UNIVERSITÀ DEGLI STUDI DI PADOVA

Advanced technologies for carbon capture and biohydrogen production

Alessandro Crescenzi - 40th Cycle

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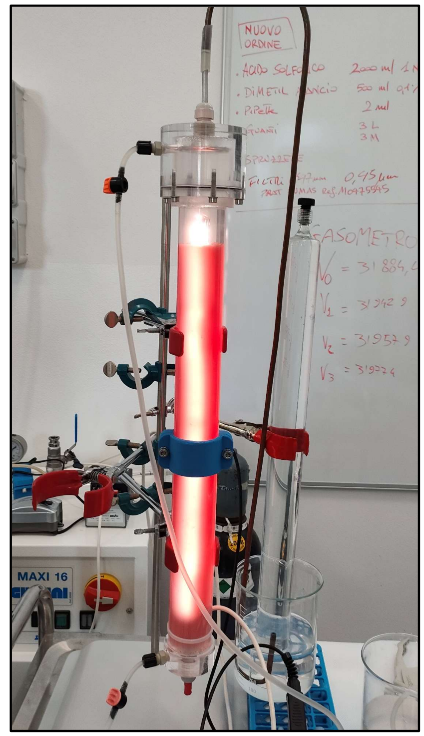
Co-supervisor: Prof. Federico Dalla Barba - Dott. Graziano Tassinato

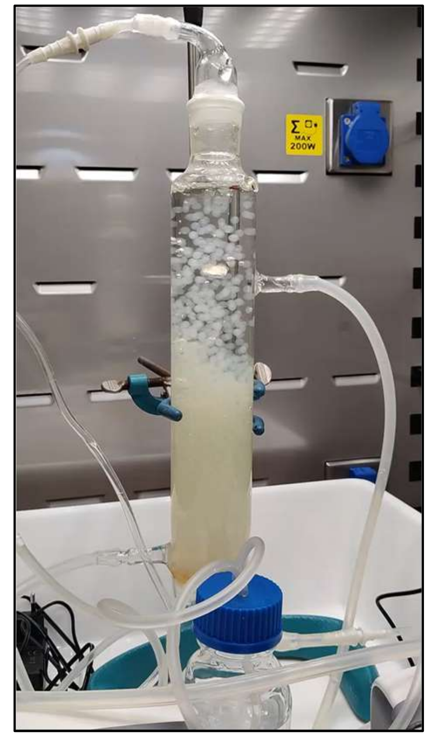
Admission to the 2nd year - 14/10/2025

Doctoral work motivation and objective

- Develop **CFD models** of **column-type bioreactors**.
- The research involves both reactors with a **fixed solid phase** (porous matrix) and ones with a **dispersed solid phase**.
- The **red bacteria (PNSB)** reactor produces hydrogen and has a solid matrix immersed in culture medium.
- The **microalgae** reactor gives oxygen and contains small spheres, free to move with the motion of water and bubbles.
- Both feature a **multiphase flow** comprising **gas, liquid and solid phases.**

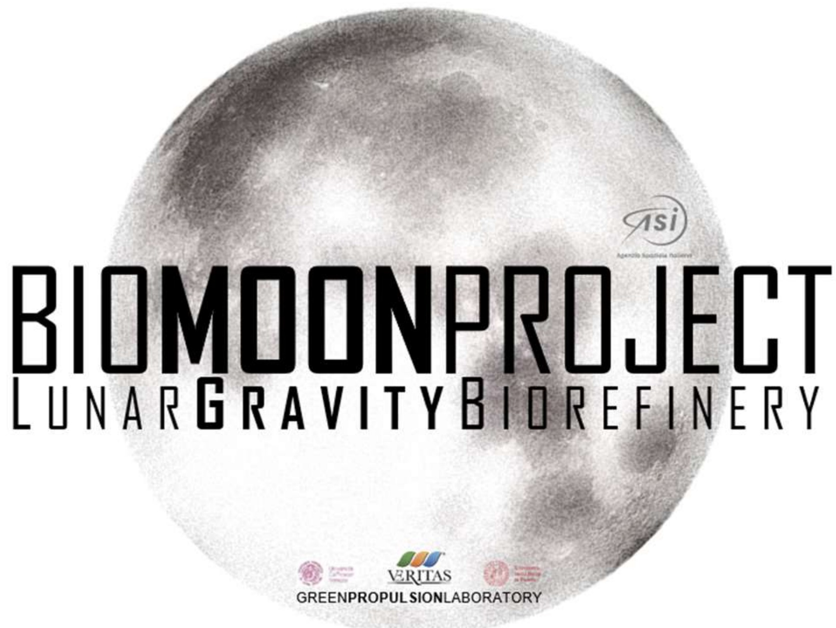


PNSB reactor



Microalgae reactor

Industry collaborations



- Project developed by **Veritas S.p.A.**, commissioned by **Agenzia Spaziale Italiana (ASI).**
- Aim to develop a **biorefinery** that uses **microorganisms** to process **waste** produced by astronauts and produce **nutrients and resources.**
- Collaboration with:
  - **Green Propulsion Laboratory** (Veritas S.p.A., Fusina) → Construction of a prototype space model;
  - **Università Ca' Foscari** → Experimentation on microorganisms in a laboratory-scale system;
  - **UniPD** → Fluid dynamics and energy modelling of the system.

Work Outline

Task #1: Macroscopic model development

- State of the art
- Multiphase flow study
  - Two Dimensional
  - Three Dimensional
- Ansys Fluent model development
- Model validation
- Improvement study
- Reduced gravity study

Task #2: BIOMOON experiments

- Tests with previous experiments
- Research and selection of suitable equipment
- Validation of the experimental set
- Data collection
- Improvement tests

Task #3: Microscopic model development

- State of the art
- Model development with in-house software (CaNS)
- Reduced gravity study

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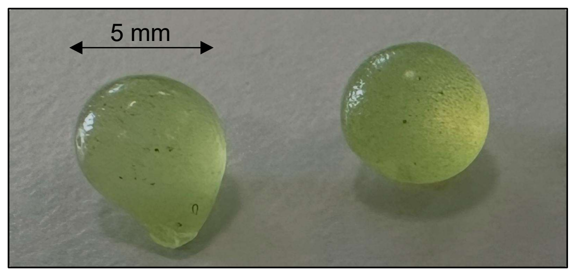
Task #1

- Modelling a **multiphase bioreactor** is complex, especially with “big particles”
- **Ansys Fluent** commercial software allows to represent the behaviour of the various phases, including **bubble motion, transport in porous media and mass transport phenomena**.
- For gas-liquid-solid systems, **different multiphase models can be used**, each with advantages and limitations:

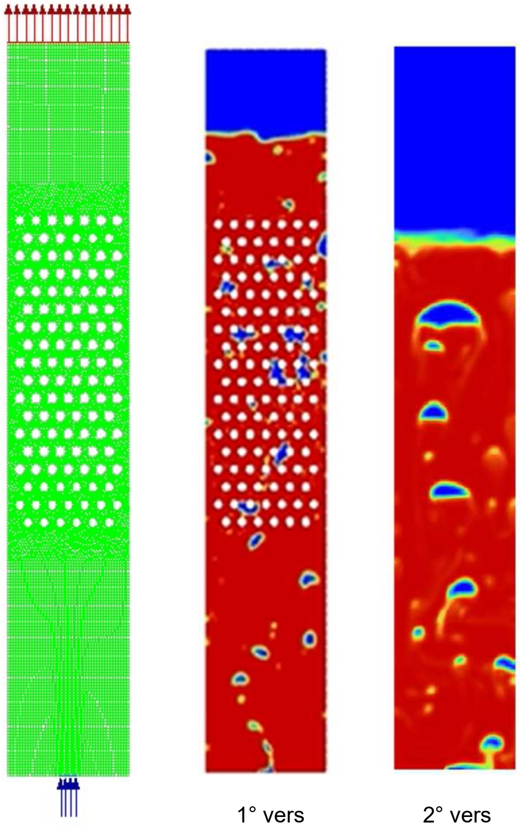
Model	Description	Pros	Cons
Volume of Fluid (VOF)	Finely resolved interface (useful for few and large bubbles)	High precision and accuracy of the interface	Expensive and not scalable for numerous bubbles
Eulero-Lagrange (DPM)	Continuous liquid phase, bubbles traced as discrete particles	Details on trajectories and forces on particles	More computationally expensive in certain case studies
Eulero-Eulero	Each phase treated as continuously interpenetrating	Robust, suitable for large volumes	Minor detail on the dynamics of individual bubbles



Task #1

VOF approach
- 2 versions:
  - Dispersed phase
  - Porous media
- **Abandoned** when GpLab told us **priority** was on the **microalgae reactor**, in combo with VOF being very heavy for our cases

Eulerian approach
- Single **bubble/sphere tracing is lost**. Phases are still distinct and have their own equations for the conservation of mass, momentum and energy.
- Interactions between phases, such as friction, heat exchange and mass transfer, are modelled using specific exchange terms. This model allows for **detailed analysis of fluidisation and sedimentation**.



Task #1

Eulerian approach

- Single **bubble/sphere tracing is lost**. Phases are still distinct and have their own equations for the conservation of mass, momentum and energy.
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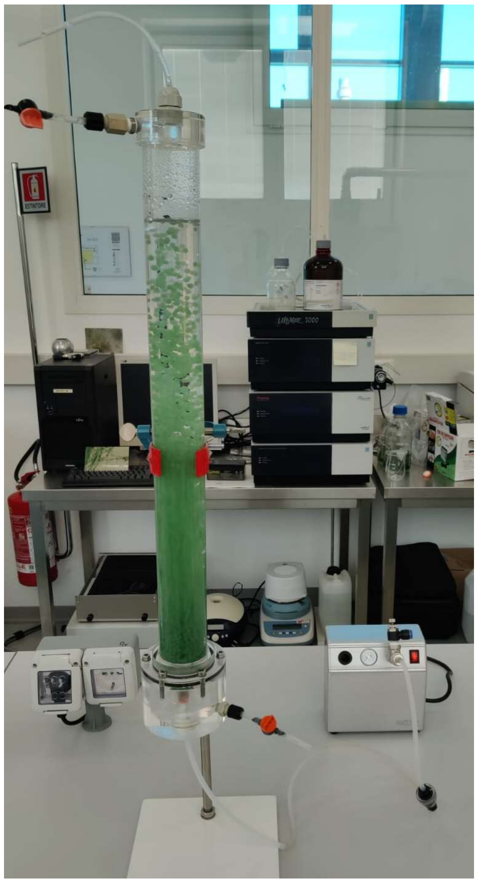
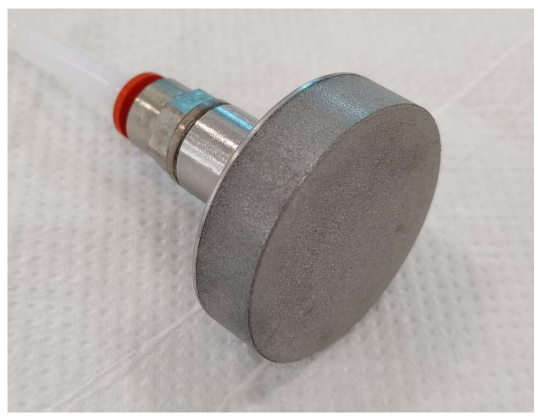
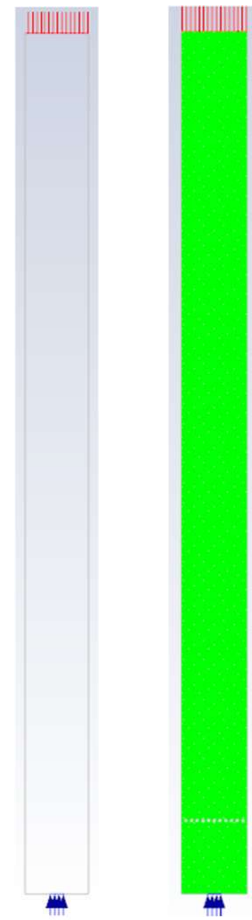
- **Test sequence** to correctly implement the three-phase problem:
  - *Inlets*
  - *Turbulence models*
  - *Solid phase dimensions*
  - *Different gravities*
  - *Particle mass density*
  - *Mesh quality*

Current results (2D)



- **Characteristics of the reactor:**
  - **Height**: *511 mm*
  - **Diameter**: *44 mm*
  - **Inlet**: *9-10 mm*
- **Gas flow rate:** *between 600 and 750 ml/min*
- **Solid phase dimension:** *5 mm*
- **Inlet pore dimension:** *20 µm*
- **Mesh quality:** *2 mm*





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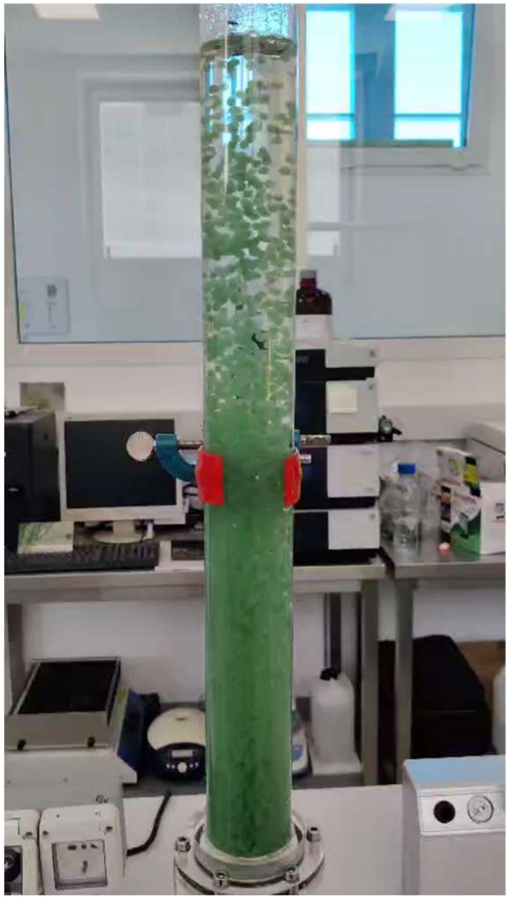
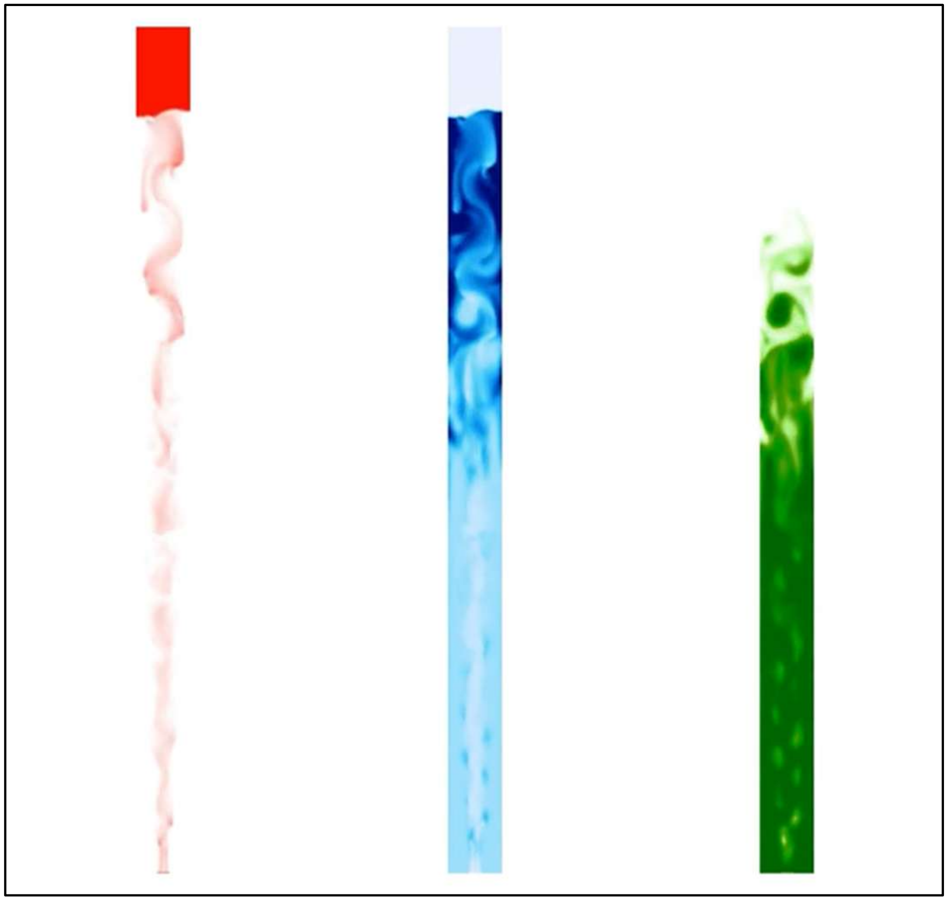
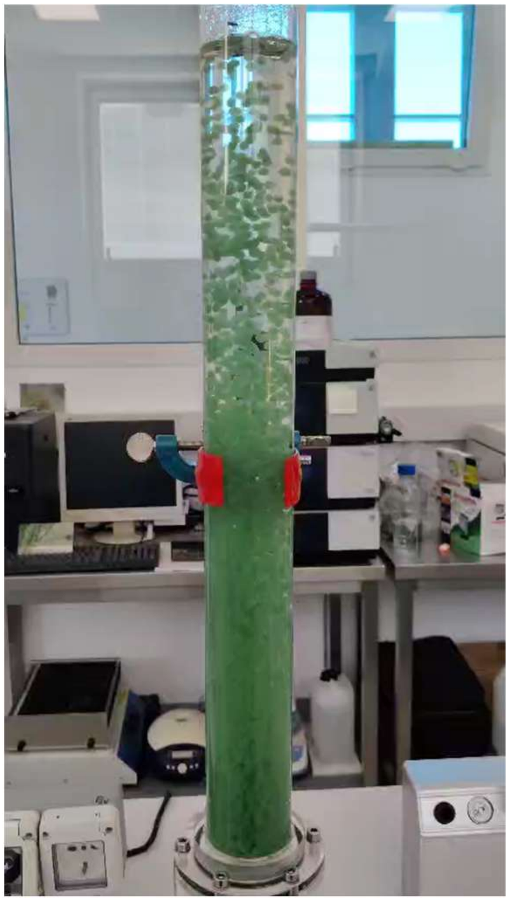
Current results (2D)

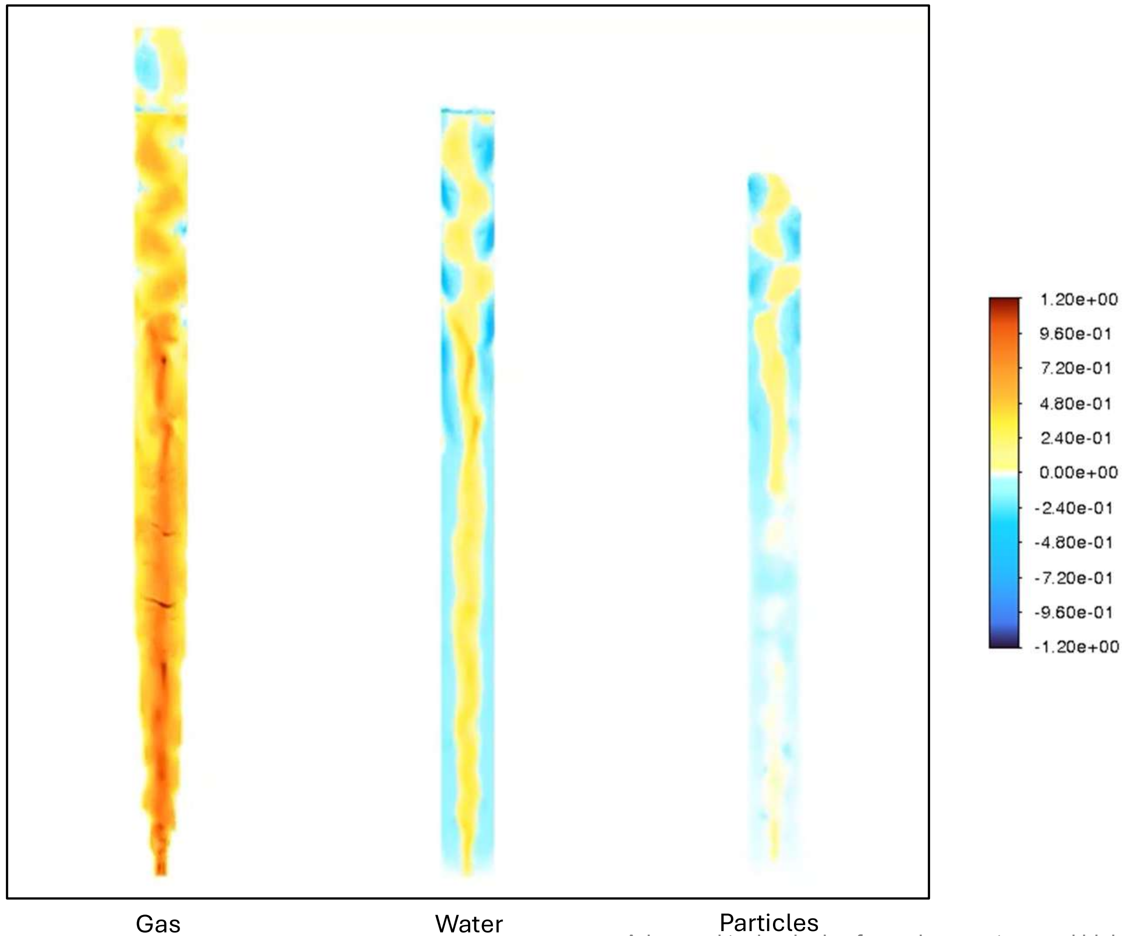




Gas Water Particles

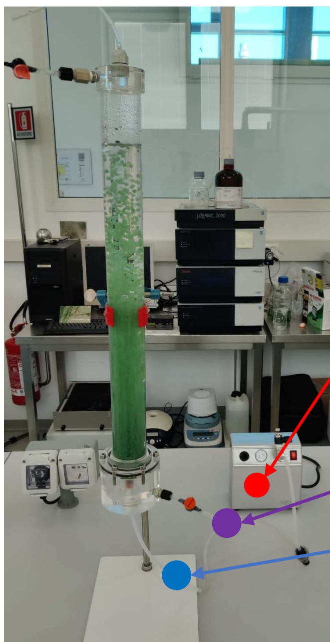
Current results (2D)





Task #2

- **Research** and **selection** of **suitable equipment**



Bioreactor needs
- 0,5 l/min minimum
- 0,5 bar minimum

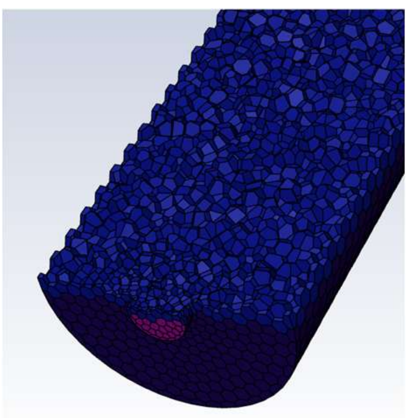
Air compressor
- Max flow rate 10 l/min
- Max pressure 5,5 bar

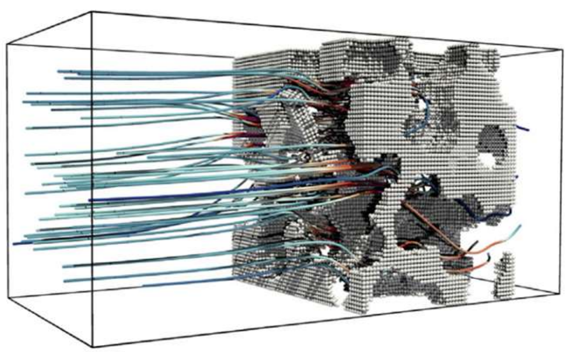
Pneumatic regulator
- Min exit pressure: 0,2 bar
- Max exit pressure: 4 bar
- Consumes around 4 l/min of air to work

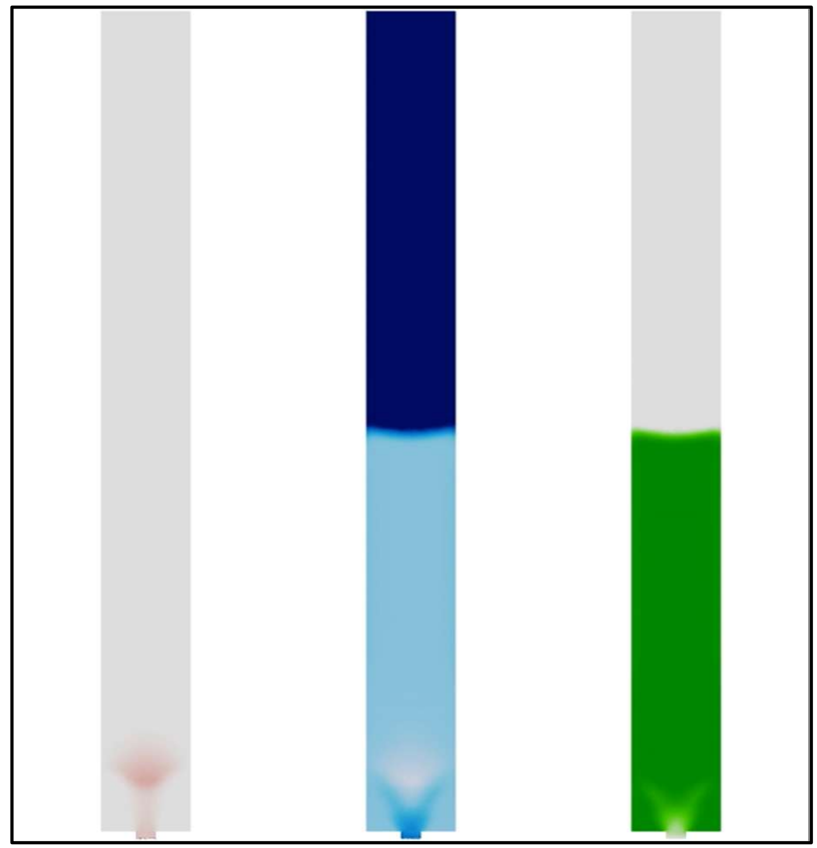
Flow rate regulator
- Max op pressure: 7,5 bar
- Flow rate: between 0.2 and 10 l/min
- Consumes around 1 l/min of air to work

Future Work

- **Data collection** with current experimental set and **comparison**
- **New experimental set up** and comparison
- **Completion of 2D versions** of all existent reactors
- Upgrade to **3D simulations**
- Reduced gravity
- Microscopic model state of the art







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GANTT Chart

WBS NUMBER	TASK TITLE	% OF TASK COMPLETE
1	BioMoon system experiments at GPLab	
1.1	GPLab acclimatisation	100%
1.2	Analysis of the state of the art	95%
1.3	Experiments with existent experiments	60%
1.4	Preparation and validation of the experimental set	25%
1.4.1	Research and selection of suitable equipment	75%
1.4.2	Validation of experimental set	0%
1.5	Data collection	0%
1.5.1	With experimental set designed by GPLab	0%
1.5.2	Testing improvements derived from simulation	0%
2	Macroscopic model development	
2.1	Analysis of the state of the art	95%
2.2	Ansys Fluent multiphase flow study	70%
2.2.1	Two Dimensional flow	90%
2.2.1.1	Bubbly flow	100%
2.2.1.1	Triphase flow	75%
2.2.2	Three Dimensional flow	25%
2.2.2.1	Bubbly flow	50%
2.2.2.2	Triphase flow	20%
2.3	Ansys Fluent model development	10%
2.3.1	Two Dimensional flow	20%
2.3.2	Three Dimensional flow	0%
2.4	Model validation	0%
2.5	Model improvements study	0%
2.5	Reduced gravity study	0%
3	Microscopic model development	
3.1	Analysis of the state of the art	0%
3.2	Model development through in-house software	0%
3.3	Model validation	0%
3.4	Reduced gravity study	0%
4	Writing thesis and reports	
4.1	Reports for admission to the next year or conferences	33%
4.2	Educational activities	80%
4.3	Writing thesis	0%

Thanks for the attention

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