In Vitro Magnetic Capsule Swimmer: Targeted Heating for Cancer Hyperthermia

Angela Mary Rajesh, Yamile Matus Gonzalez, Razan K. Yousef, Michael I. Adikaibe, Cullen College of Engineering
Faculty Advisor: Dr. Aaron T. Becker, Department of Electrical & Computer Engineering

Objective

Analyze heat distribution in magnetically actuated swimmer tips within biological-like environments by comparing geometries under constant volume conditions.

Background

- **Problem:** Cancer remains one of the leading causes of death worldwide, with cases projected to reach approximately 33 million annually by 2050.
- **Current methods:** Hyperthermia is a promising strategy to treat cancer; however traditional hyperthermia delivery methods often face limitations such as non-uniform heating, poor temperature control, damage to surrounding healthy tissue, and reliance on invasive catheter-based approaches.
- **Proposed solution:** Analyze heat transfer in untethered, magnetically actuated Miniature Magnetic Rotating Swimmers (MMRSs) by comparing different iron tip geometries to evaluate temperature distribution.

Methods

- Finite Element Method Magnetics (FEMM) was used to compute power dissipation (P) for each tip geometry.
- A volumetric heat source 'Q' was calculated using P and constant volume V=20.35 mm³: Q=P/V and implemented in COMSOL Multiphysics to simulate heat transfer under varying geometries and boundary conditions, including fluid surroundings, tissue-like domains, and insulated configurations.
- Preliminary work explored FEMM–OpenFOAM coupling via Python scripting for fully coupled multiphysics simulations:

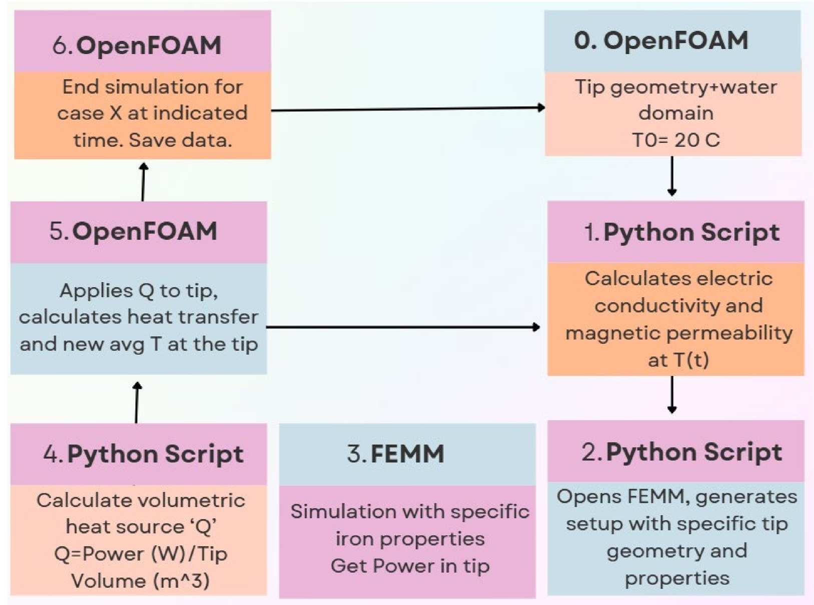

Figure 1. OpenFOAM flowchart

Results

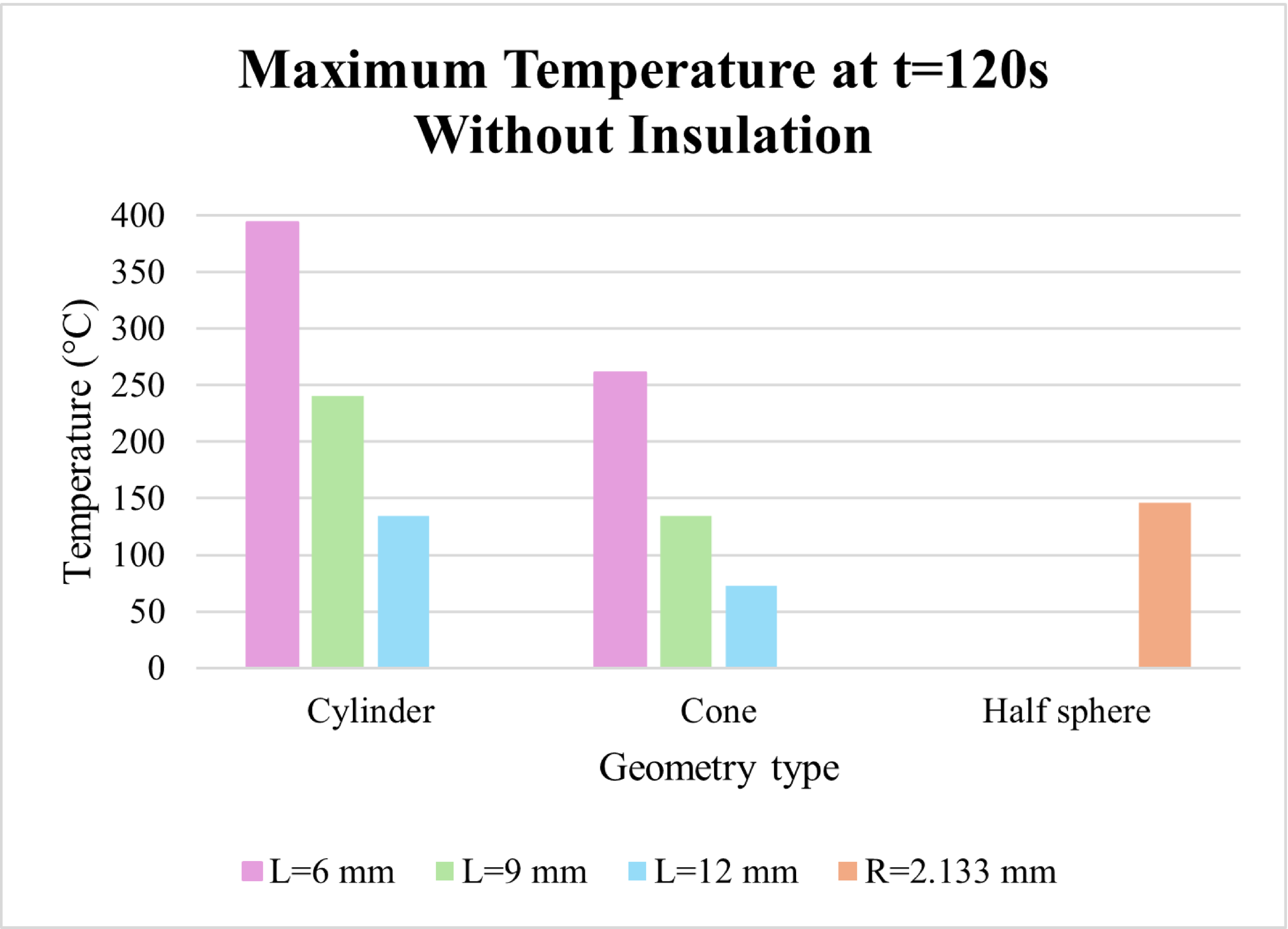

Figure 2. Maximum temperature comparison for different geometries and dimensions keeping constant volume V=20.35 mm³.

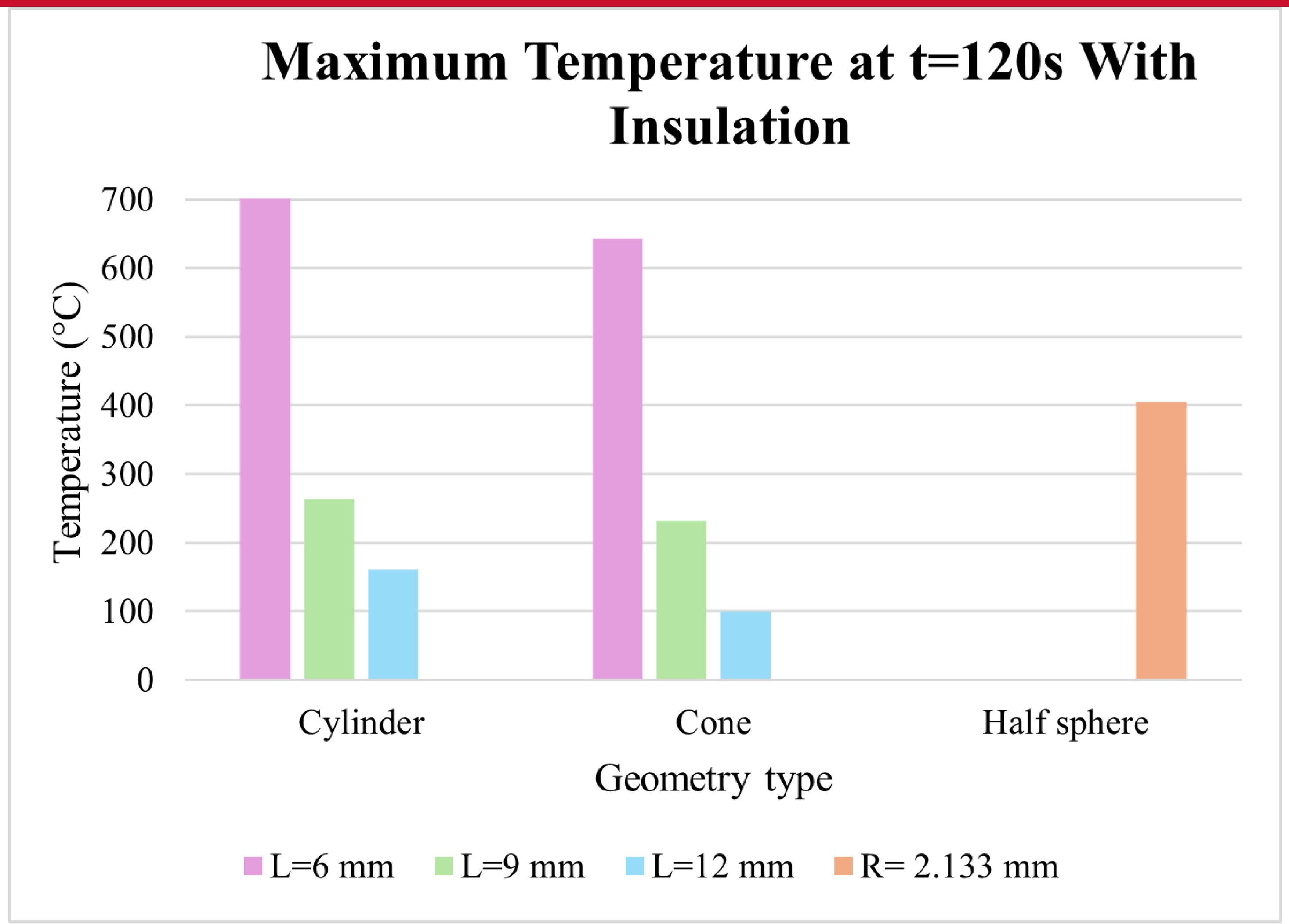

Figure 3. Maximum temperature comparison for different geometries and dimensions keeping constant volume V=20.35 mm³ and using an insulator around the tip.

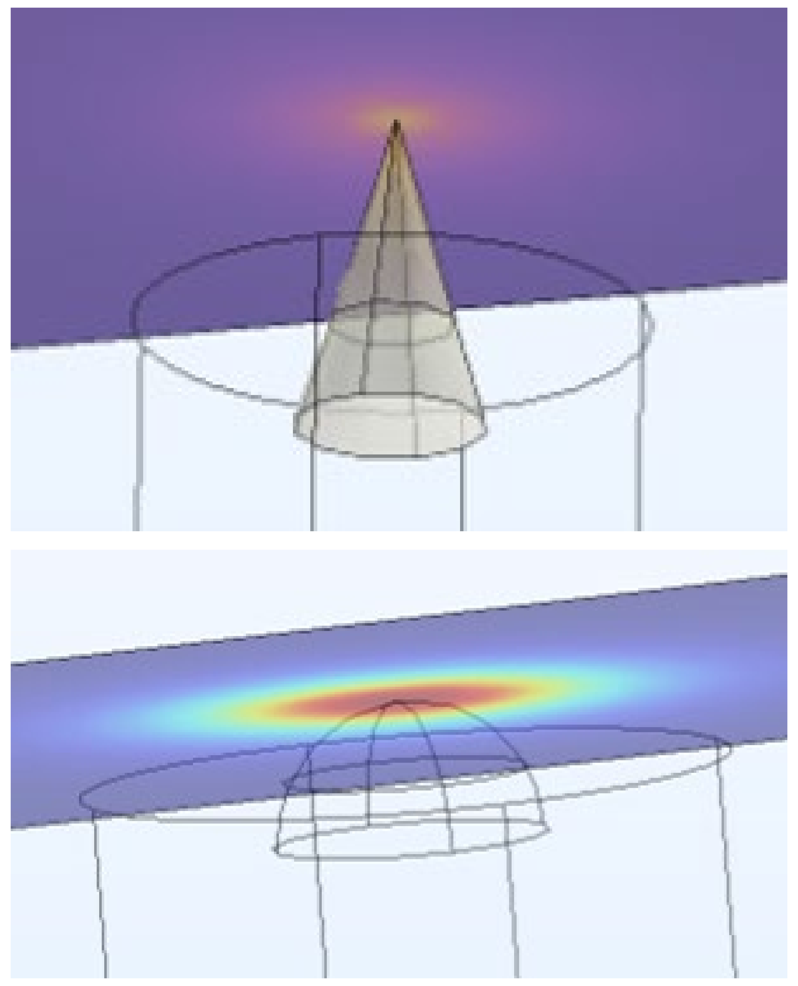

Figure 4. Heat transfer simulation example of a conical and half spherical iron tip in contact with domain modeled as flesh.

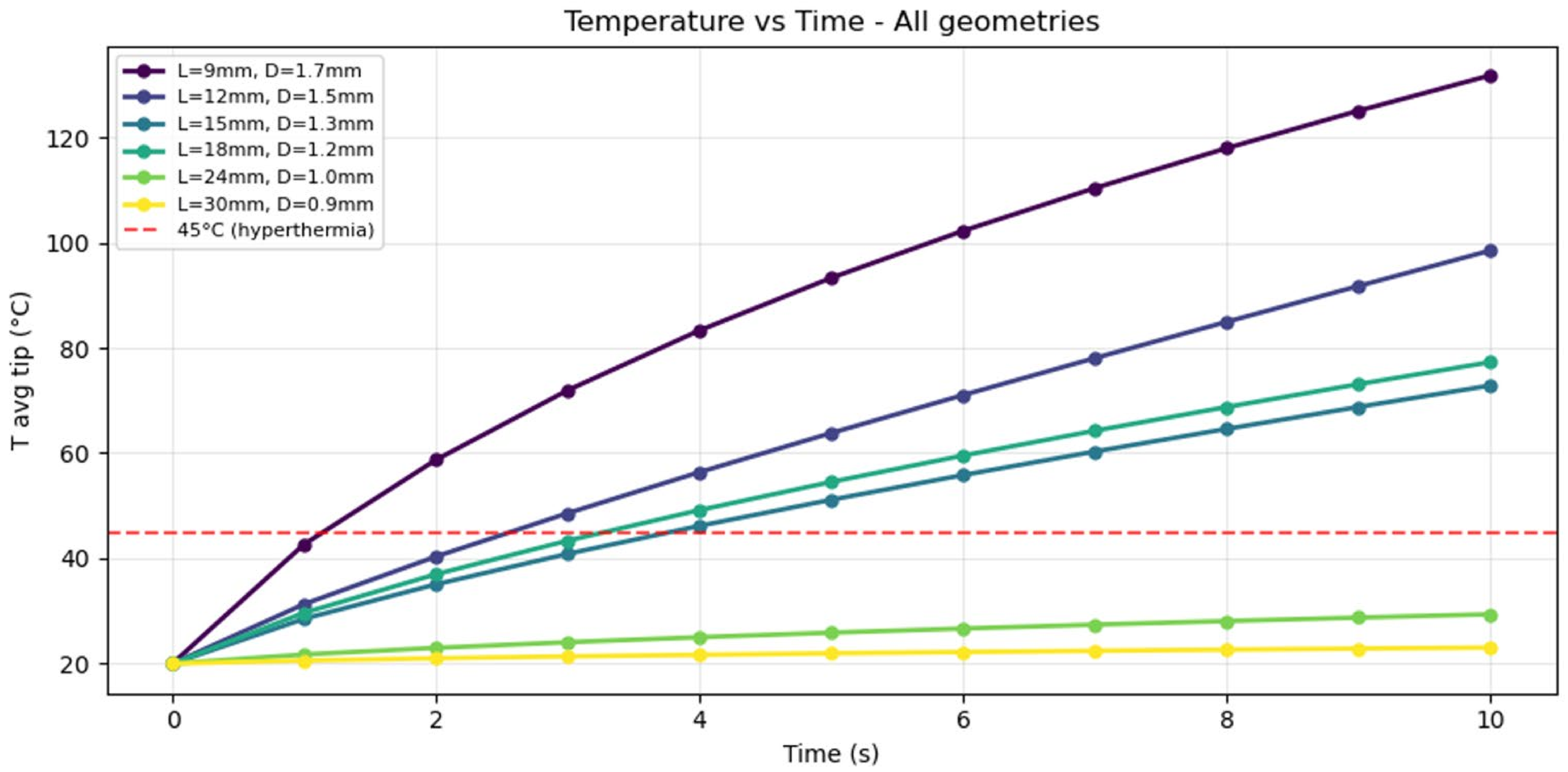

Figure 5. Preliminary Temperature vs. Time results for different lengths of a cylindrical tip using FEMM–OpenFOAM coupling via Python scripting.

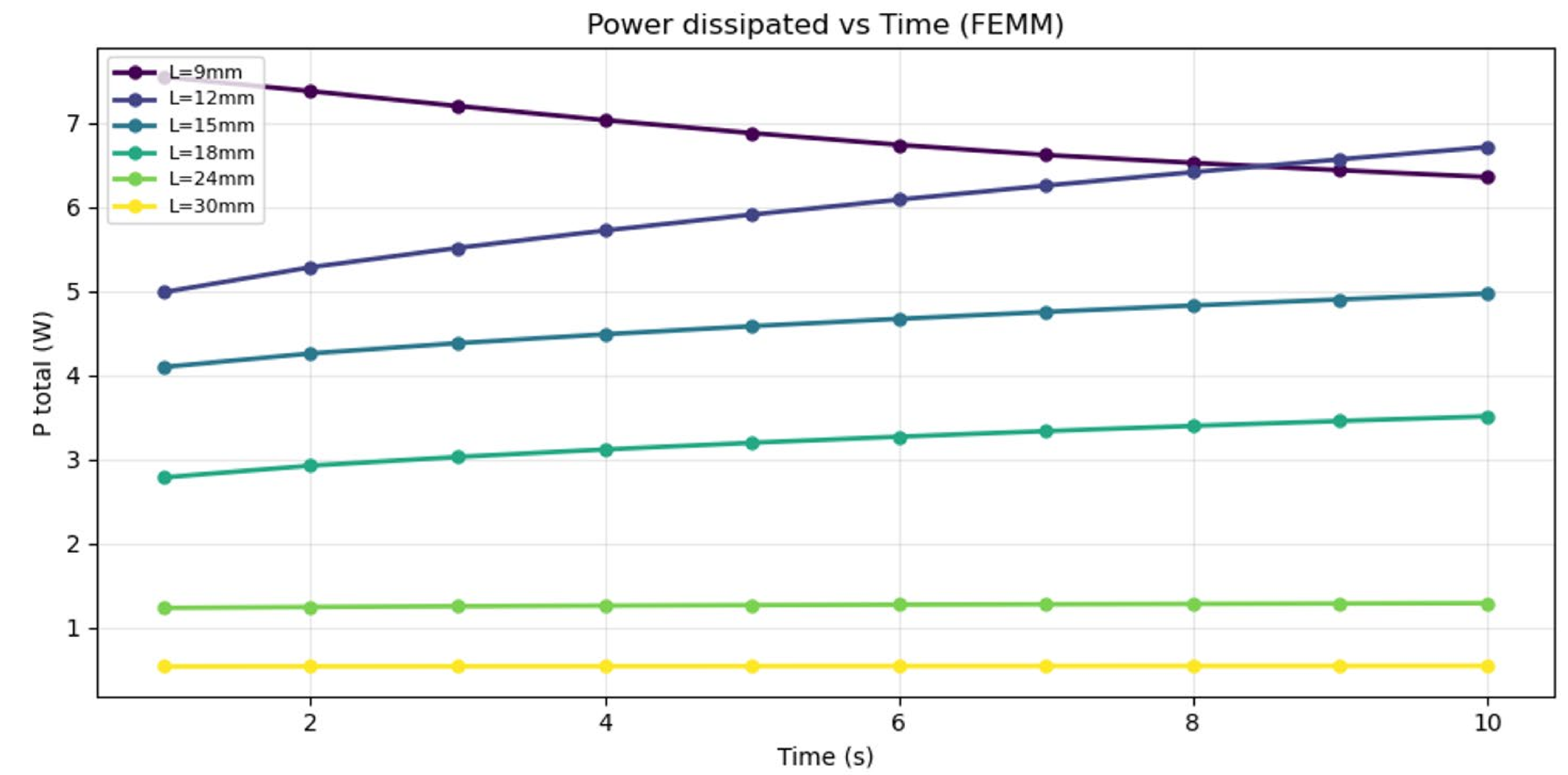

Figure 6. Preliminary Power vs. Time results for different lengths of a cylindrical tip using FEMM–OpenFOAM coupling via Python scripting.

Conclusion

- A COMSOL Multiphysics thermal model was costumized to simulate heat generation in MMRSs tip geometries using FEMM-derived power values.
- Results demonstrate that geometry and boundary conditions strongly influence temperature distribution under constant volume.
- This framework enables informed design choices for safer and more effective thermal actuation and can be used as a base to design more complex geometries.
- In progress and future work: Fully coupled FEMM–OpenFOAM simulations for integrated multiphysics analysis.

References

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