

# MARINE WATER CLEANING SYSTEM

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Fuel oil



Engine



Scrubber



Flocculation



High-speed  
separator

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# INTRODUCTION

- Kasper Bilde
- Industrial PhD student at Alfa Laval
- Aalborg University
  - Department of Energy Technology
- Currently 1 year into the study



**AALBORG  
UNIVERSITET**



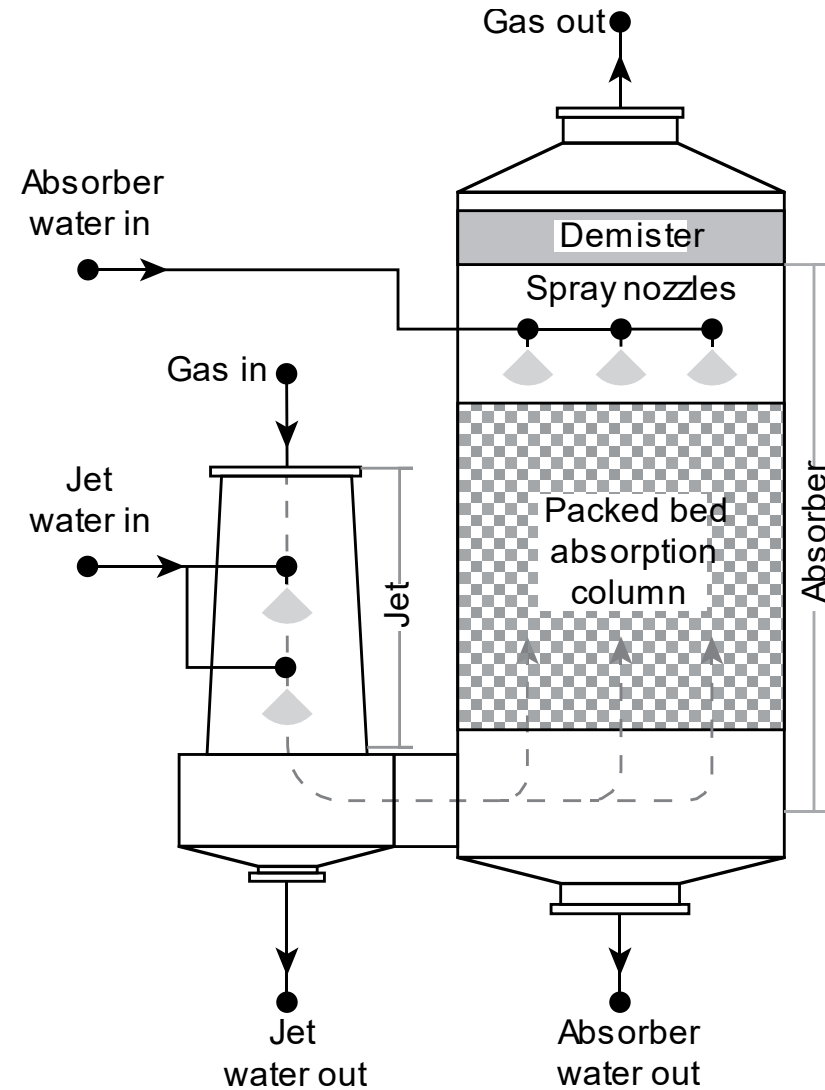
# BACKGROUND

- SOx regulation by January 2020
  - Worldwide: 0.5%<sub>wt</sub>
  - ECA zones (blue): 0.1%<sub>wt</sub>
- Marine industry must comply
  - Compliant fuels
  - Exhaust gas cleaning systems



# BACKGROUND

- Wet scrubber
  - Cleaning exhaust gas by washing
  - Removes 99% Sox
  - Removes ~40% of PM
- Operates in either open- or closed-loop mode



## BACKGROUND

- Open-loop scrubber operation prohibited in many places of the world
- Closed-loop operation preferred
- Need for water cleaning



# WATER CLEANING SYSTEM



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separator

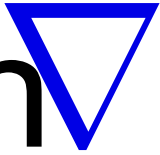
# WATER CLEANING SYSTEM

- Test setup in Aalborg
  - Flocculator and high-speed separator
- 2 MW MAN 4-stroke engine
  - Operated on DO/MGO/HFO



# OBJECTIVES

- Resolve the turbulent eddies in the fluid flow
  - Particle collision and agglomeration due to turbulence
- Large-eddy simulation of the fluid flow
  - OpenFOAM
- Discrete element model of particle collision
  - LIGGGHTS®
- Coupled using CFDEM® project
- Open-source approach

Open  FOAM

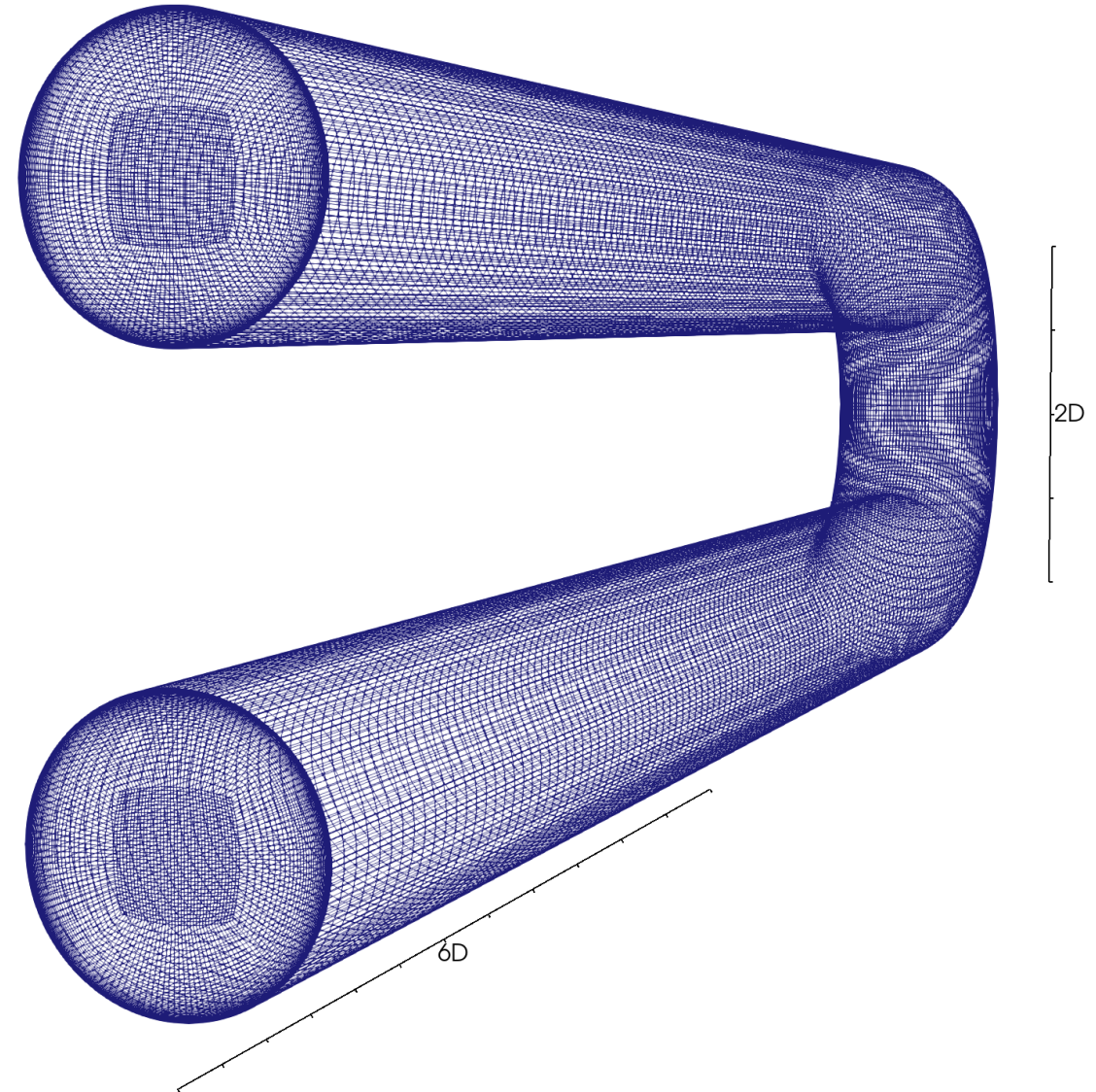


# LARGE-EDDY SIMULATION OF A PIPE U-BEND

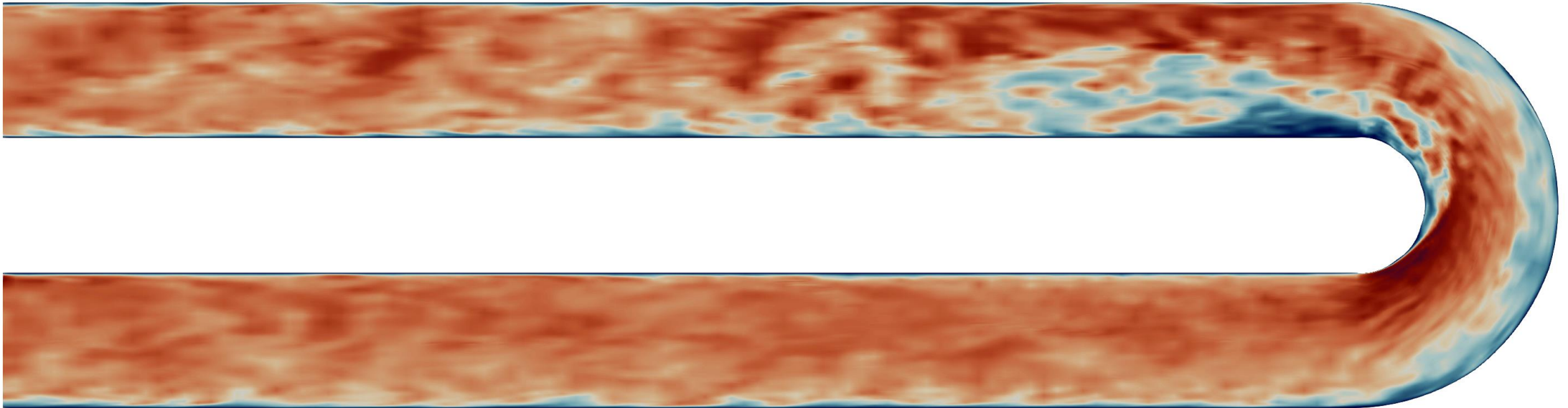
- Simulate part of the pipe flocculator
- Fully developed turbulent velocity flow profile at inlet
  - Mapping the velocity field at  $L = 6D$
- Study velocity gradient for different bending diameters

$$G = \sqrt{\left(\frac{\partial u}{\partial y} + \frac{\partial v}{\partial x}\right)^2 + \left(\frac{\partial u}{\partial z} + \frac{\partial w}{\partial x}\right)^2 + \left(\frac{\partial v}{\partial z} + \frac{\partial w}{\partial y}\right)^2}$$

- Fixed Reynolds number
  - $Re = 17800$
- Particle settling velocity:  $U_s = \frac{2}{9} \frac{\Delta \rho \, g \, r_p^2}{\mu_f}$



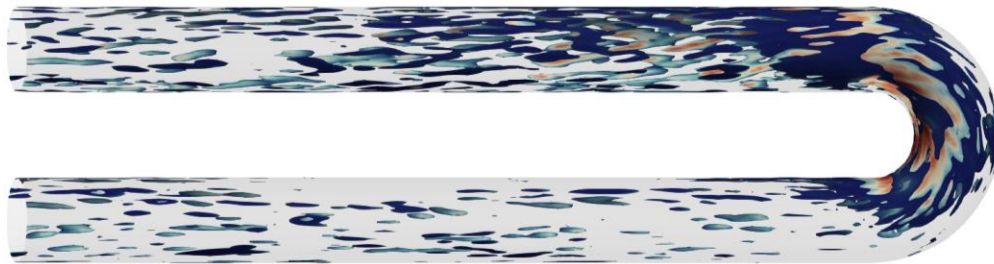
# LARGE-EDDY SIMULATION OF U-BENDS



# VELOCITY GRADIENT

Isosurface  $G=3000 \text{ 1/s}$

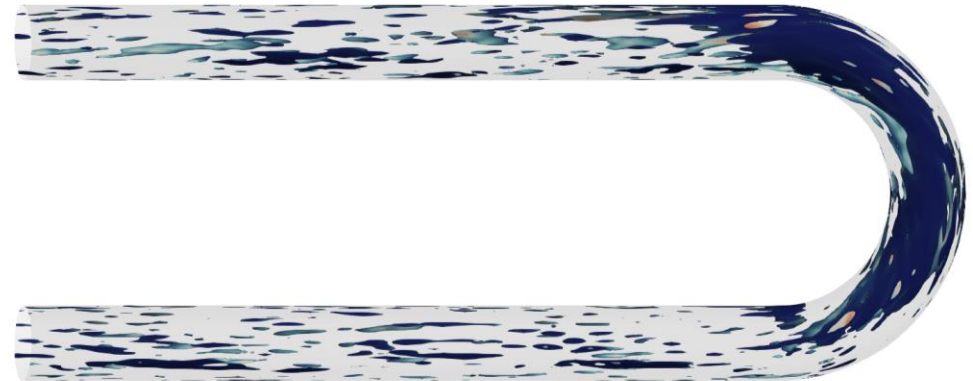
2D



U Magnitude  
0.0e+00      1   1.5e+00



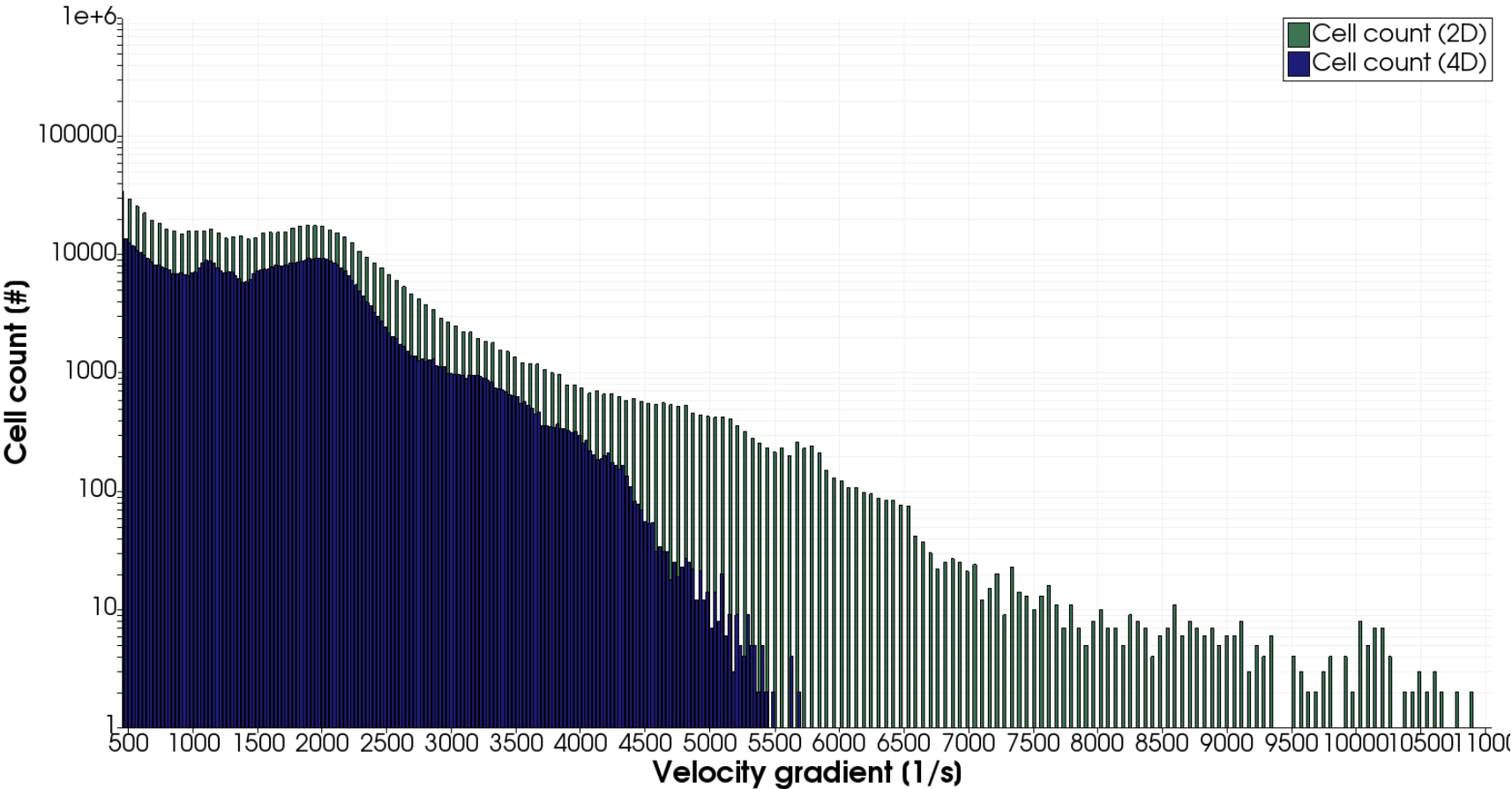
4D



U Magnitude  
0.0e+00      1   1.5e+00

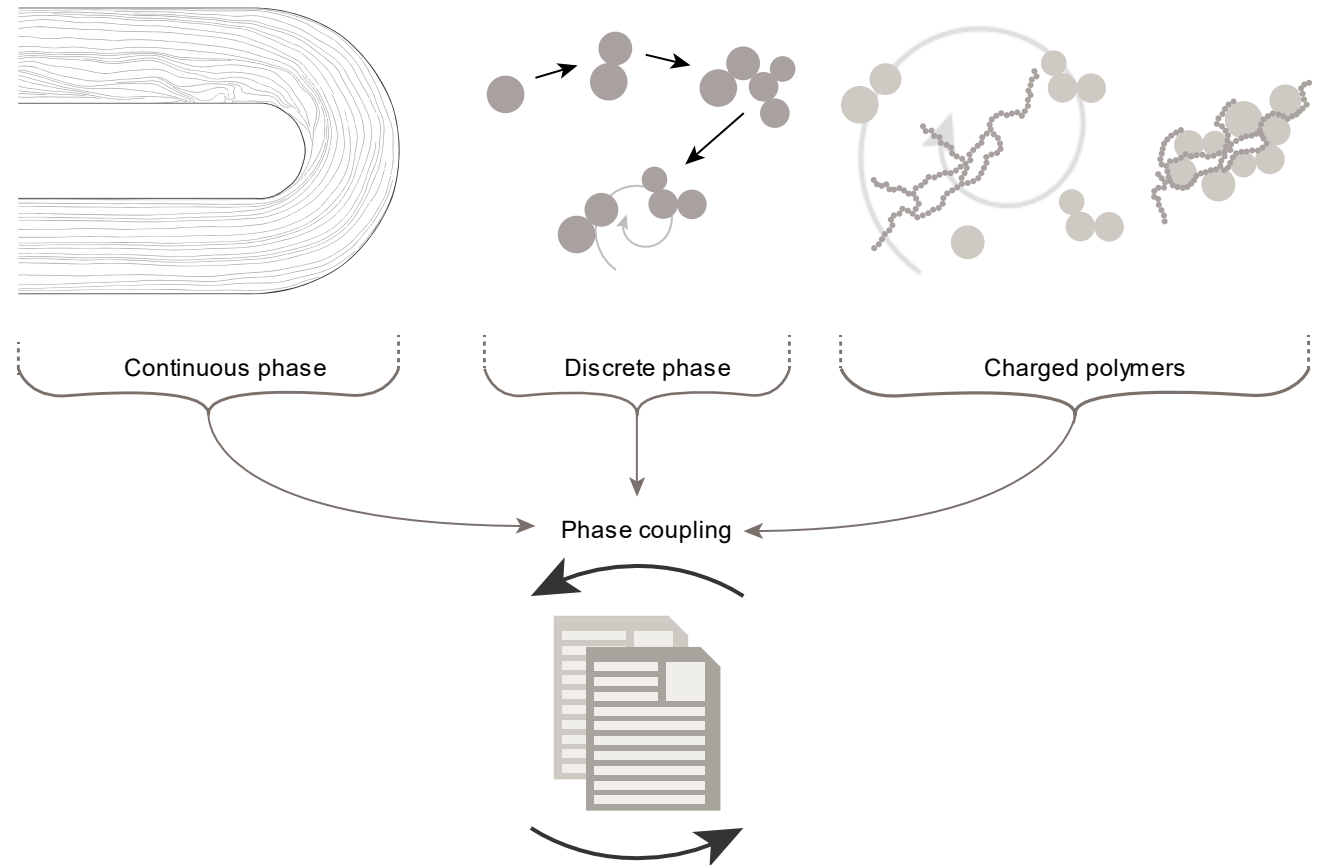


# VELOCITY GRADIENT



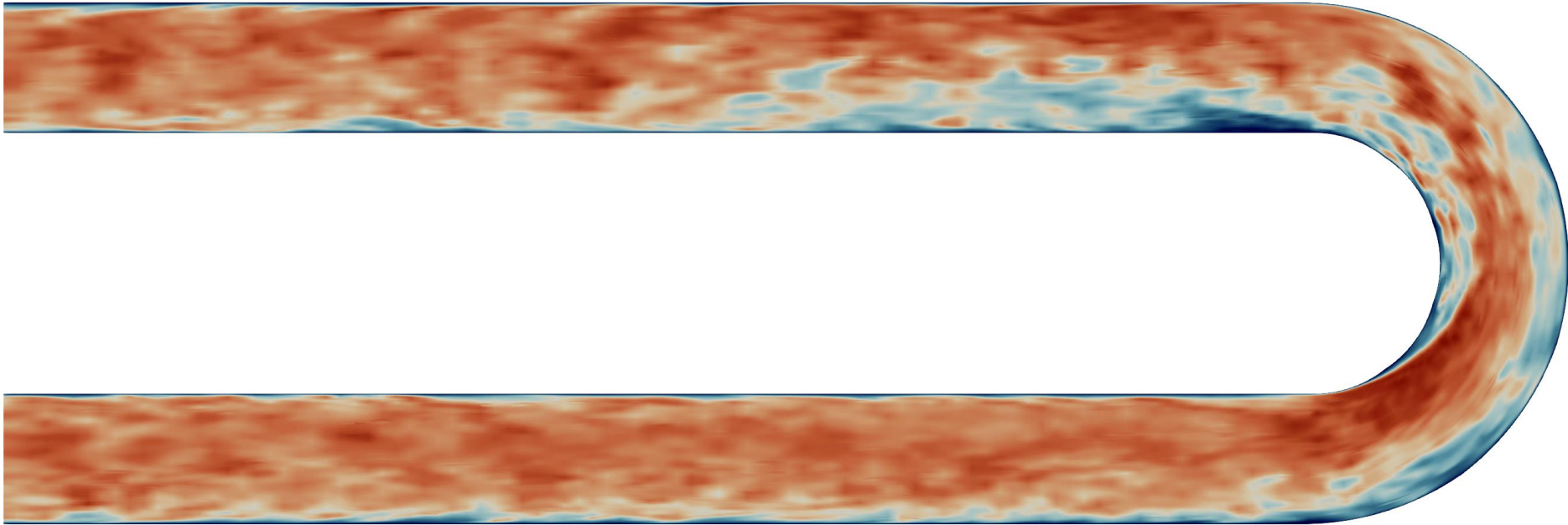
# CFD-DEM SIMULATIONS

- Continuous phase: LES
- Discrete phase: DEM
- Charged polymers: Not yet included
- Coupling: unresolved four-way coupling



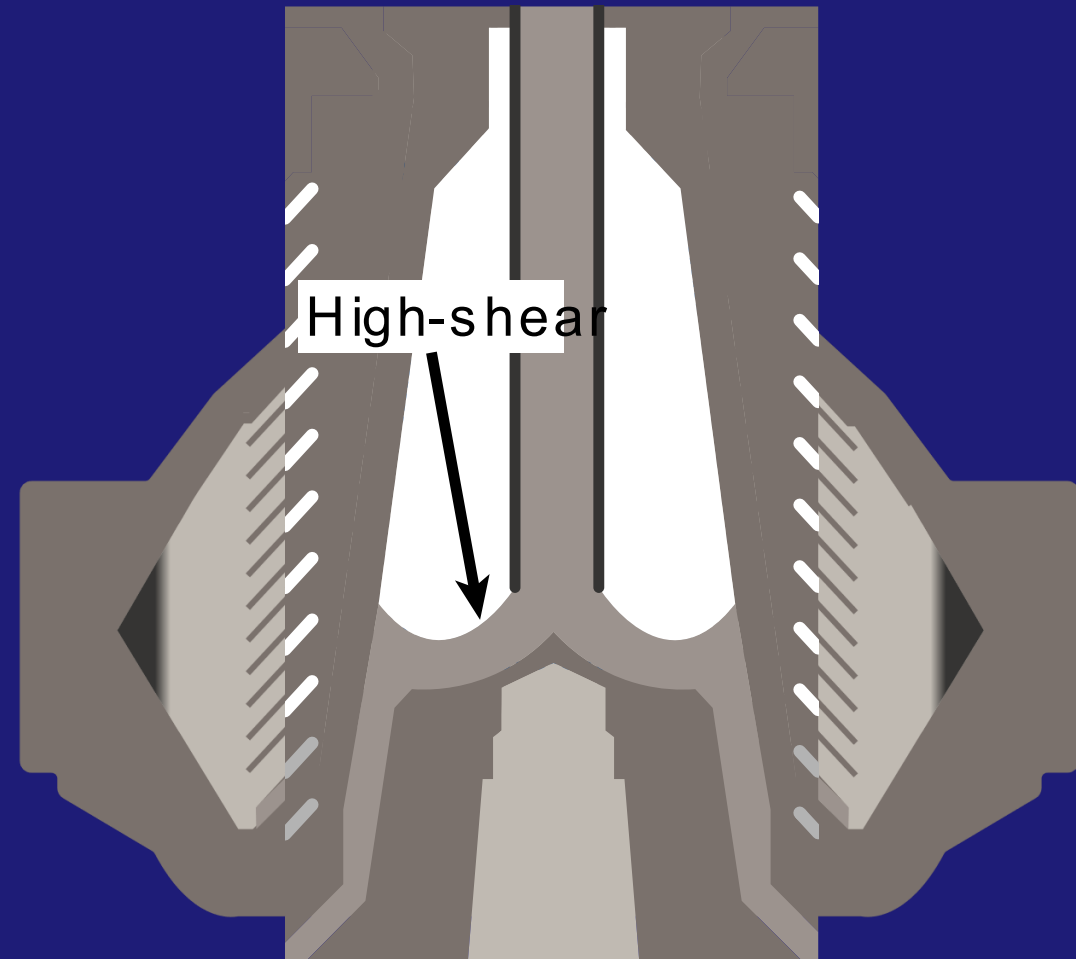
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## CFD-DEM SIMULATIONS



## MOVING FORWARD

- CFD of high-speed separator
- Breakage of particle agglomerates at inlet
  - ~8000 RPM
- VOF model



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# THANK YOU FOR YOUR ATTENTION

