Heat & Mass Transfer(HMT) between XDEM & OpenFOAM using preCICE coupling library

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Outline

- Why do we need HMT coupling?
- How do we do the HMT coupling?
- Results & Validation
- Discussions & Open Questions
- Conclusions

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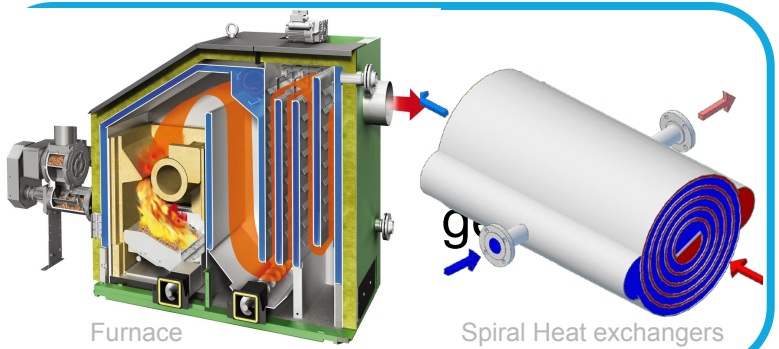
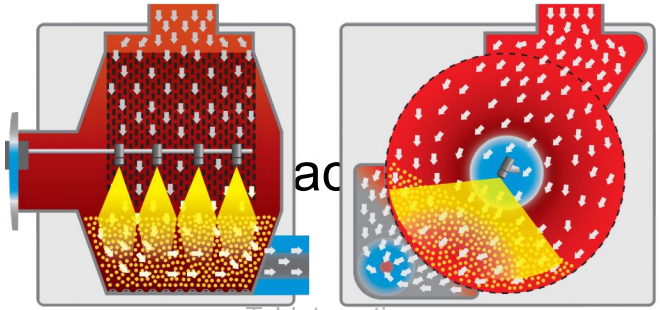
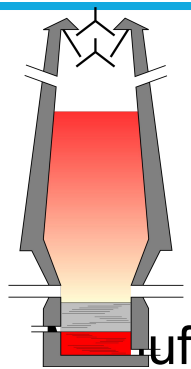
Processes achieved with HMT between particles & fluids

- Drying
- Gasification
- Pyrolysis
- Combustion
- Melting
- Solid - Fluid Reactions

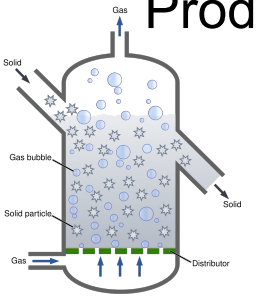
HMT between particles & fluid has several industrial applications



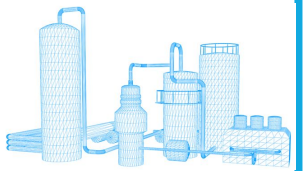




ufacturing & Production



Fluidised Bed reactor



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eXtended Discrete Element Method (XDEM) [1]

- **Dynamics:** Particle Motion, Forces & Torques
- **Conversion:** Heat & Mass Transfer, Chemical reactions
- **Ad-Hoc Coupling:**
  - **CFD:** Foam-Extend / OpenFOAM (XDEM direct coupling)
  - **FEM:** Diffpack

Rapid prototyping is possible with modularity

- Flexibility of changing/swapping software
- Version upgrades in coupled softwares/libraries
- Lack of features
- Unavailability/Inaccessible softwares

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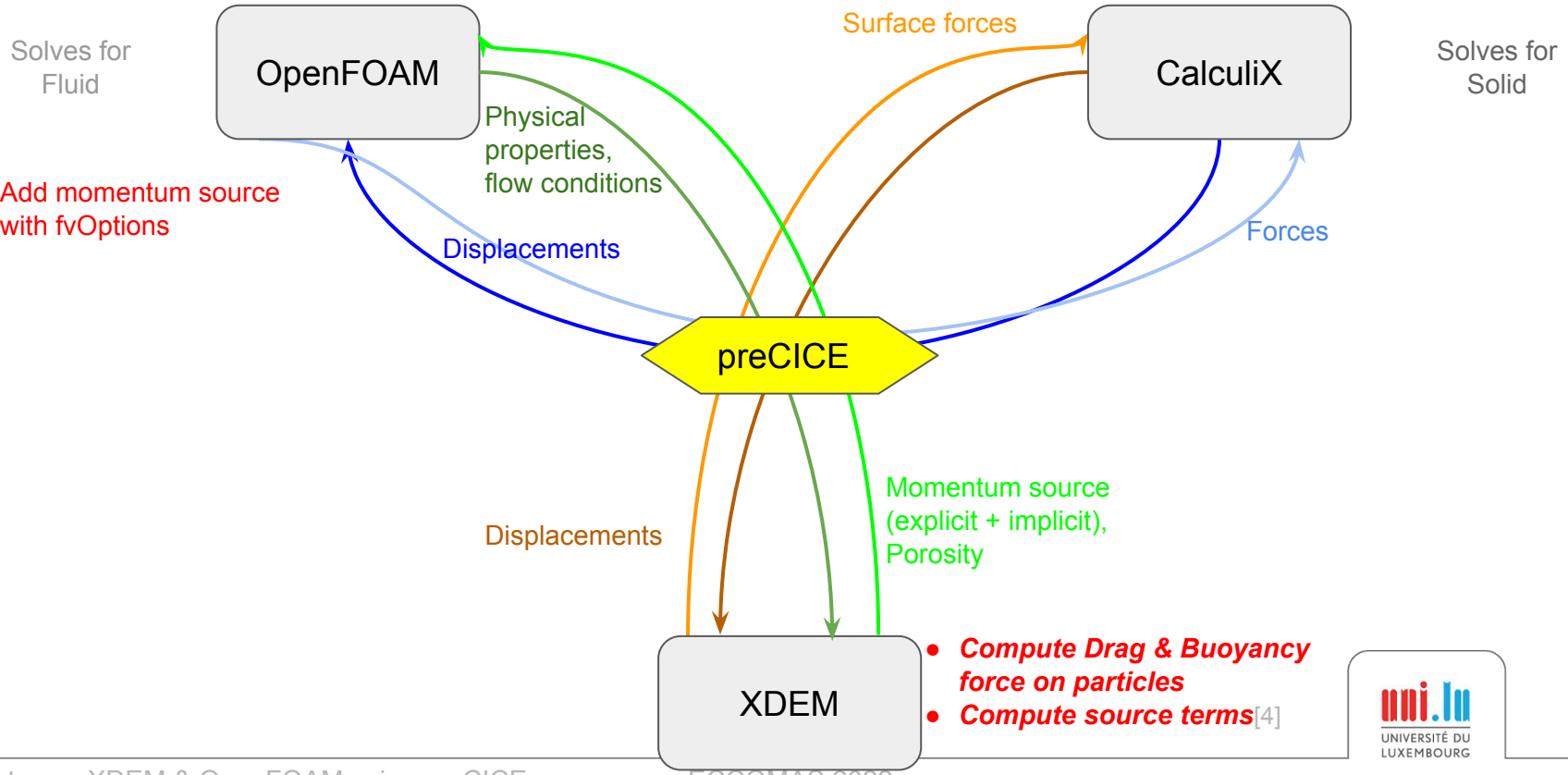
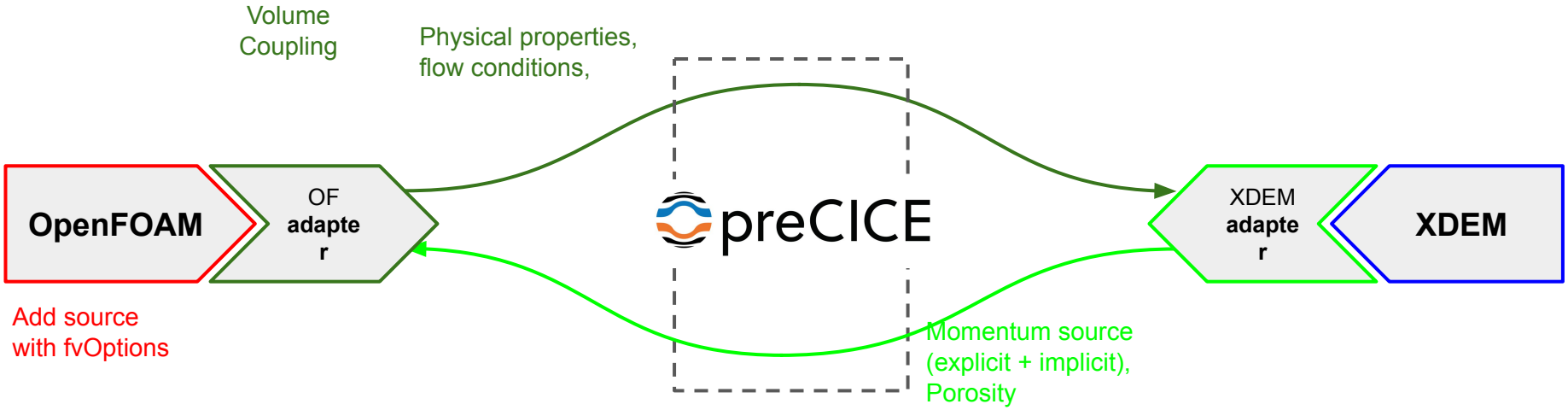
6-way[2] Momentum coupling using preCICE[3]

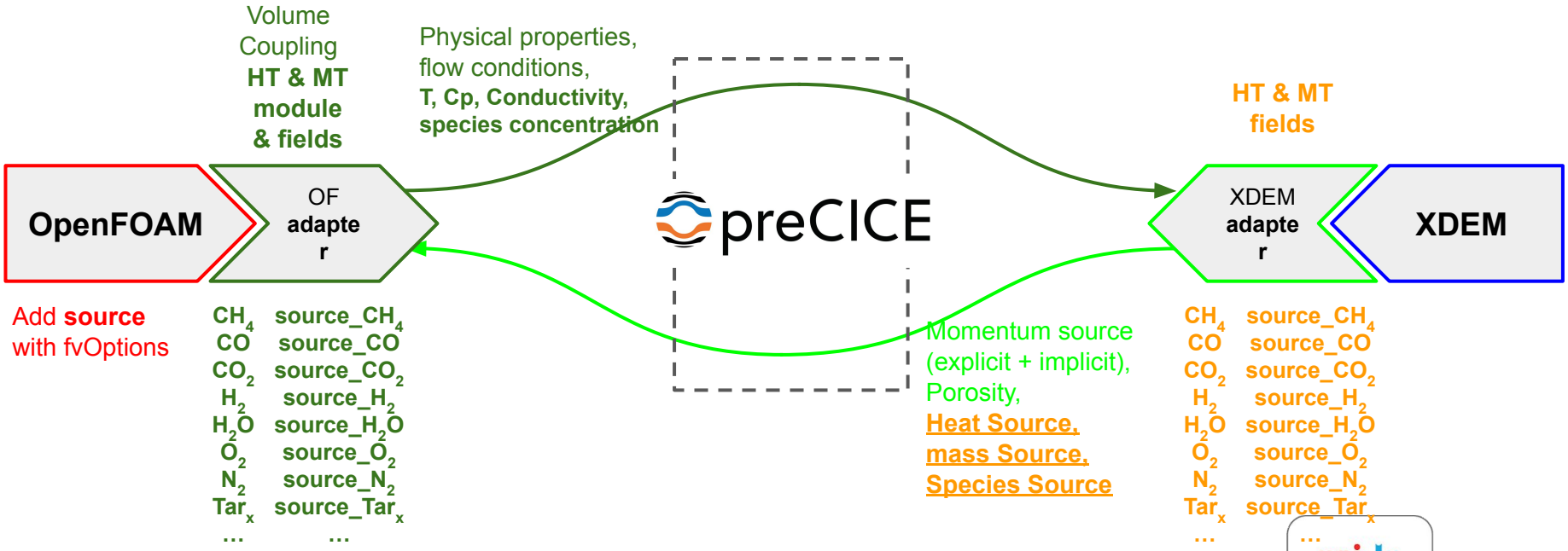


- Add momentum source with fvOptions

Previous work in preCICE
OpenFOAM & XDEM adapter



Developments done in preCICE
OpenFOAM & XDEM adapter for HMT



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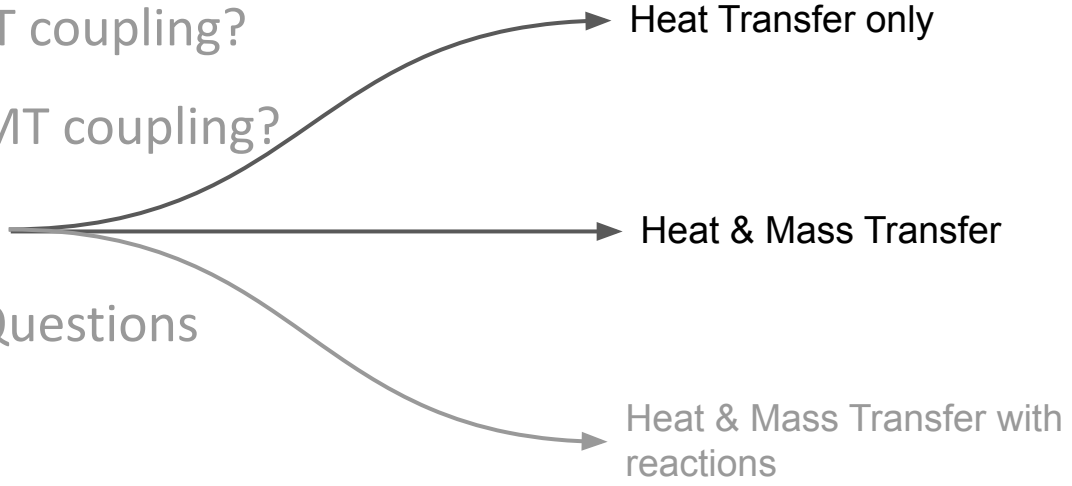
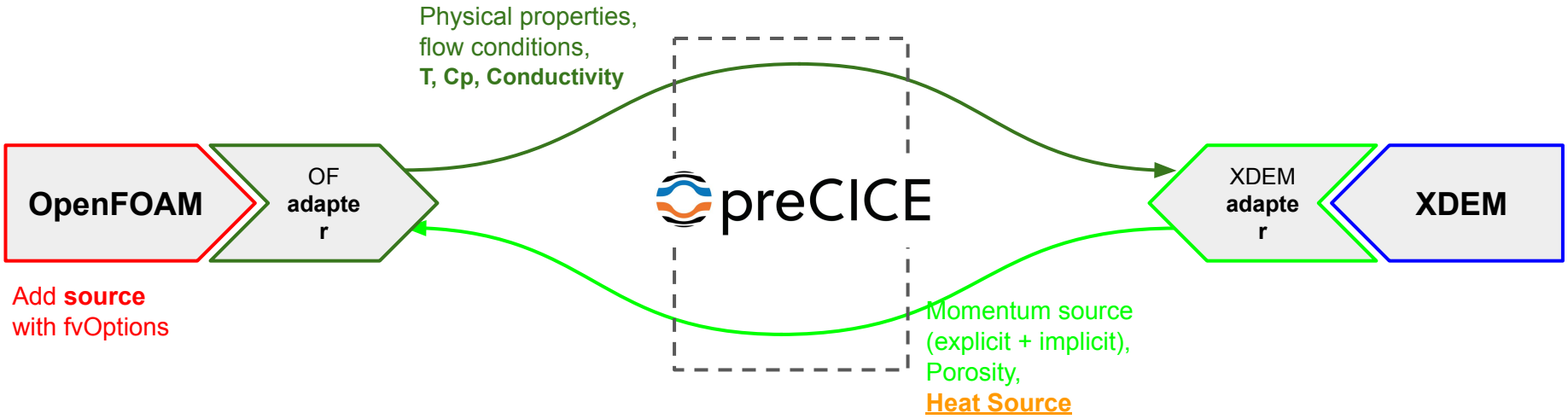
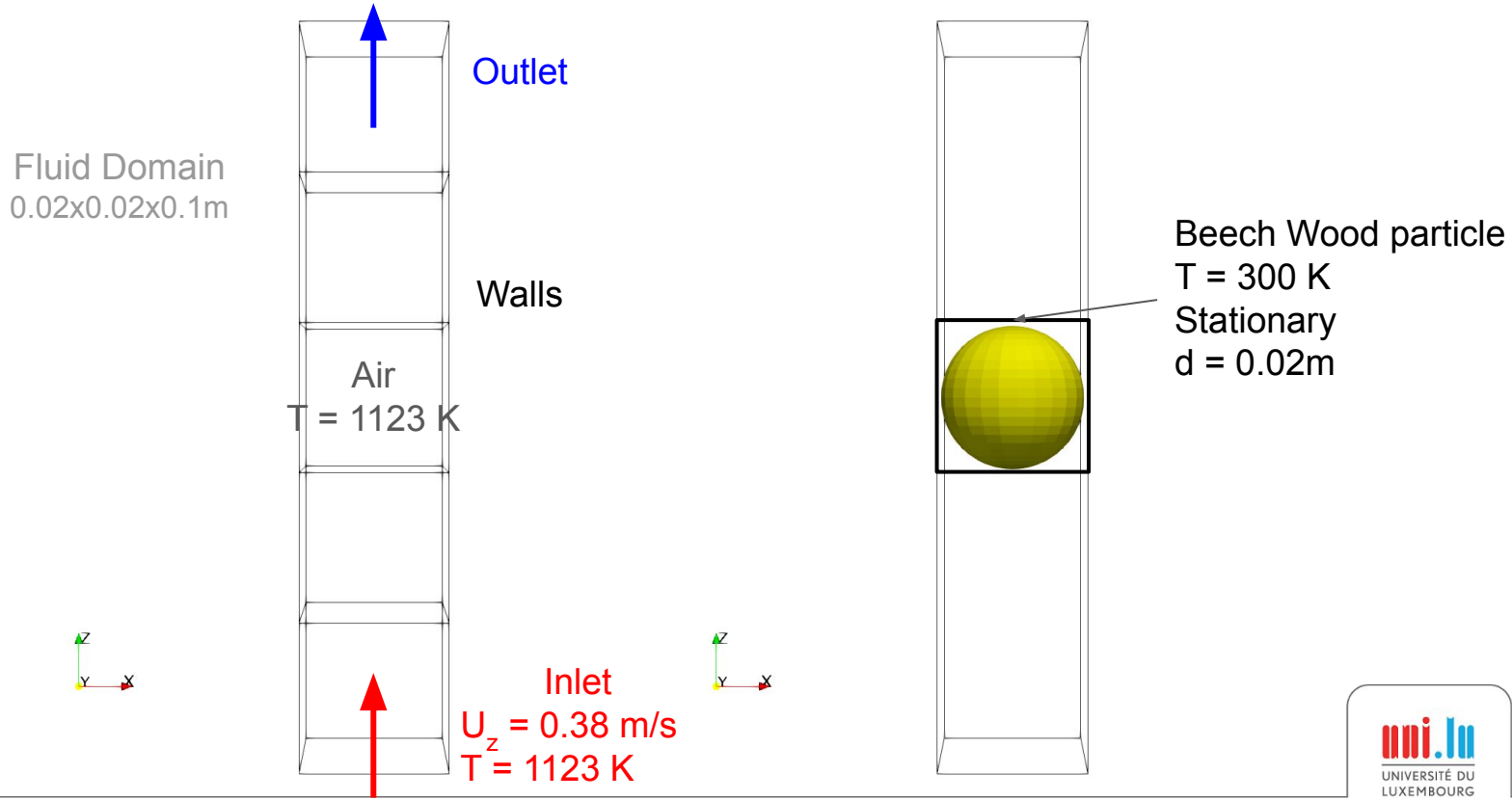


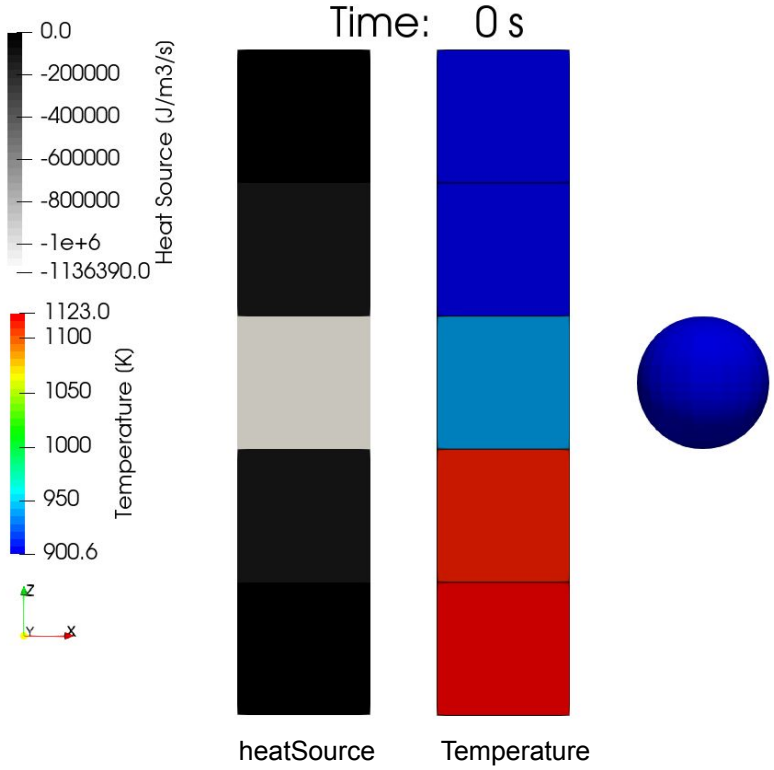
Heat Transfer Only



Heat Transfer only Case Set up



Fluid heat used to heat-up the particle resulting in Fluid temperature dip



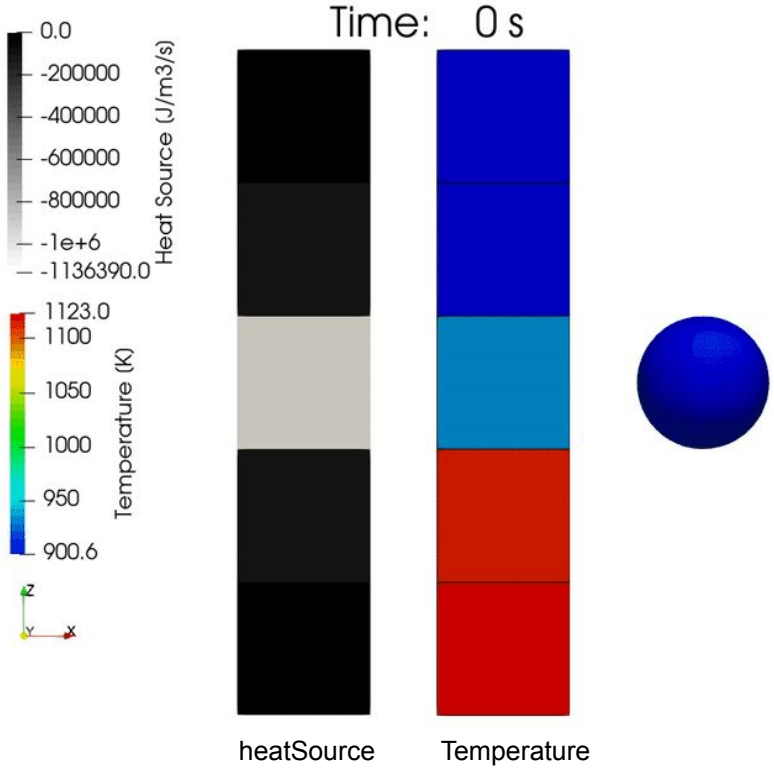
rhoPimpleFoam

dt OF = 0.01s

dt XDEM = 0.01s

preCICE coupling
dt = 0.01s

Fluid heat used to heat-up the particle resulting in Fluid temperature dip



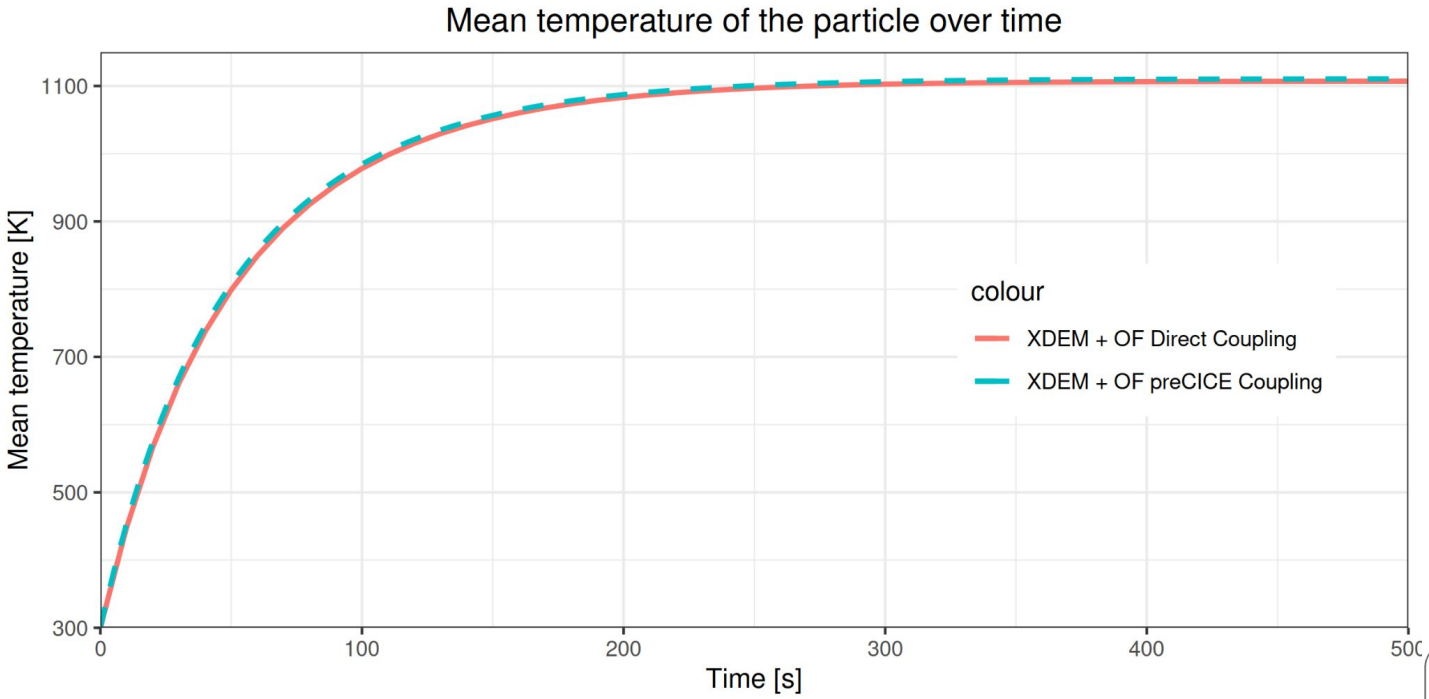
rhoPimpleFoam

dt OF = 0.01s

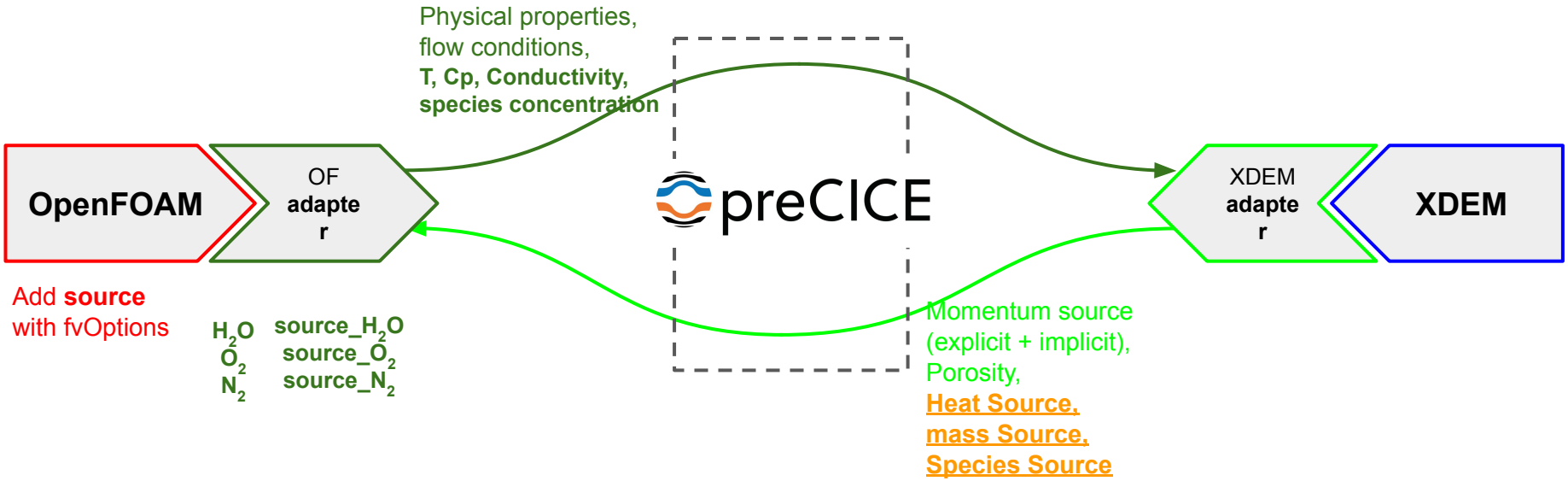
dt XDEM = 0.01s

preCICE coupling
dt = 0.01s

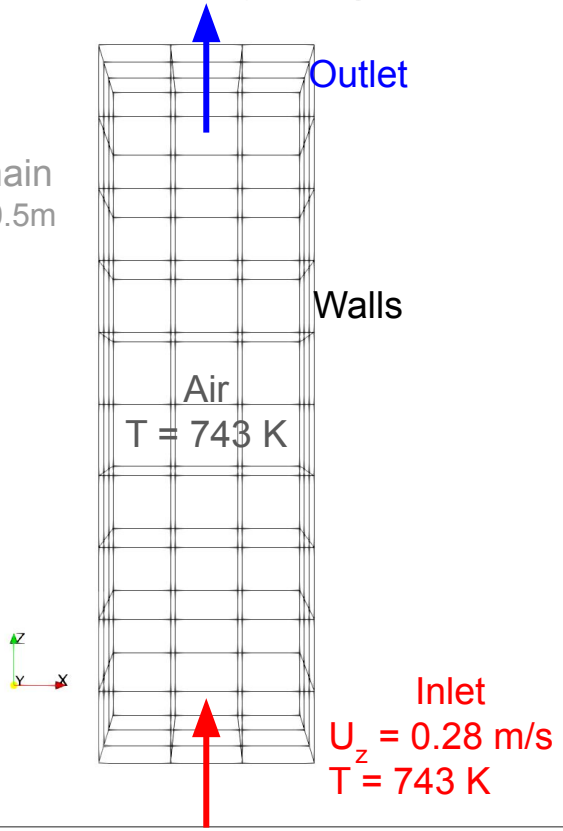
Mean temperature of the particle for presented couplings is in good agreement

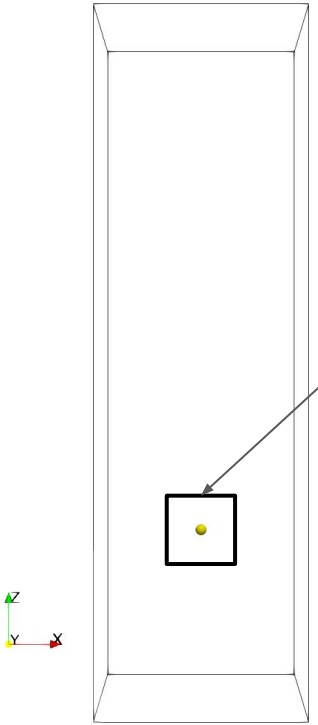


Heat & Mass Transfer Only



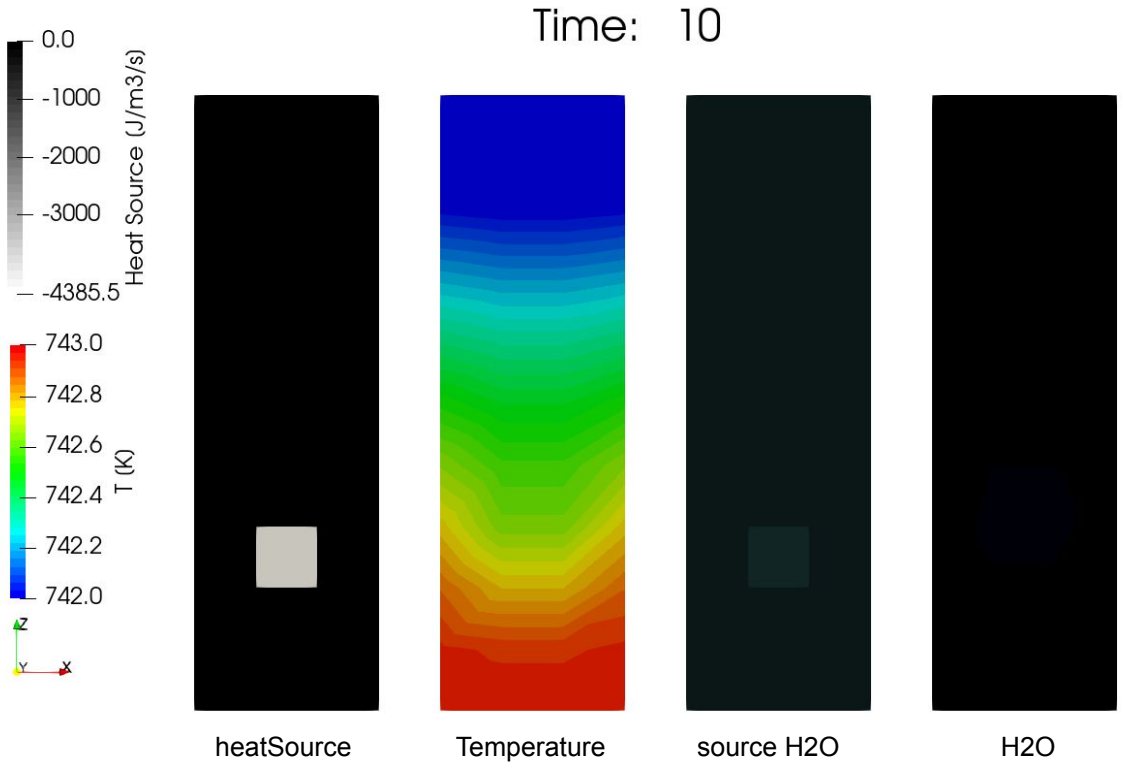
Fir Wood Drying Case Set up[4]





Fir Wood particle
T = 297 K
Stationary
d = 0.008m
Moisture content:
case1 = 33%
case2 = 66%

Fluid heating up fir wood thus converting moisture to steam



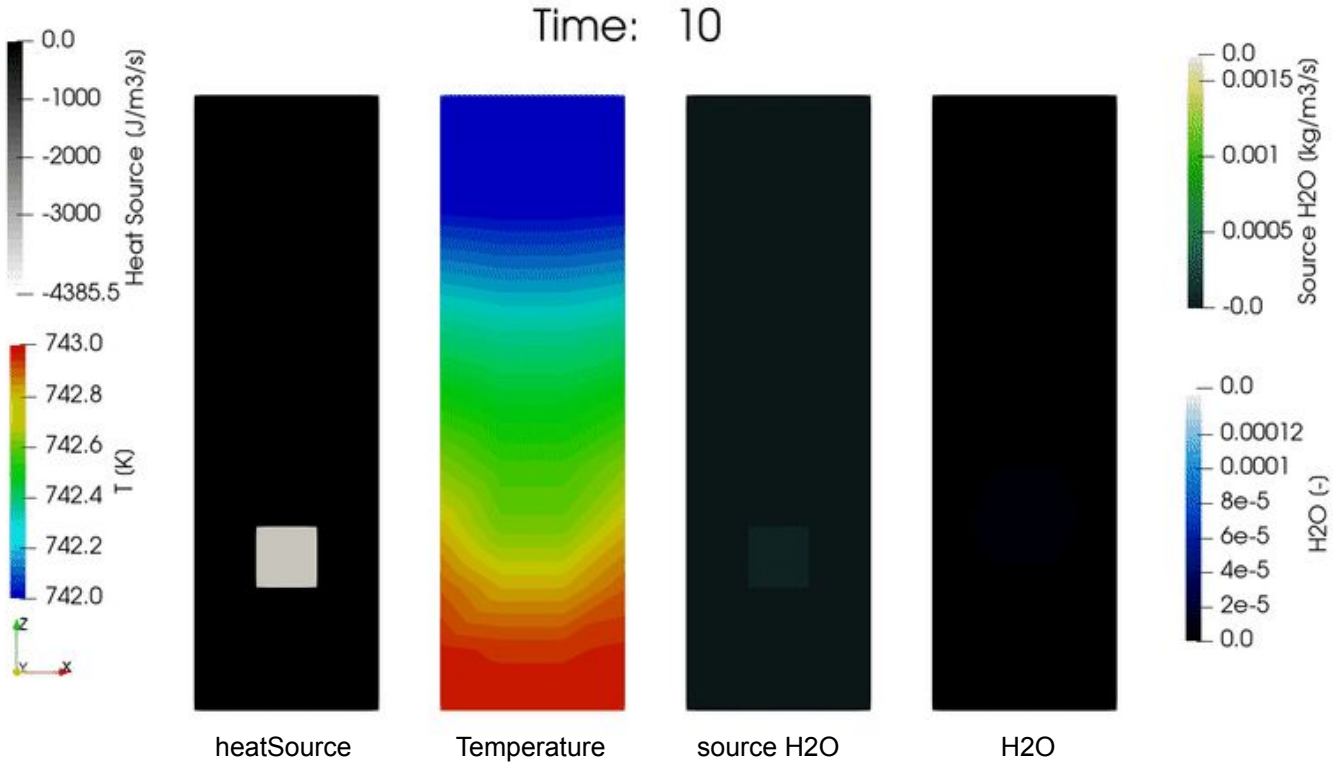
reactingFoam

dt OF = 0.5

dt XDEM = 0.5

preCICE coupling
dt = 0.5

Fluid heating up fir wood thus converting moisture to steam



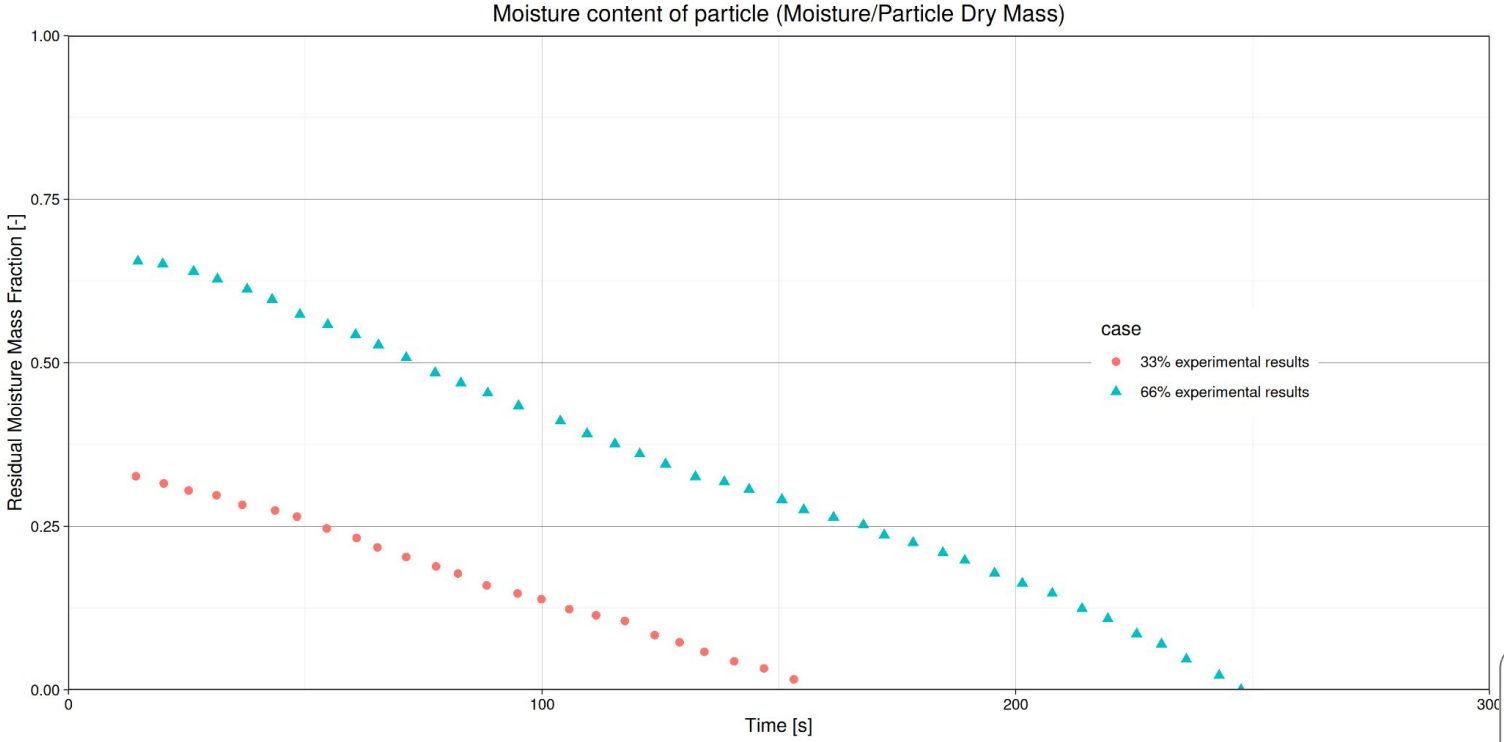
reactingFoam

dt OF = 0.5

dt XDEM = 0.5

preCICE coupling
dt = 0.5

Moisture content in particle closely matches XDEM reference simulations[5]



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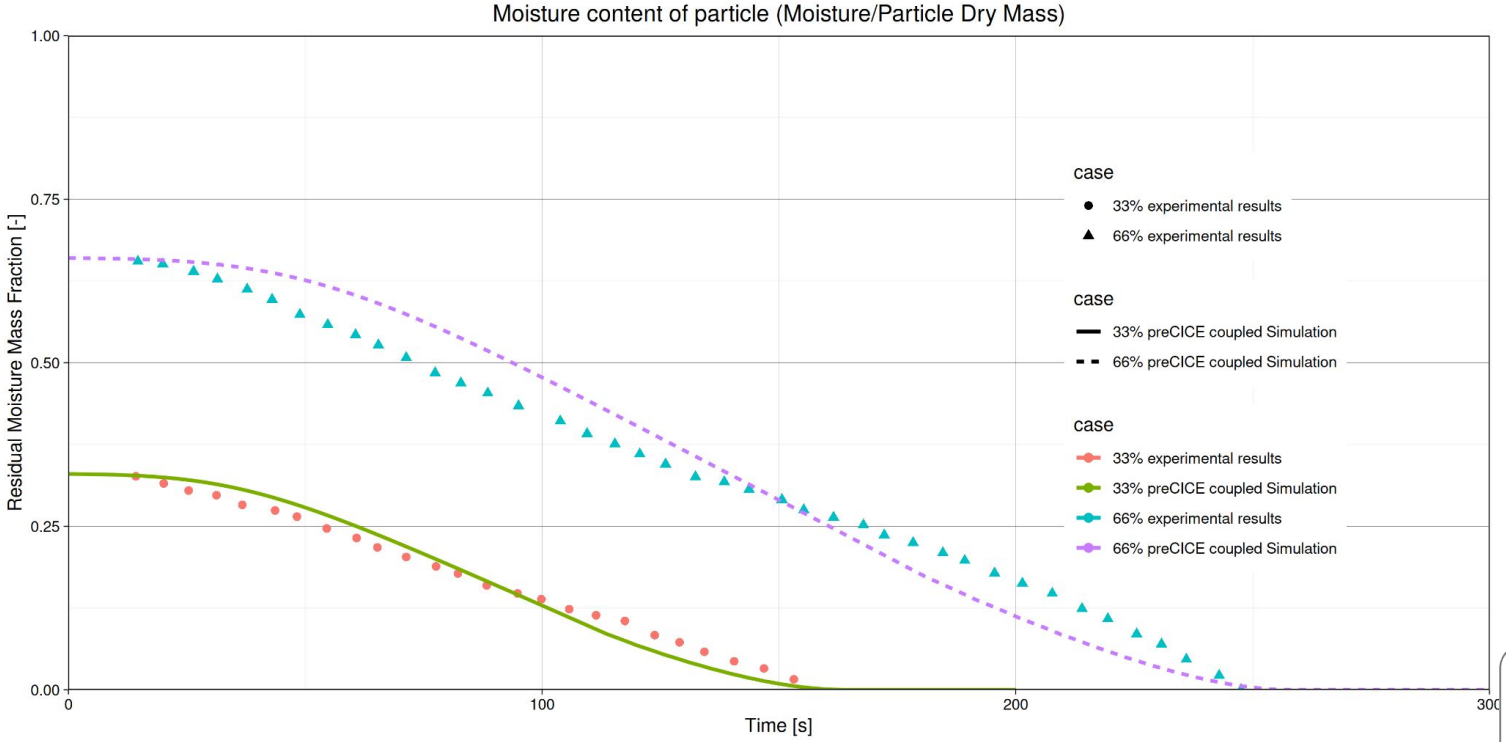

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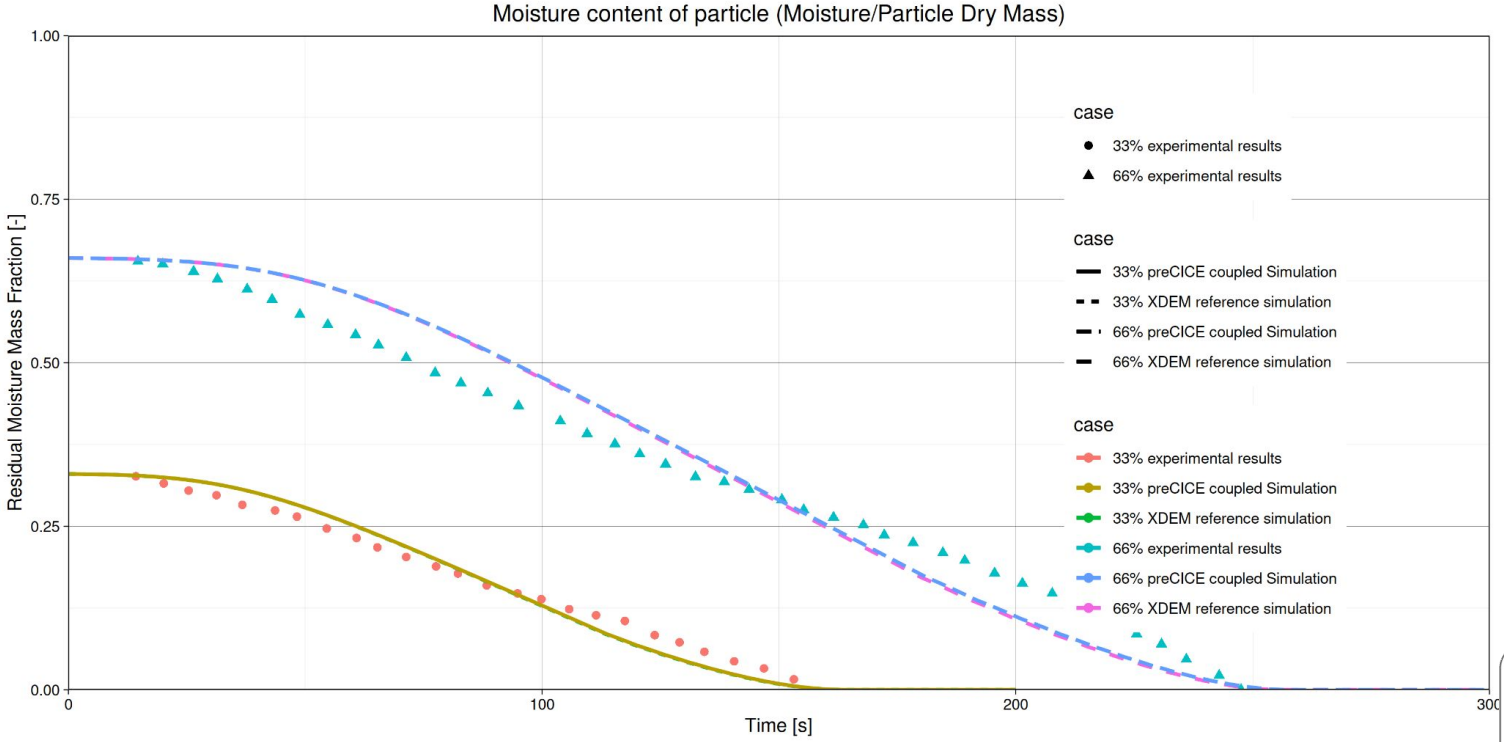
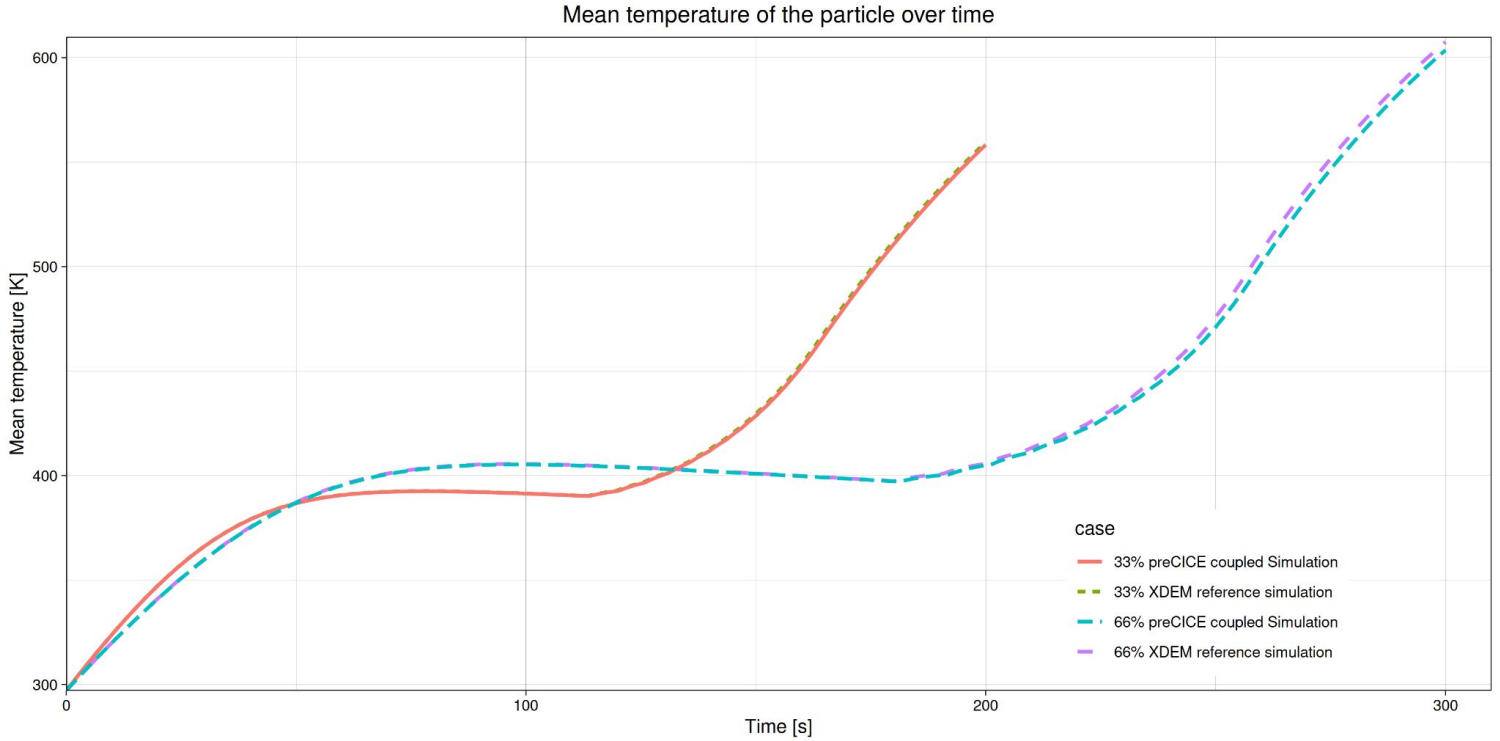
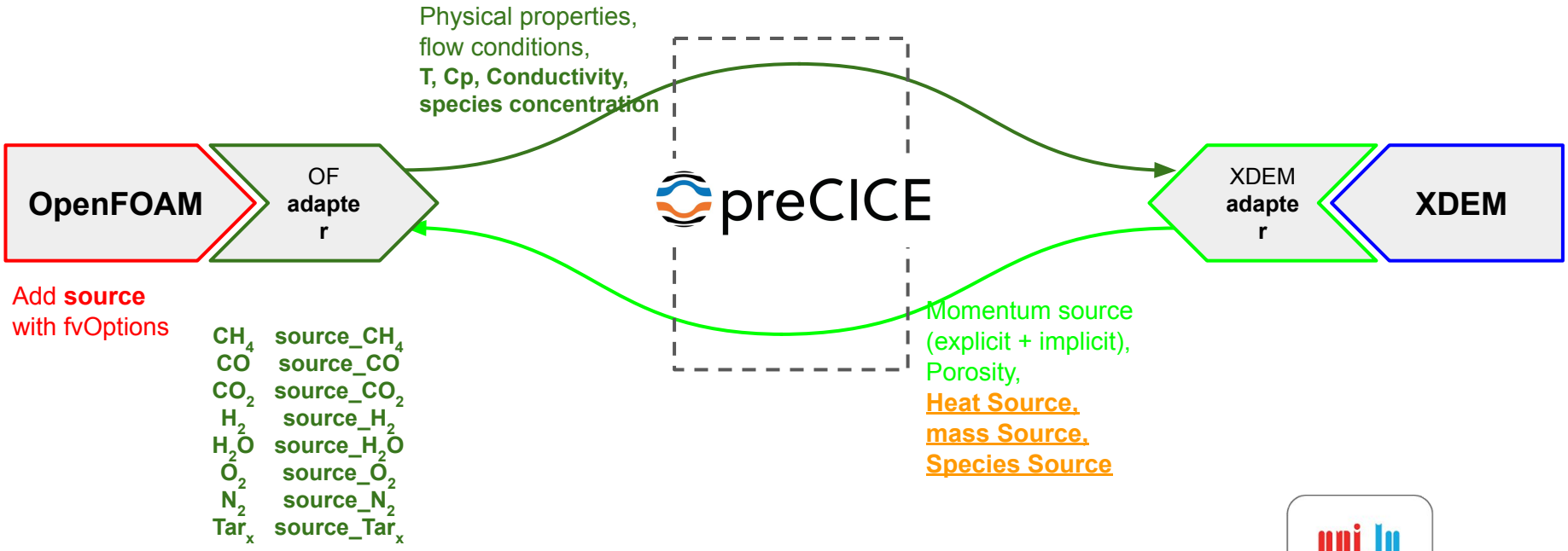


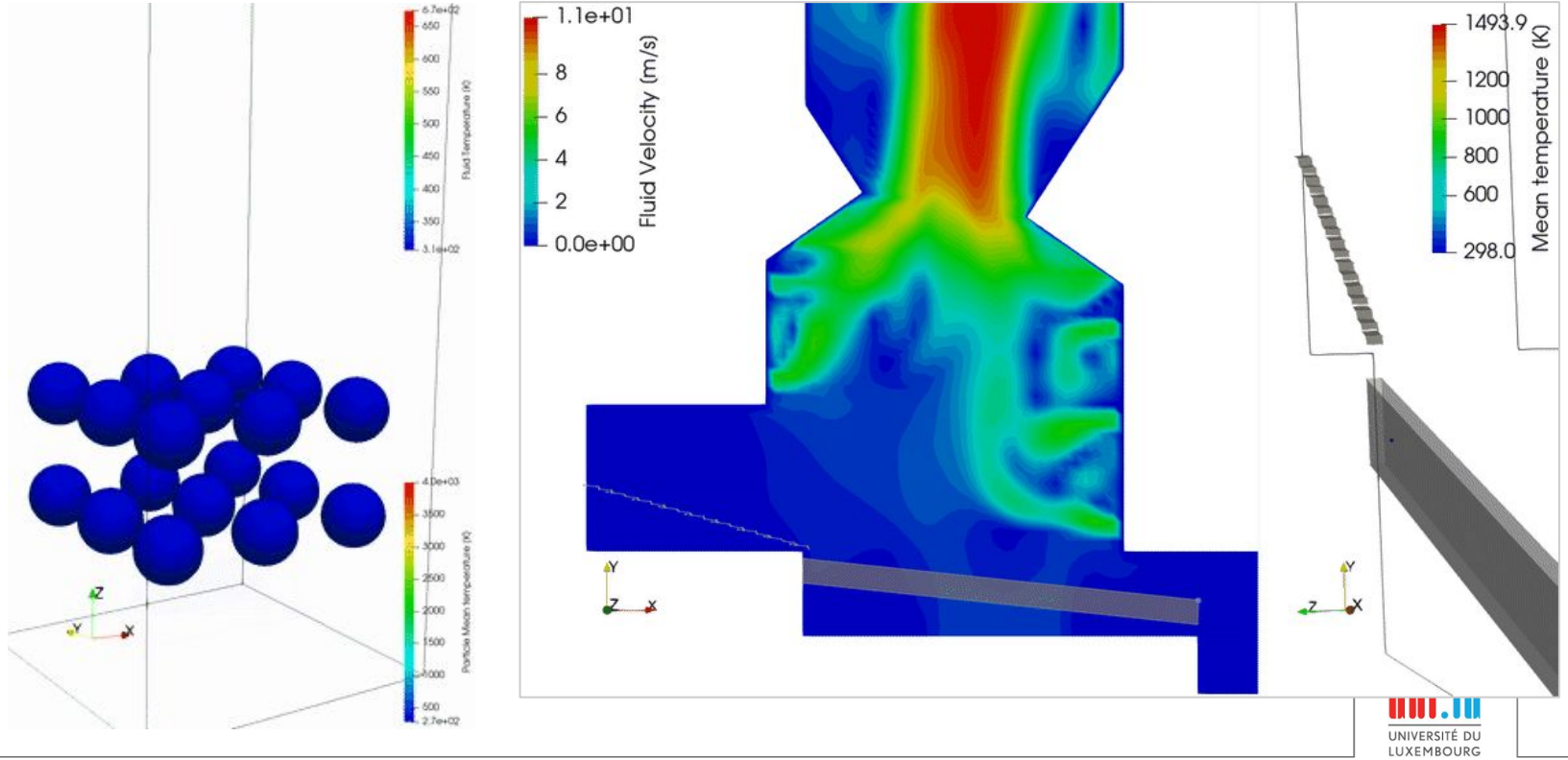
Mean temperature of the particle closely matches XDEM reference simulations[5]



Heat & Mass Transfer with Reactions: Validation W.I.P



Prototype Biomass Furnace Results: Validation W.I.P



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Open Questions & Limitations

- Time steps of all components needs to be equal (software implementation constraint)
- How to handle species automation? (OF/XDEM Adapter)
- How to handle Euler Multiphase type solvers? (Melting)

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Achieved HMT volume coupling between XDEM & OpenFOAM using preCICE

- Flexibility of changing CFD solver
- Validation of results with pre-existing simulations & experiments[4]
- Can simulate single-phase fluid w/ particles
- Enable drying, pyrolysis, gasification, combustion
- Contribution to preCICE OF adapter

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References

[1] Peters, Bernhard, et al. "XDEM multi-physics and multi-scale simulation technology: Review of DEM–CFD coupling, methodology and engineering applications." Particuology 44 (2019): 176-193.
[2] Adhav, Prasad et al “AWJC Nozzle simulation by 6-way coupling of DEM+CFD+FEM using preCICE coupling library“, ECCOMAS Coupled Problems 2021, https://orbilu.uni.lu/handle/10993/48725
[3] Bungartz, Hans-Joachim, et al. "preCICE–a fully parallel library for multi-physics surface coupling." Computers & Fluids 141 (2016): 250-258.
[4] Xiao H, Sun J. Algorithms in a robust hybrid CFD-DEM solver for particle-laden flows. Communications in Computational Physics. 2011;9(2):297-323.
[5] Peters, Bernhard, and Christian Bruch. "Drying and pyrolysis of wood particles: experiments and simulation." Journal of analytical and applied pyrolysis 70.2 (2003): 233-250.

Image References:

[Furnace] https://www.zerobiomass.co.uk/en/buyers-guides/what-is-a-biomass-boiler/wood-chip-boilers
[Spiral Heat Exchanger] https://heseman.com/product/spiral-heat-exchangers/
[Blast Furnace] https://commons.wikimedia.org/wiki/File:Blast_furnace_nocaption.svg
[Additive Mfg] https://all3dp.com/1/selective-laser-melting-guide/
[Fluidised Bed Reactor] https://en.wikipedia.org/wiki/Fluidized_bed_reactor
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