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TPMS Hydraulic Performance - Experiment and CFD

August 2024

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Changing the World's Energy Future

Idaho National Laboratory

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TPMS Hydraulic Performance - Experiment and CFD

Benchmarking Triply Periodic Minimal Surface (TPMS) lattices with CFD

Intern: Brett Prussack
Mentor: Austen Fradeneck
University: University of Wisconsin - Madison

Motivation

- **Nuclear fuel is traditionally confined to plates, cylinders, and spheres**
  - Easily manufacturable
  - Not ideal for heat removal
- **Advanced manufacturing allows complex, bio-inspired geometries to be studied in the context of nuclear fuel**
  - Triply periodic minimal surfaces (TPMS)
  - High surface area–volume ratio
- **Validation between experiments and models are critical**

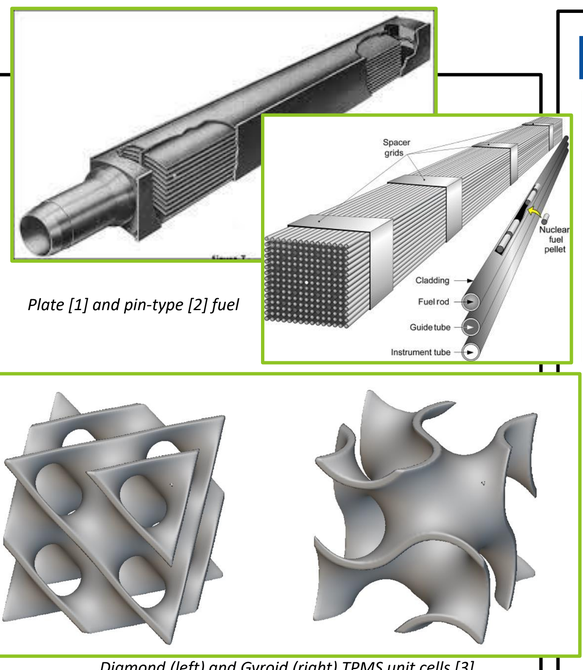


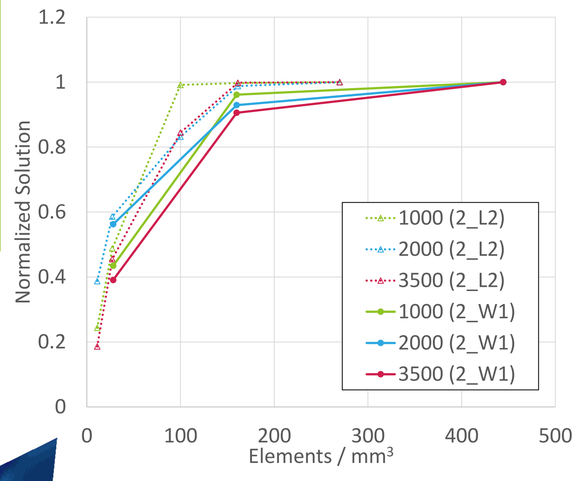
Plate [1] and pin-type [2] fuel

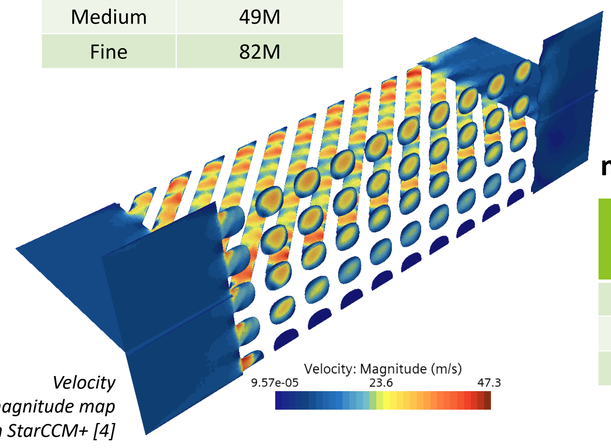
Diamond (left) and Gyroid (right) TPMS unit cells [3]

Meshing / Grid Convergence

Three meshes studied to confirm grid independence

Mesh	Elements
Coarse	1.5 M
Medium	49M
Fine	82M





Velocity magnitude map from StarCCM+ [4]

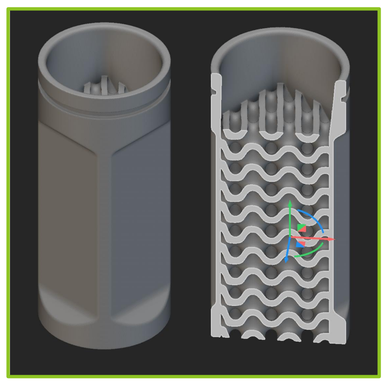
Grid independence obtained for meshes with 150-200 elements / mm³

Reynolds Number	Uncertainty (psi)	Uncertainty (%)
1000	0.00043	**0.03**
2000	0.002	**0.052**
3500	0.01	**0.26**

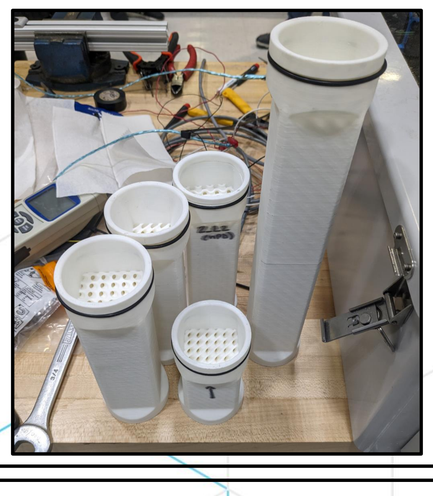
Experiment Design and Goals

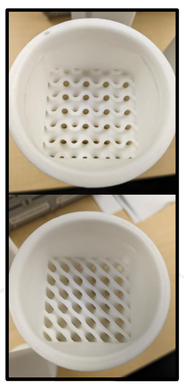
- Target several key behaviors relevant to reactor core designers:

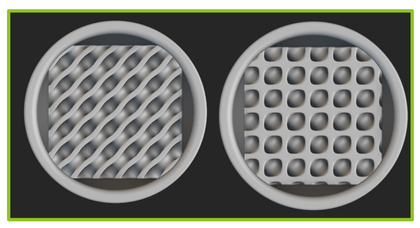
1. Length effect
2. Unit cell effect
3. Bypass effect
4. Wall effect
5. Tortuosity Effect
6. Truncation Effect
7. Rotation effect

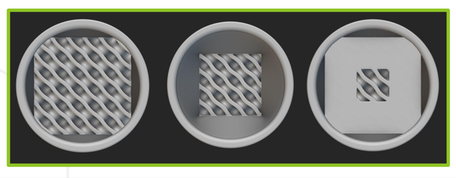


9 TPMS lattices were printed, tested, and simulated in StarCCM+ [4]



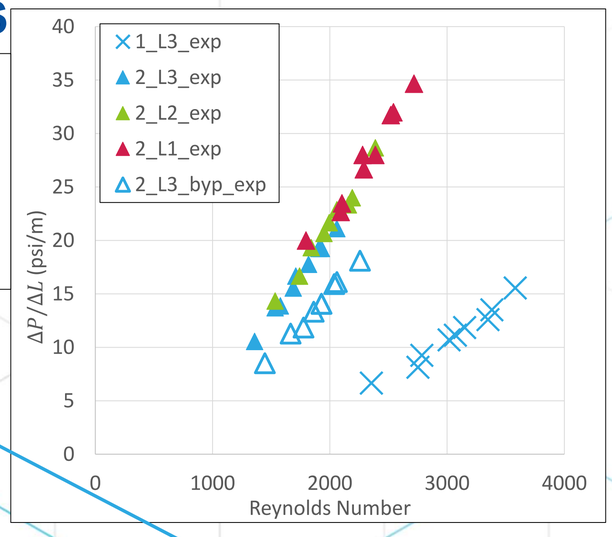


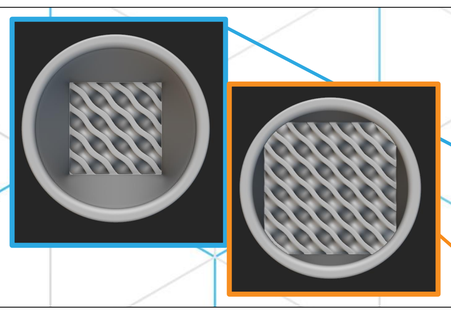




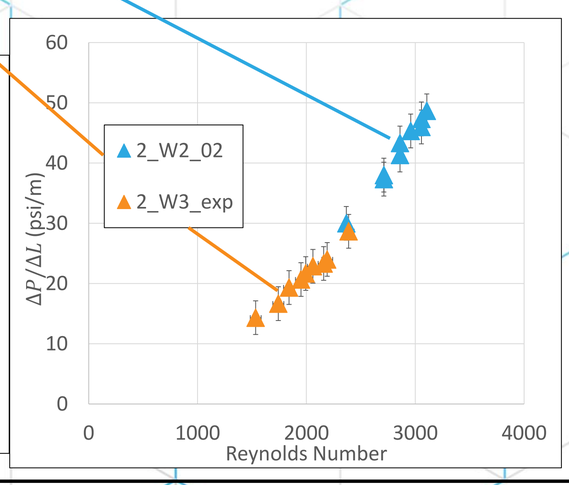
Experimental Results

1 . Length Effect:
ΔP scales linearly with length beyond 5UC
2. Unit Cell Effect:
Different unit cells do not collapse w/ Reynolds #
3. Bypass effect:
1mm bypass results in 25% reduction in ΔP





4 . Wall effect:
Wall friction effect is not significant beyond 2UC in width
5. Tortuosity effect:
Axial stretching along the flow direction by 2x reduces ΔP by 6x
6. Rotation effect:
A 45 rotation off the principal axis results in a 30-40% increase in ΔP
7. Truncation effect:
Entrance and exit effects are independent of the inlet geometry



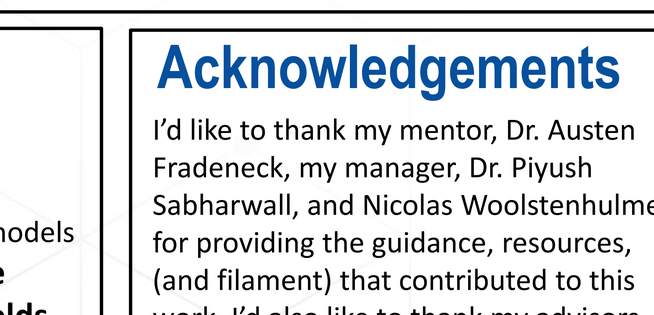
Experiment / Simulation Agreement

- **Experiment and simulation have ≥ 50% error**

Simulation trends that agree with experiments:
- Linear length scaling
- Wall effect
- Unit cell effect
- Bypass effect
- Truncation effect
- Tortuosity effect

Simulation trends that disagree with experiment:
- Rotation

Troubleshooting Steps:
1. ~~Grid convergence~~
2. ~~Turbulence models~~
3. ~~Fluid properties~~
4. **Experiment error**
5. **Simulation error**



Future Work

- **Improve agreement between experiment and CFD**
  - Explore turbulence models
- **Determine mesh convergence requirements at higher Reynolds numbers**
- **Develop larger test loop for wider range of data**
- **Develop porous media model to reduce computational requirements**

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[1] Myerscough, P. B., and I. G. Crossland. *Nuclear Power Generation*. Pergamon Press, 1992.
[2] "Nuclear Fuel." Nuclear @ McMaster, 28 Feb. 2023, nuclear.mcmaster.ca/resources/how-does-it-work-2/nuclear-fuel/.
[3] nTop, Release 4.24.3, nTop Inc., https://ntop.com
[4] Siemens Industries Digital Software. Simcenter STAR-CCM+, version 2024.02, Siemens 2024.