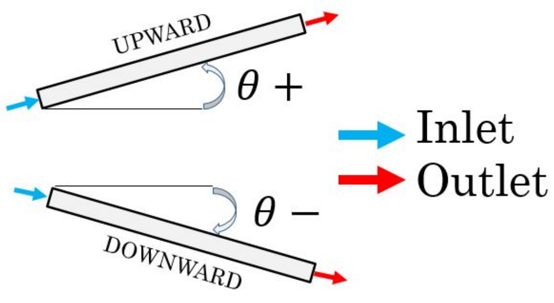


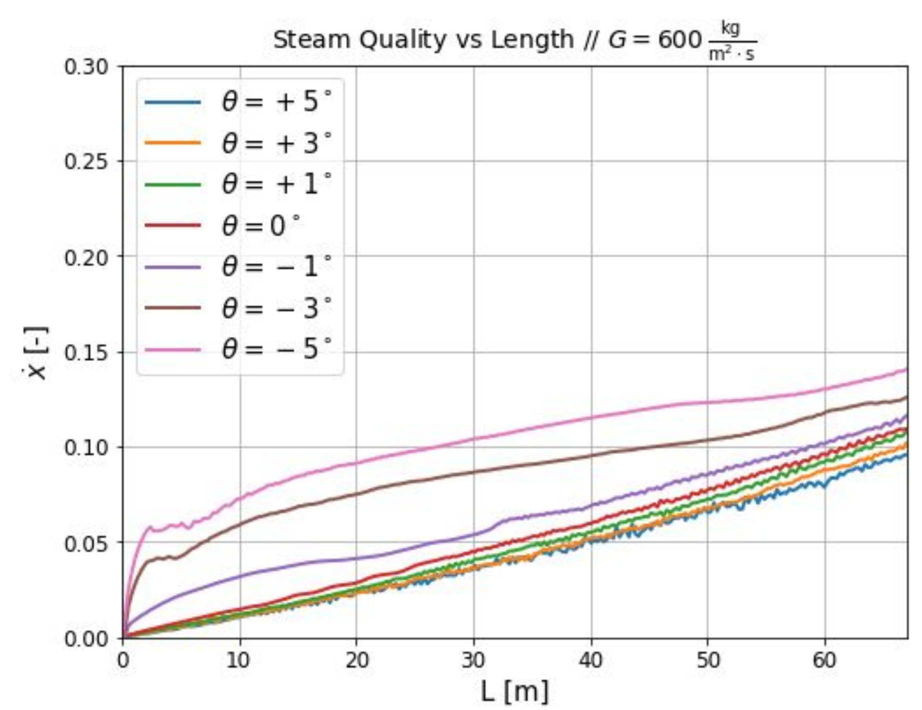
$$\varepsilon = \frac{A_v}{A_v + A_l}$$



$$\dot{x} = \frac{\rho_v\, \varepsilon}{\rho_v\, \varepsilon + \rho_l\, (1 - \varepsilon)}$$







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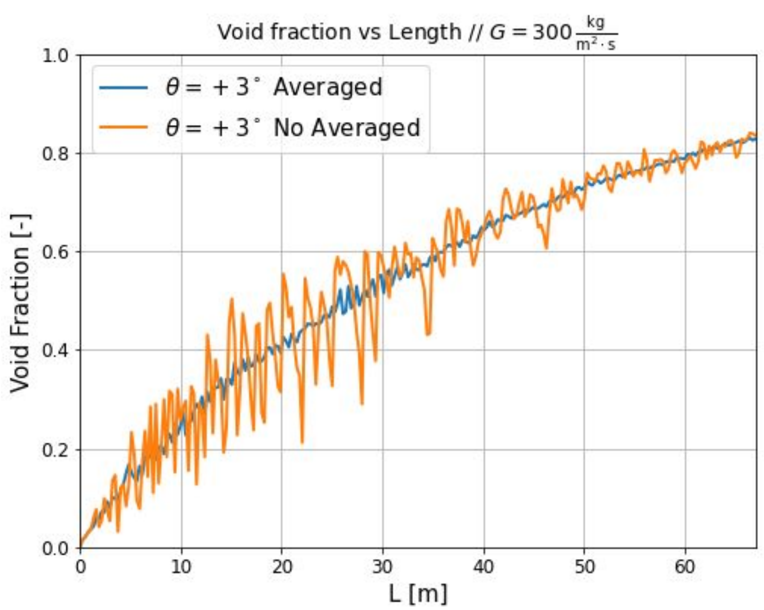
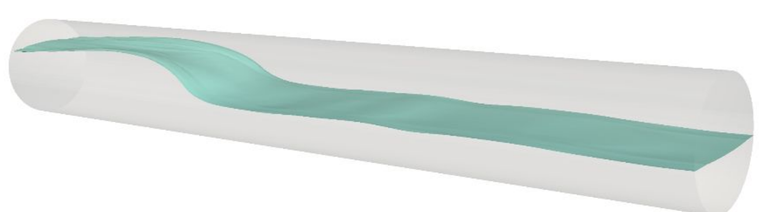
RESULTS – HOMOGENEOUS FLUX

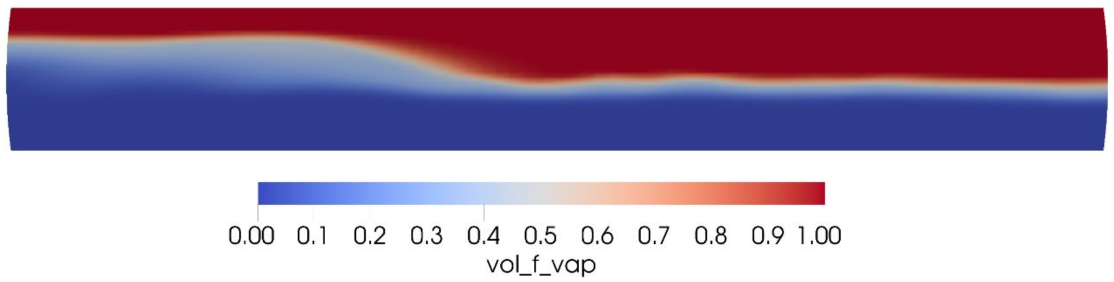
FLUID DOMAIN

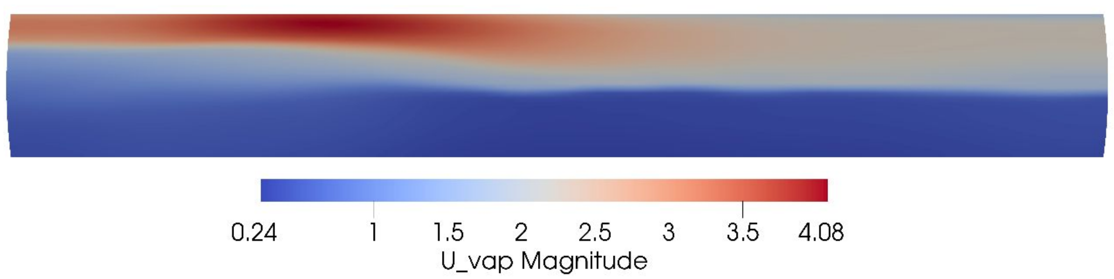
$\theta = +3°$

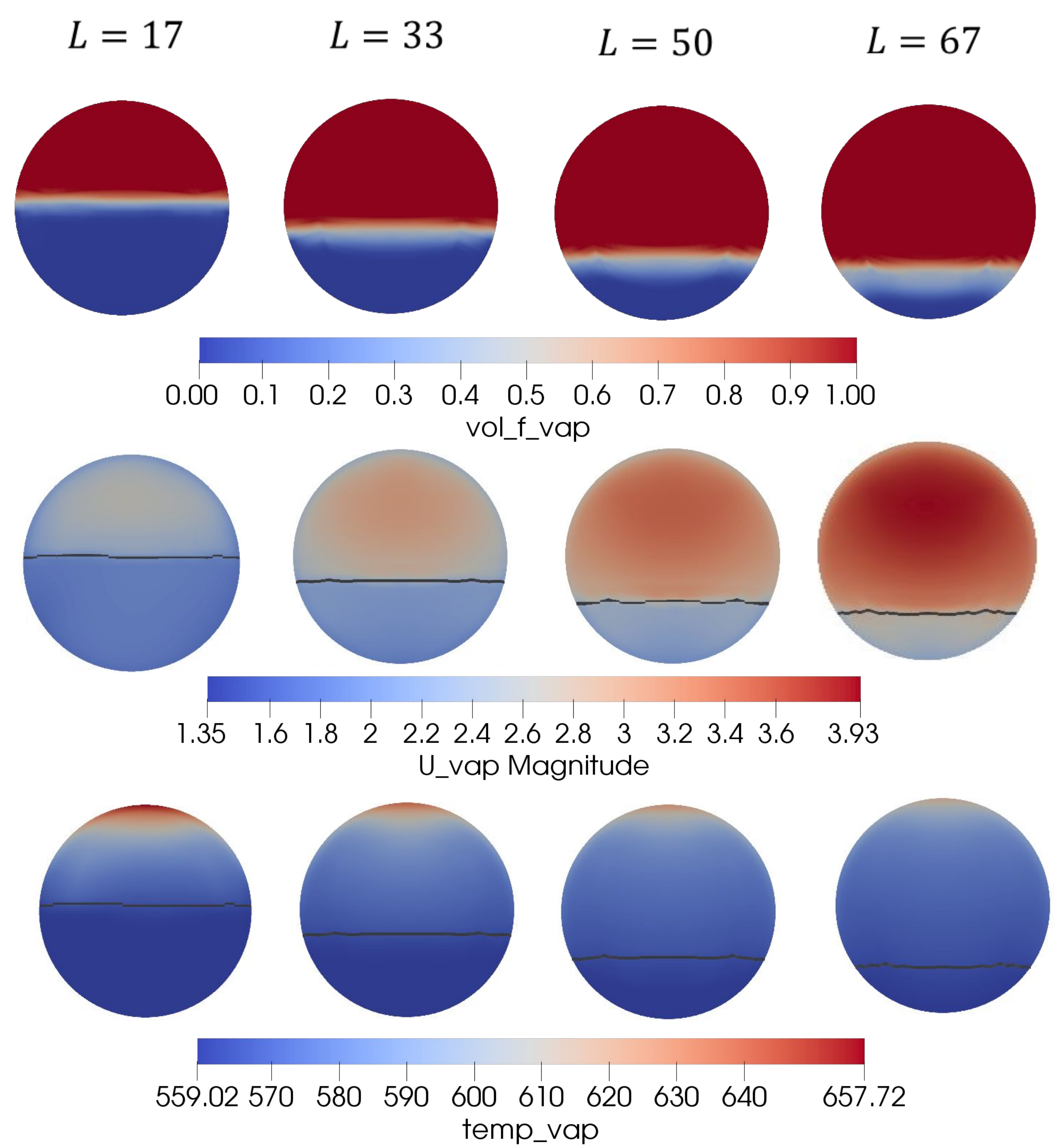
$\theta = 0°$











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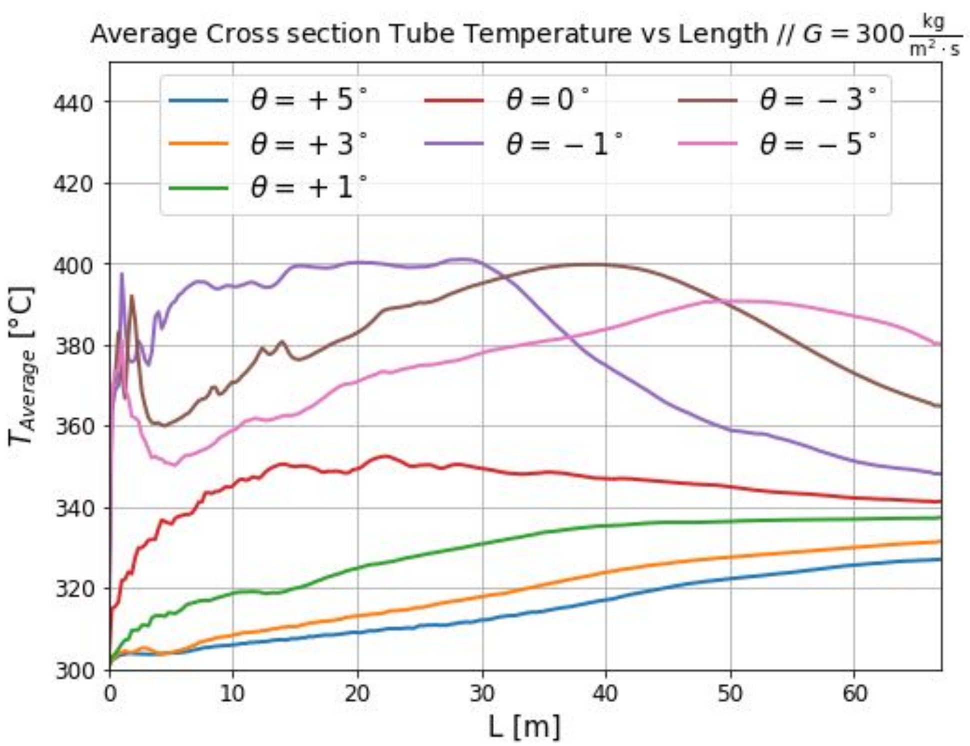
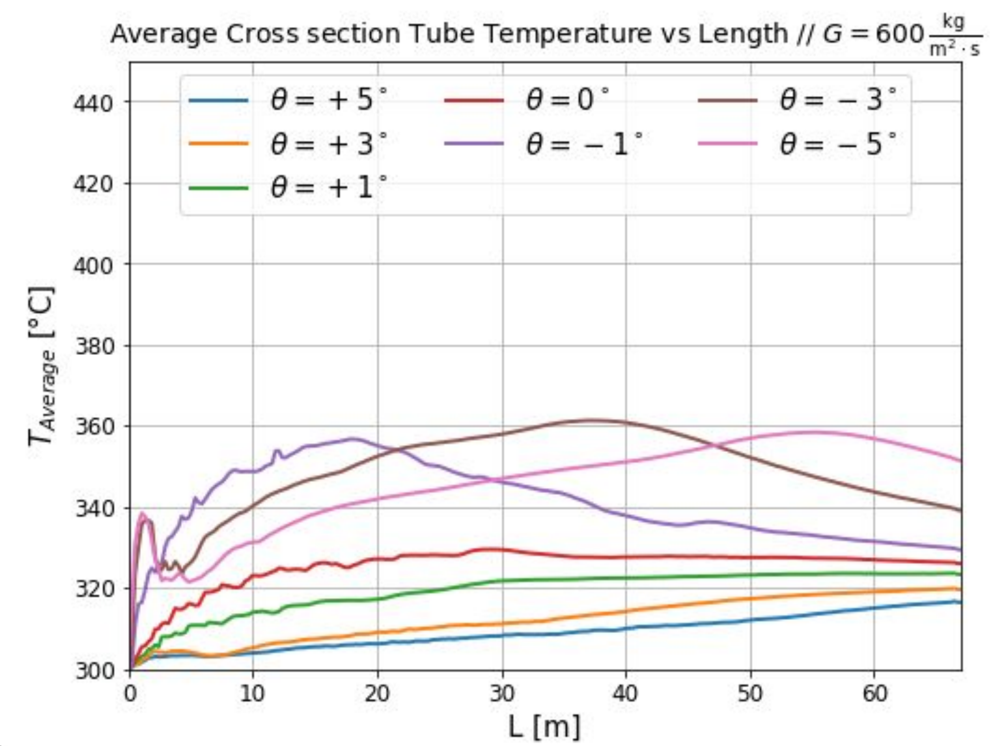
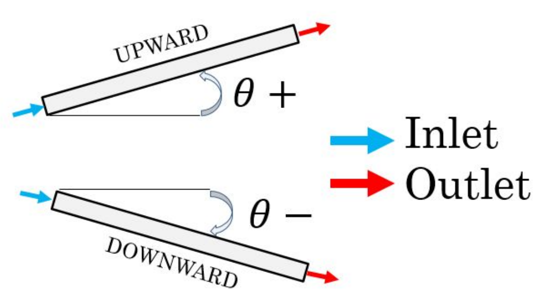
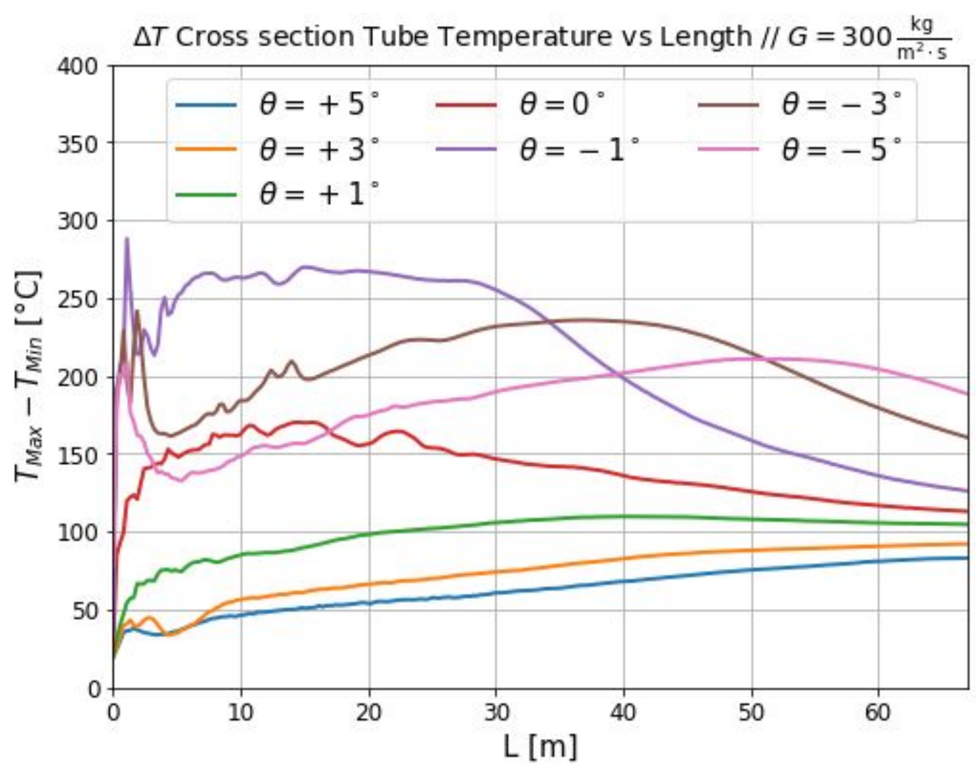
RESULTS – HOMOGENEOUS FLUX

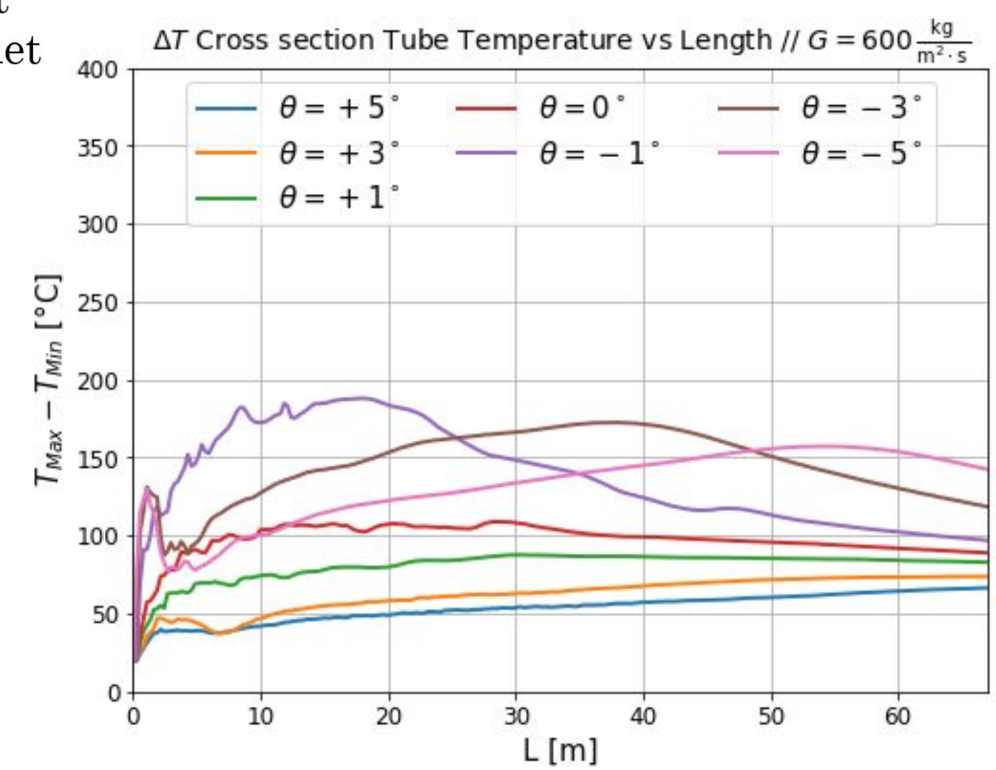
SOLID DOMAIN











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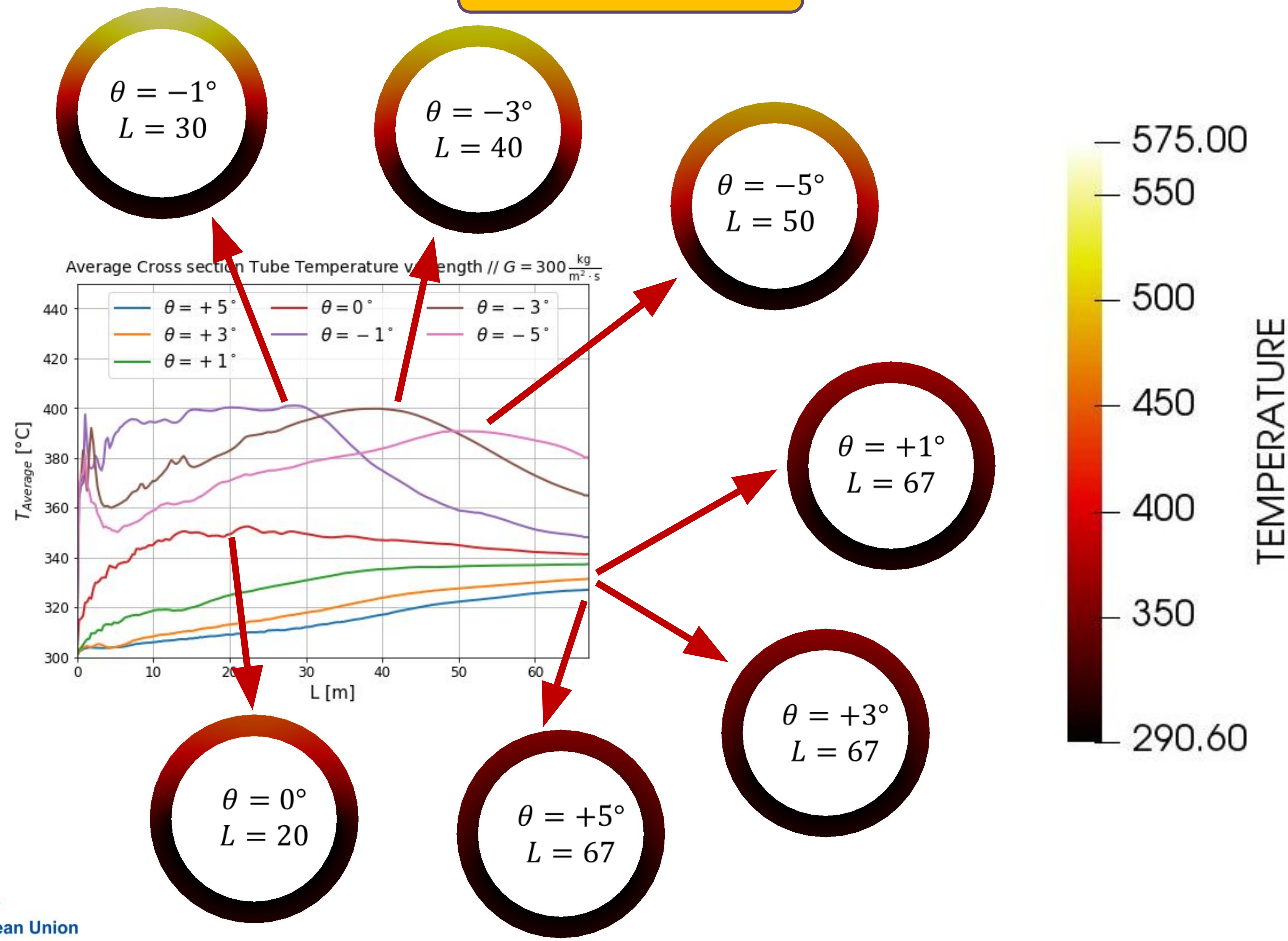
RESULTS – HOMOGENEOUS FLUX

SOLID DOMAIN



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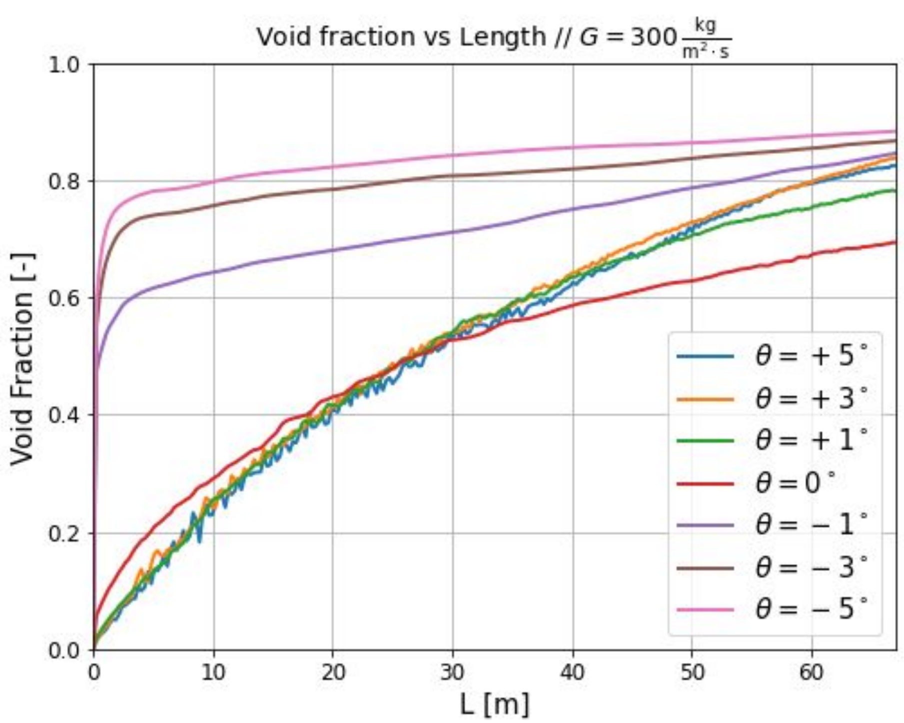
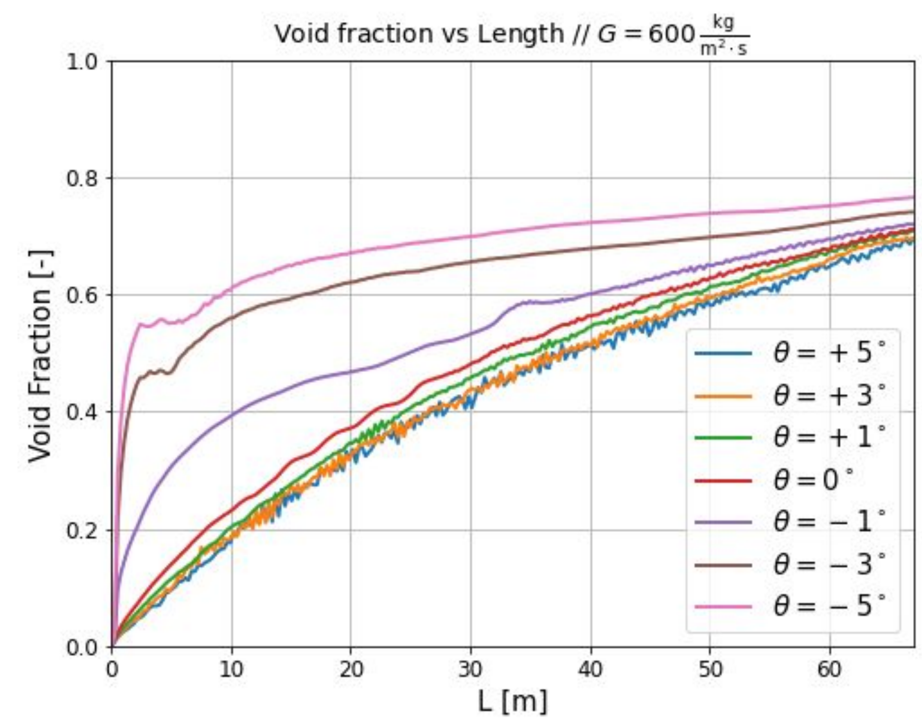
Turbulent boiling flows in DSG solar receiver

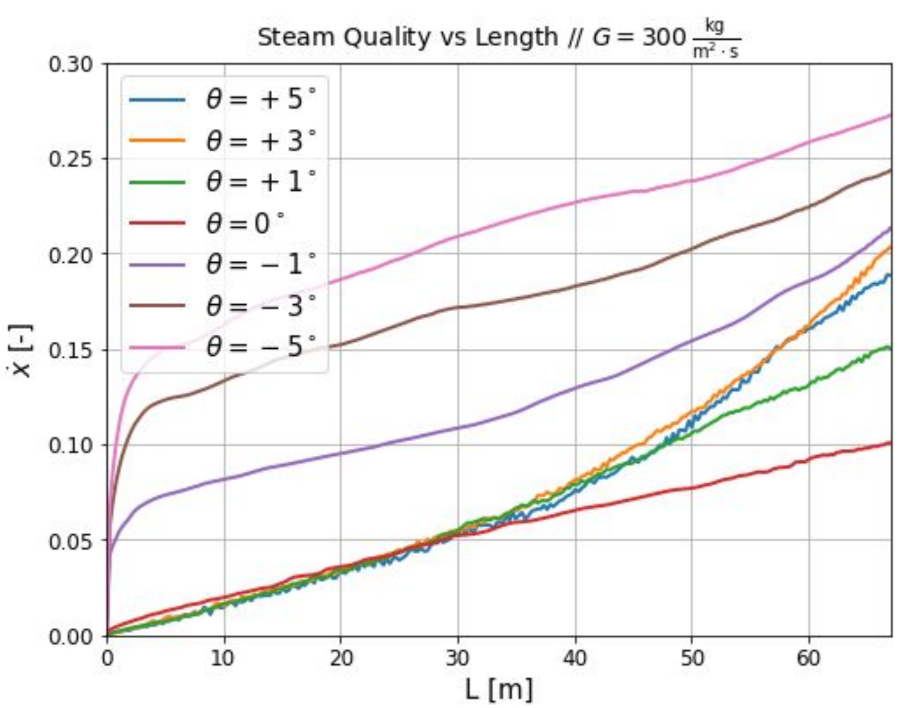
RESULTS – NONHOMOGENEOUS FLUX

FLUID DOMAIN

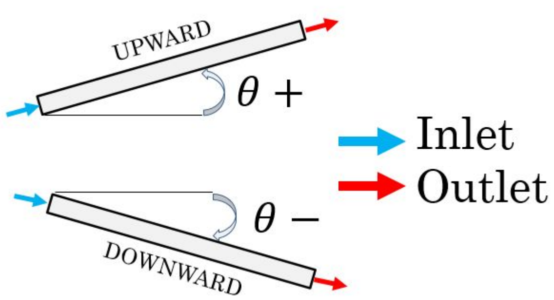


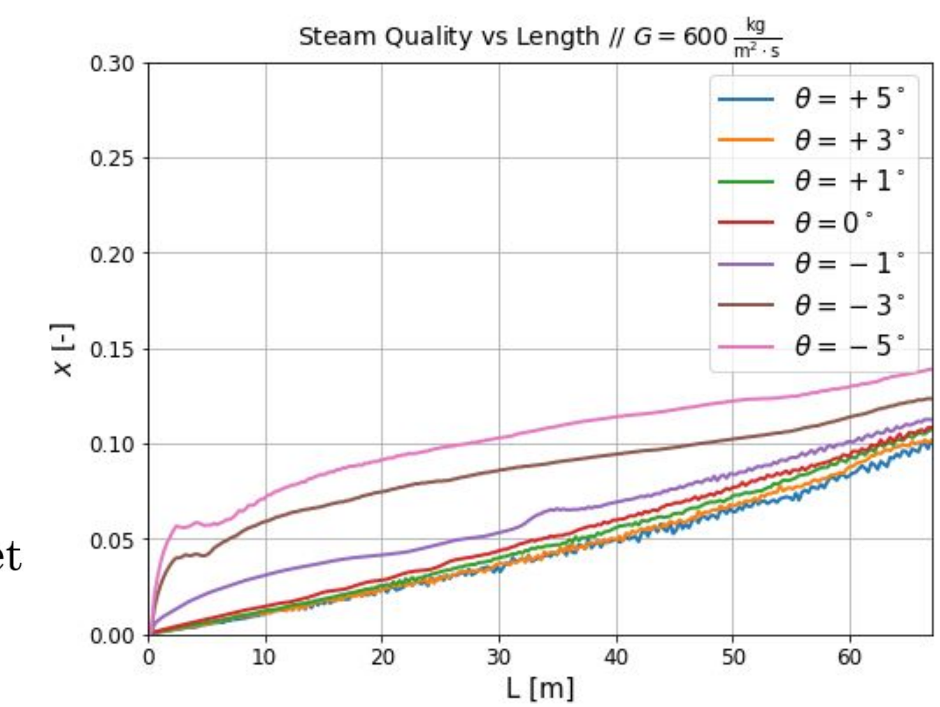
$$\varepsilon = \frac{A_v}{A_v + A_l}$$





$$\dot{x} = \frac{\rho_v \, \varepsilon}{\rho_v \, \varepsilon + \rho_l \, (1 - \varepsilon)}$$





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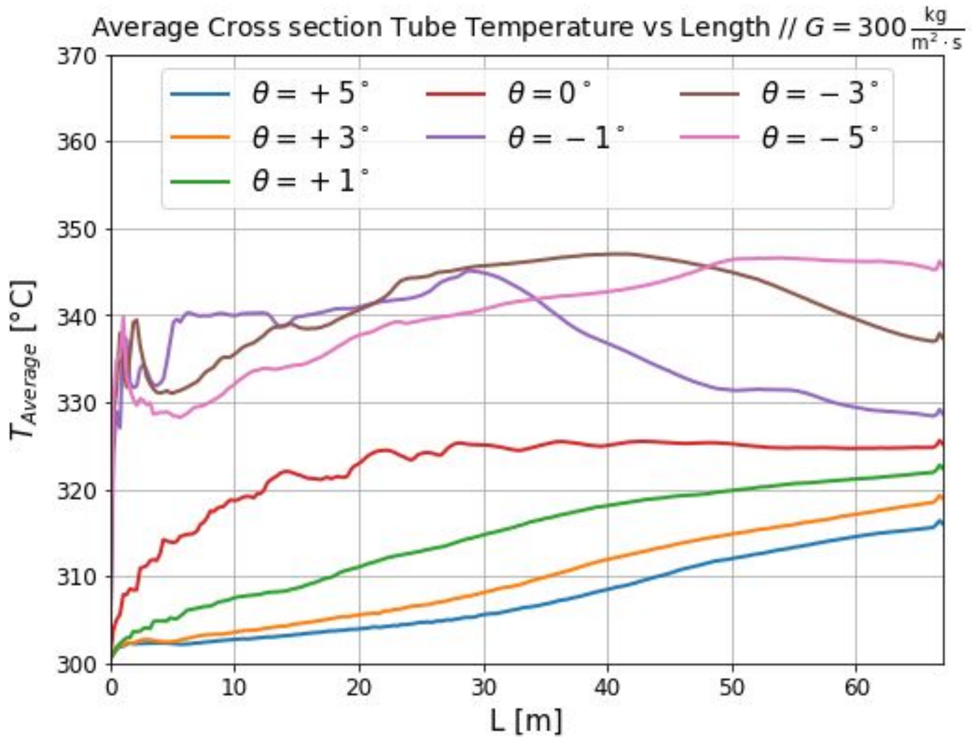
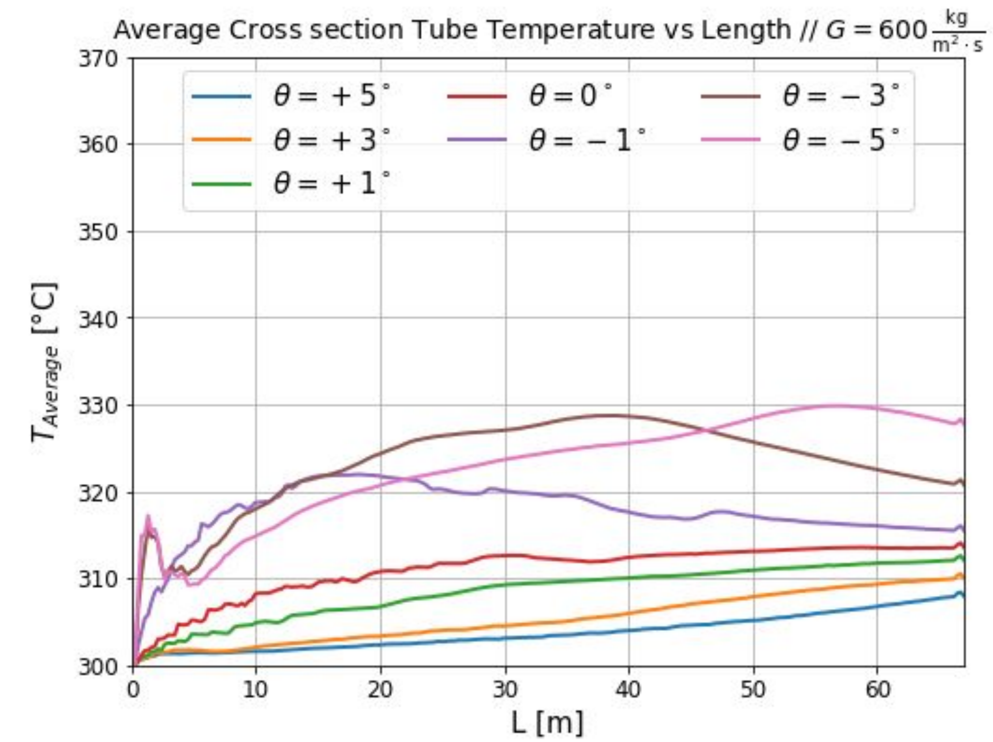
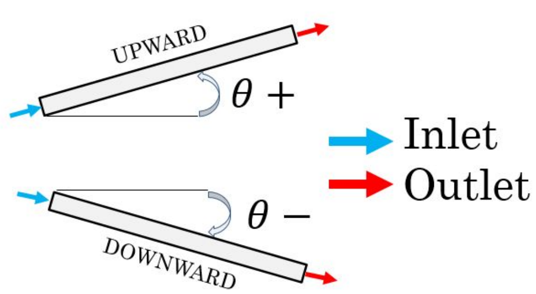
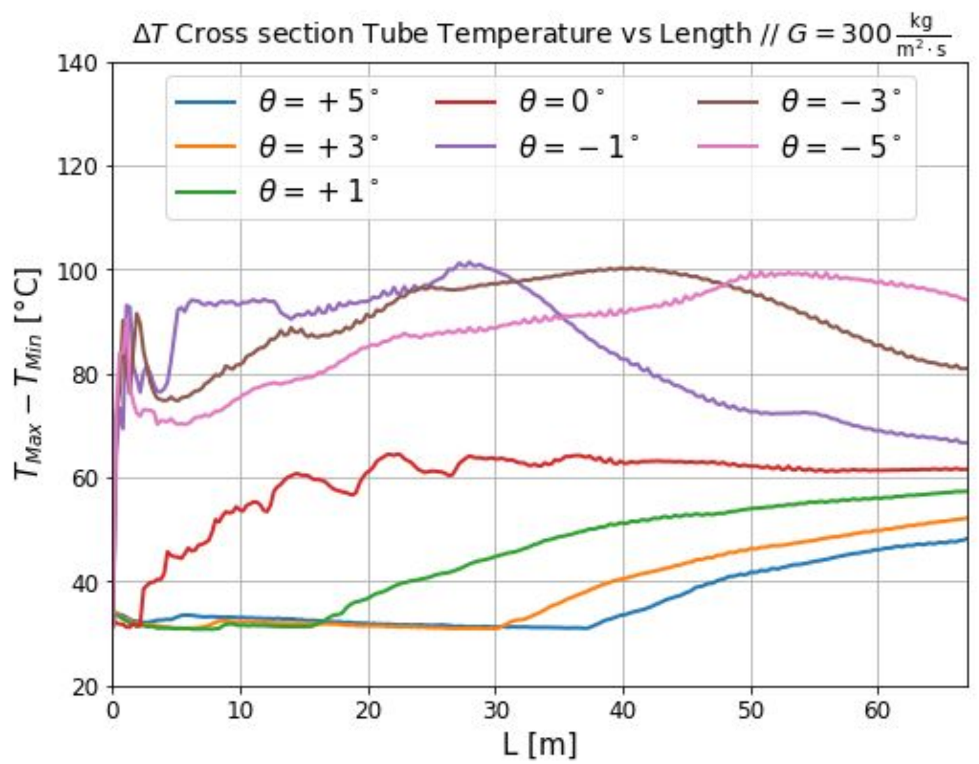
RESULTS – NONHOMOGENEOUS FLUX

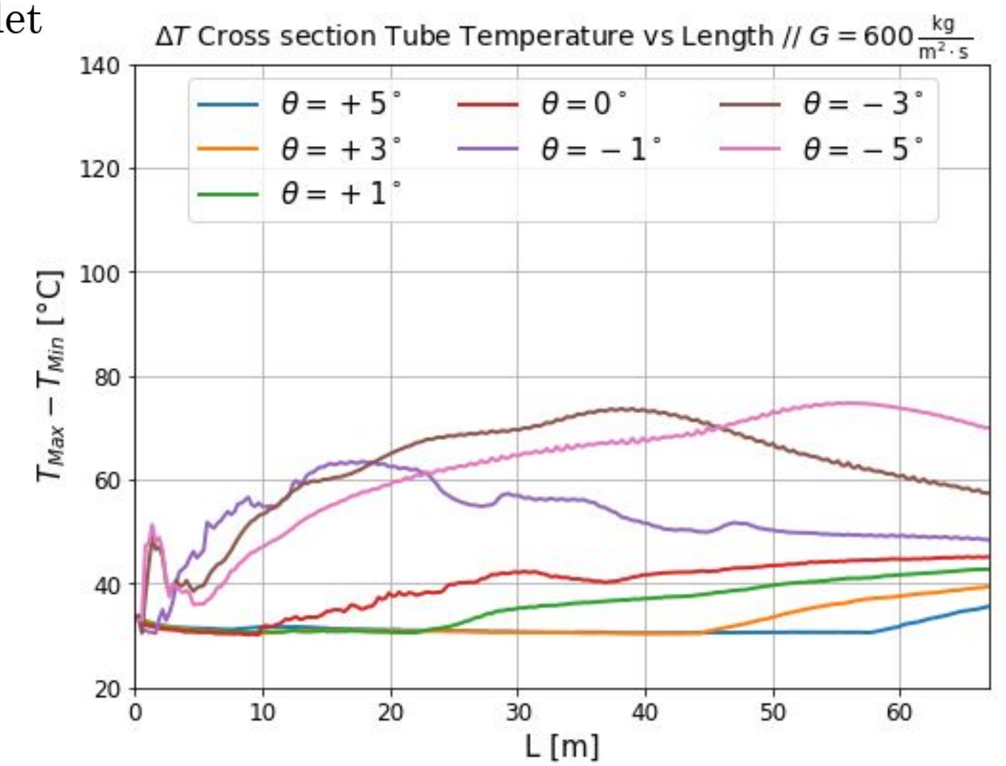
SOLID DOMAIN











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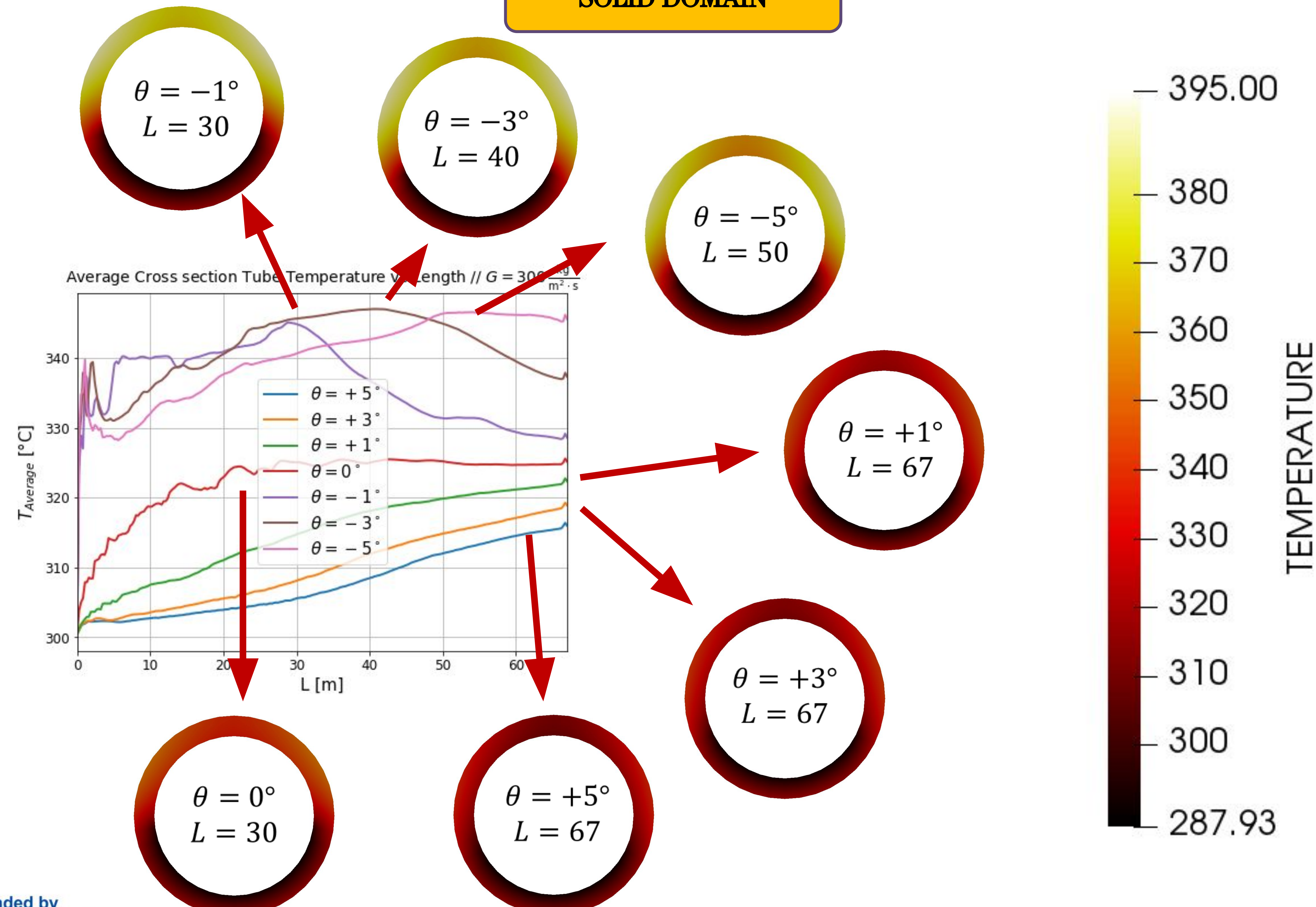
RESULTS – NONHOMOGENEOUS FLUX

SOLID DOMAIN



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EXPERIMENTAL SETUP

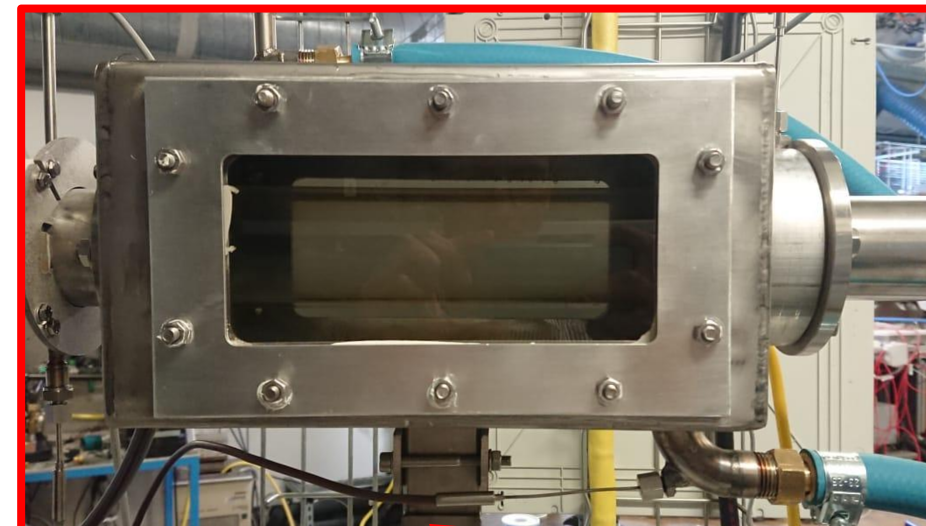
FEATURE	SPECIFICATION/VALUE
Working Fluid	
Tube material	Steel
Temperature sensors	15
Pressure sensors	3

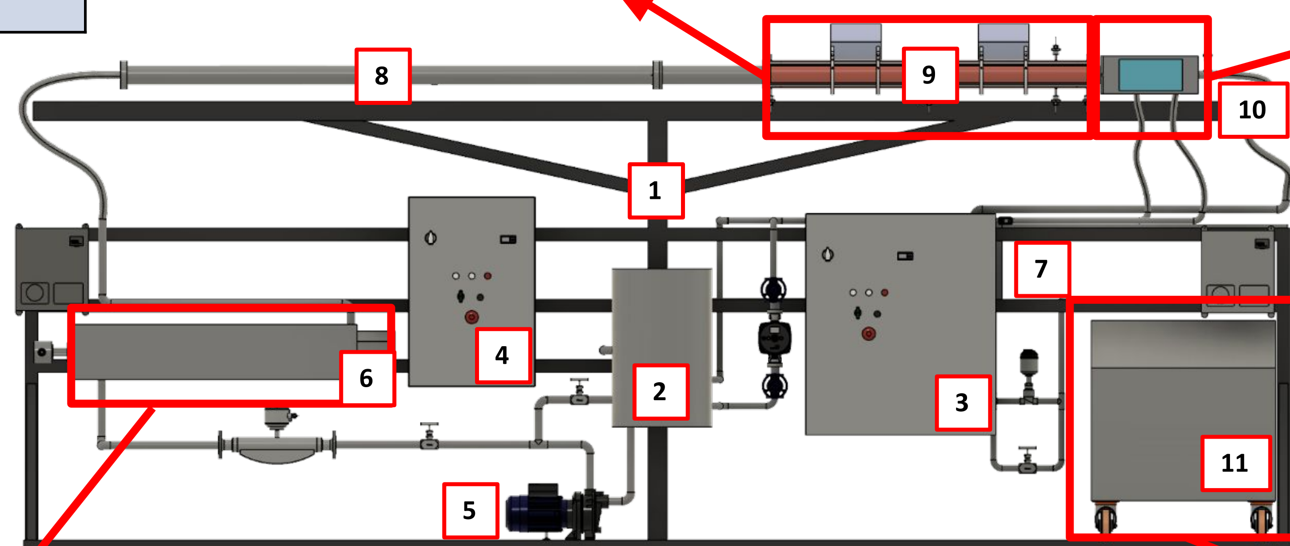
Components

1) Inclination device.
2) Water tank.
3) Data acquisition box.
4) Pre-heater regulation.
5) Water pump.
6) Pre-heater.
7) Condenser.
8) Establishment section
9) Induction heating
10) Visualization box.
11) Induction generator

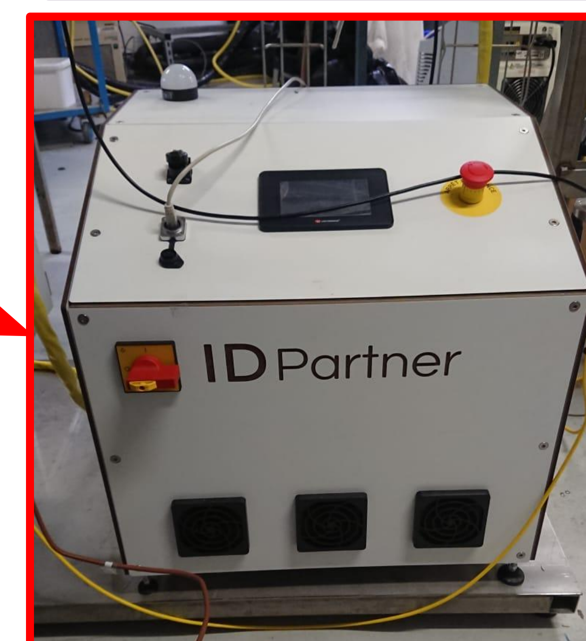
INDUCTION COIL

VISUALIZATION BOX





INDUCTION GENERATOR



PREHEATER

HIGH SPEED CAMERA

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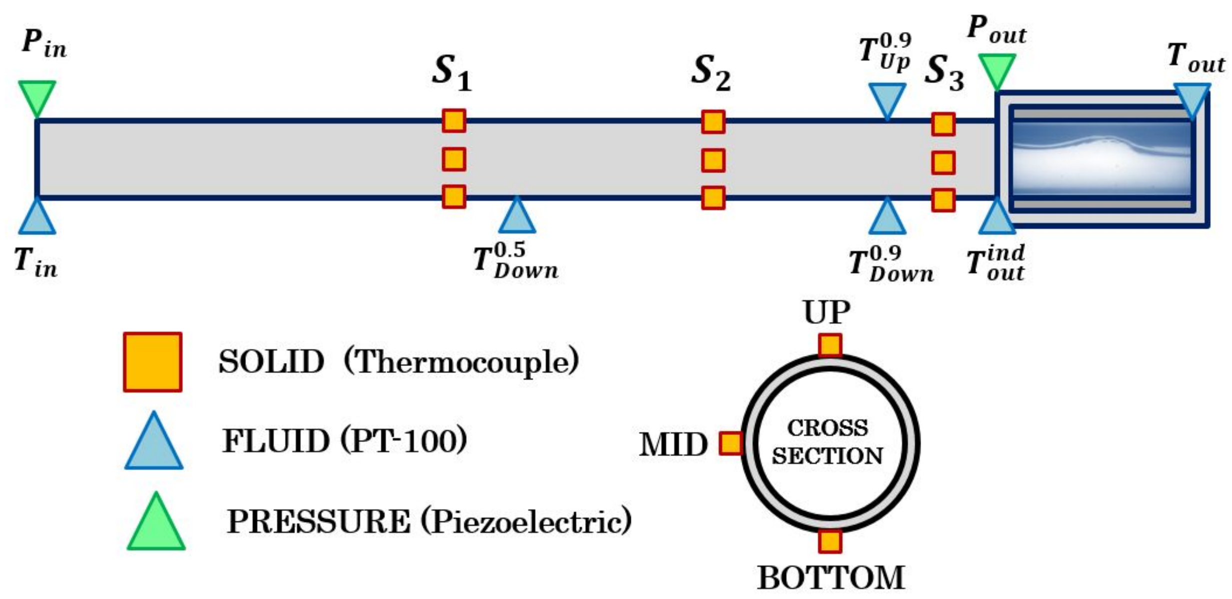
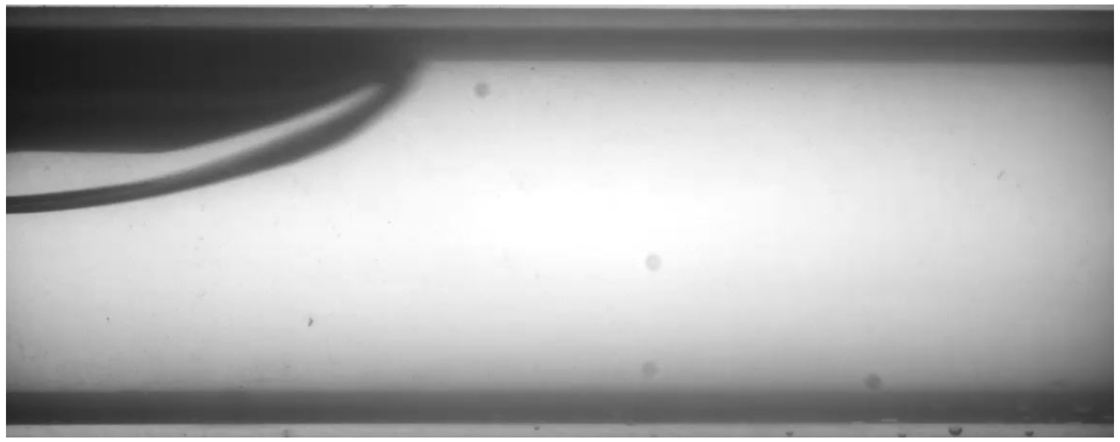
EXPERIMENTAL SETUP – EARLY RESULTS

INSTRUMENTATION



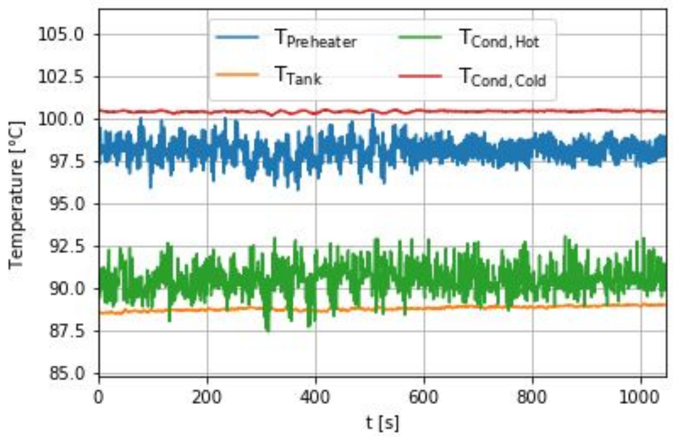
VISUALIZATION BOX



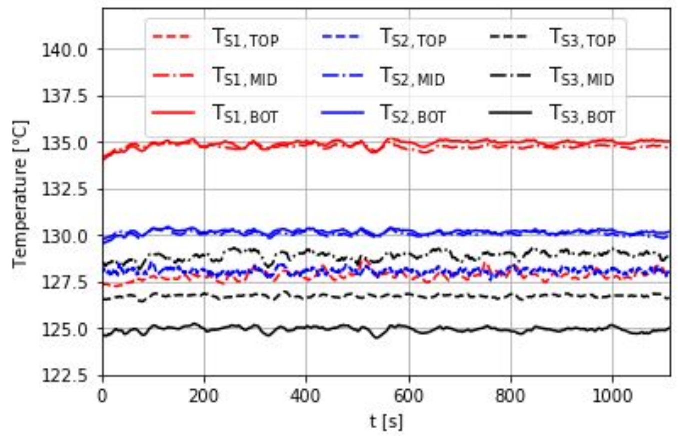
RESULTS

$\dot{m} = 185\ g/s$ | $T_{In} = 98\ °C$ | $T_{Wall} = 130\ °C$ | $\dot{q} \sim 30\ kW/m^2$ | $\theta = 0\ °$

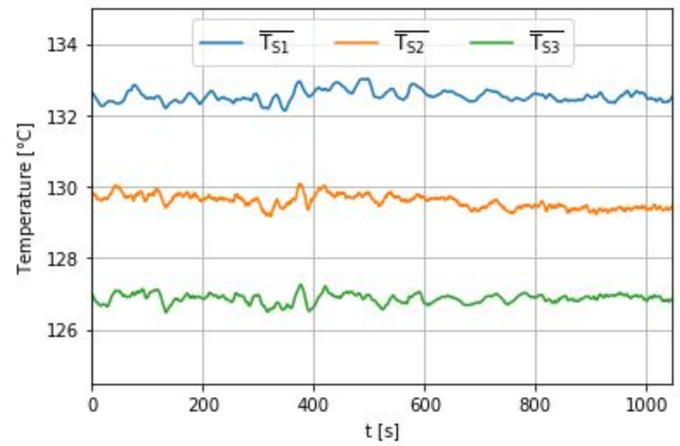
Process Temperatures



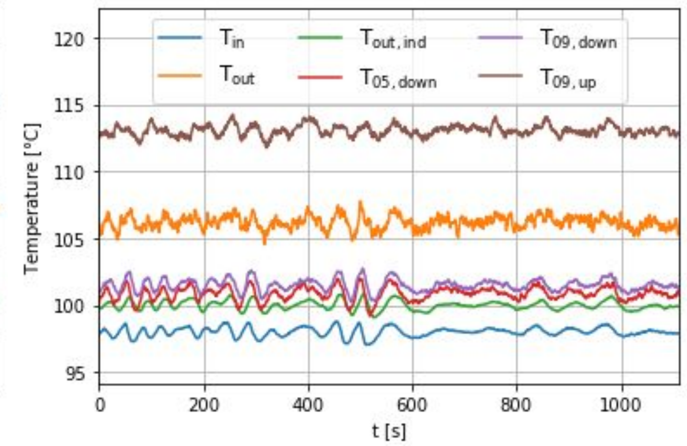
Solid Sections Temperatures



Solid Sections Temperatures (Averaged)



Fluid Temperatures



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PERSPECTIVES

MORE EXPERIMENTAL RESULTS ⇄ **NUMERICAL MODEL OF THE EXPERIMENTAL SETUP** → **THERMOMECHANICAL ASSESSMENT**

MORE EXPERIMENTAL RESULTS

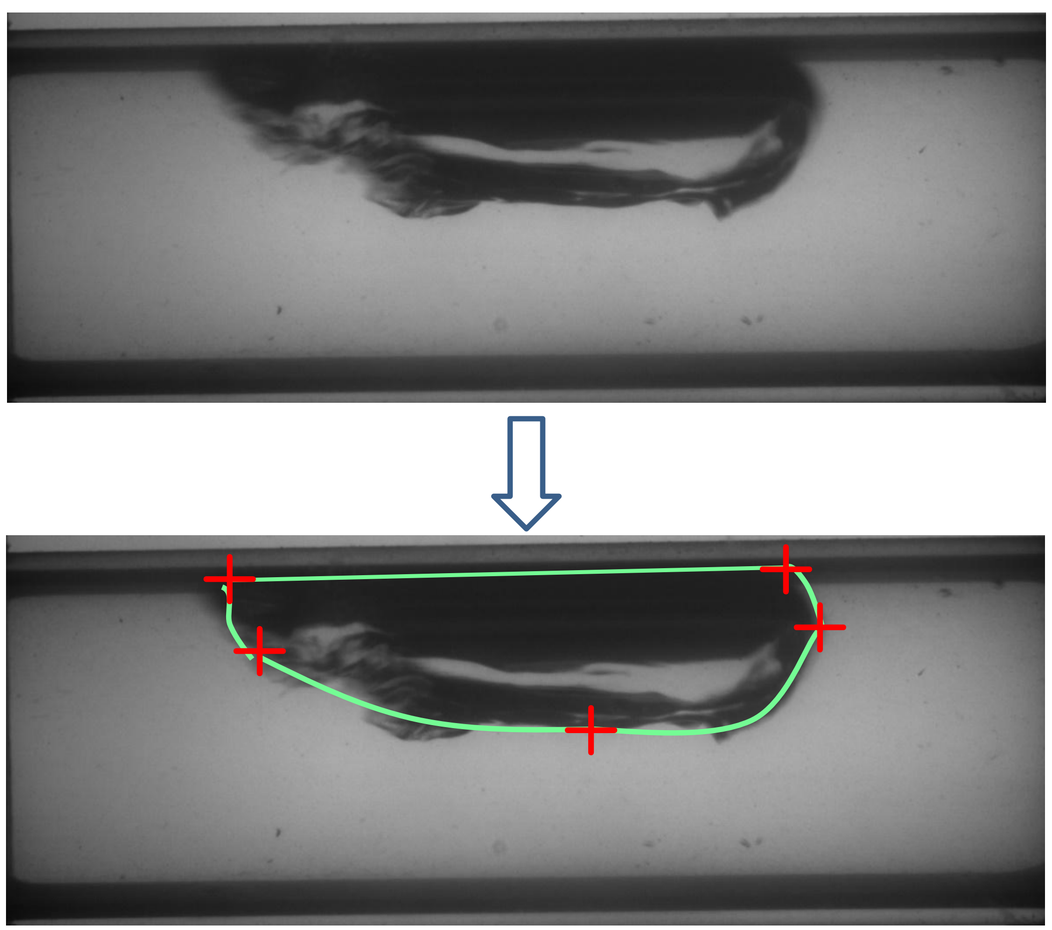
- Test all possible configurations
- Collect data and analyse it

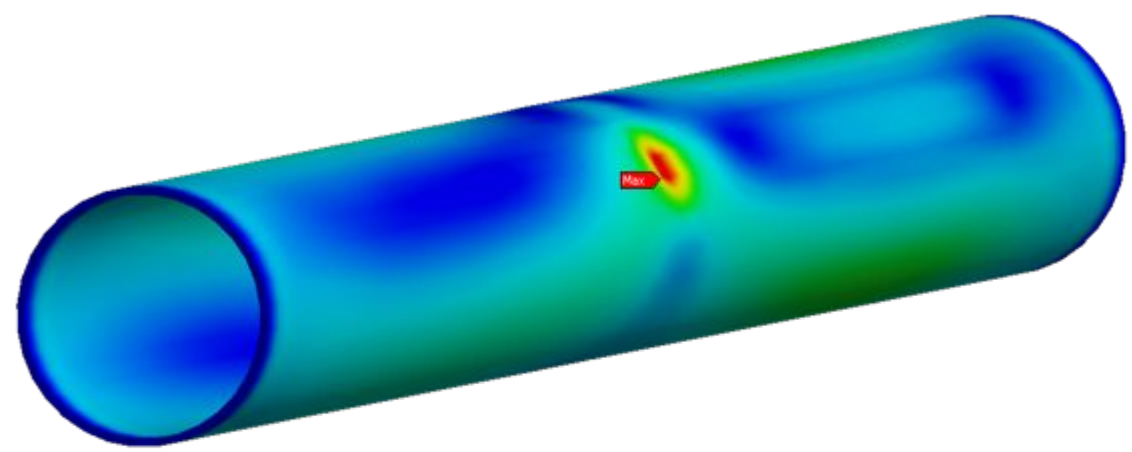
NUMERICAL MODEL OF THE EXPERIMENTAL SETUP

- Build a CFD model of the experimental setup and validate the results.
- Analyse the images obtained

THERMOMECHANICAL ASSESSMENT

- Use the temperature fields obtained in the simulations to calculate stresses and strains.





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