Harnessing Ocean Thermal Gradients Using Thermoelectric Based Submersibles for Ocean Power Applications

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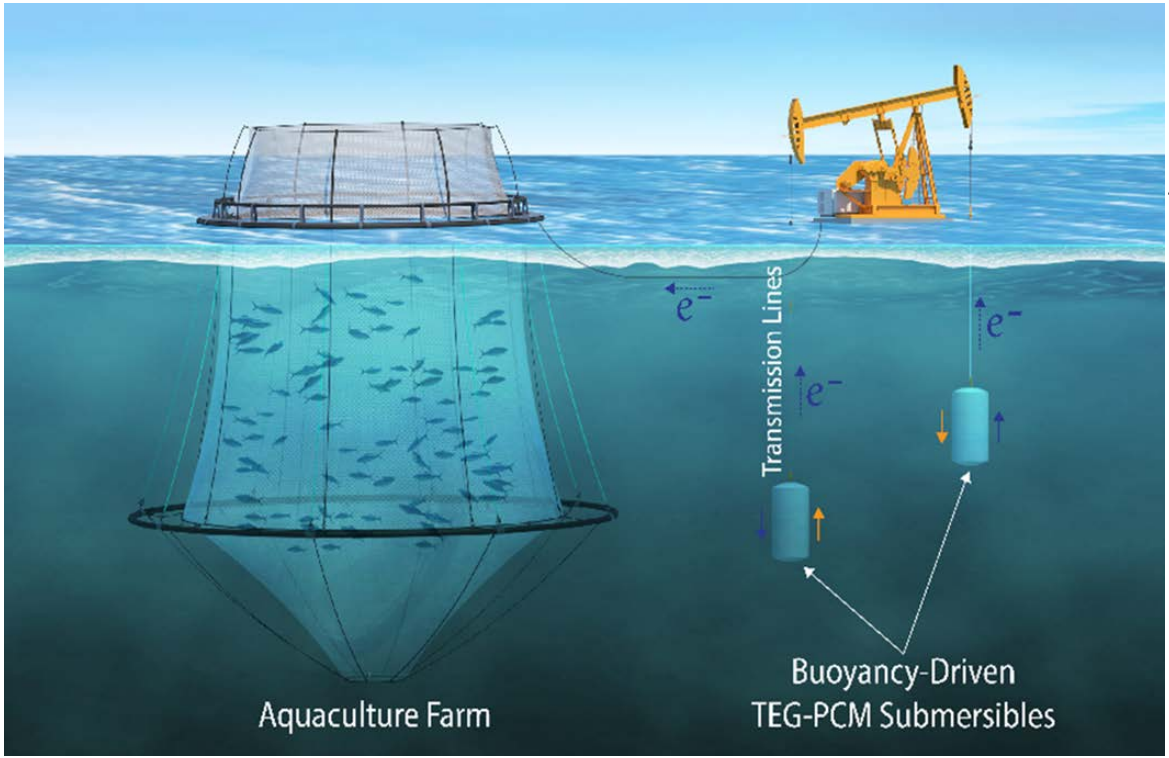
WATER POWER TECHNOLOGIES OFFICE

Photo by Josh Bauer, NREL 61725

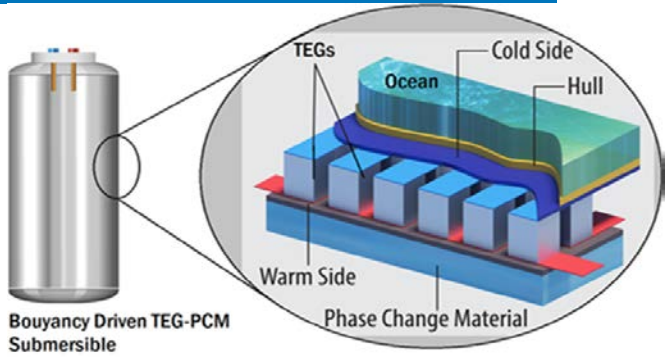
This presentation was produced when the laboratory operated as the National Renewable Energy Laboratory (NREL). The laboratory is now the National Laboratory of the Rockies (NLR).

Contents

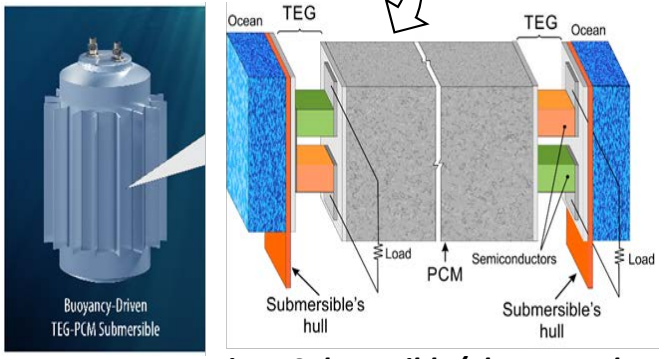
Concept



Concept



Buoyancy Driven Submersible/Thermopod

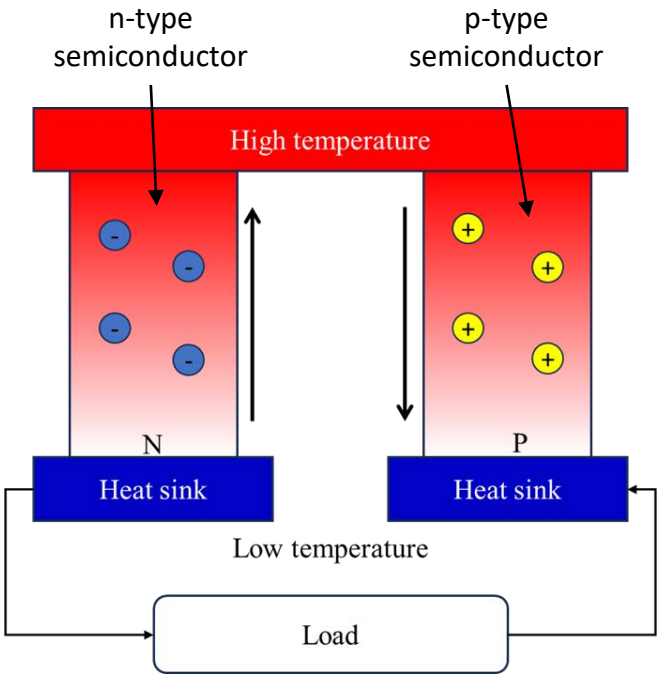


Buoyancy Driven Submersible/Thermopod

Patent submitted: PCT/US25/26372

Introduction

- TEGs is a solid-state device that converts the heat flux directly into the electrical energy (i.e., called as Seebeck effect).
- A thermoelectric module is a circuit containing dissimilar thermoelectric materials (semiconductors) joined at their ends & these semiconductors are:
  - n-type semiconductors (negative charge carrier)
  - p-type semiconductors (positive charge carrier)



Working Principle of TEGs

Performance Evaluation of TEGs

Figure of Merit (zT):

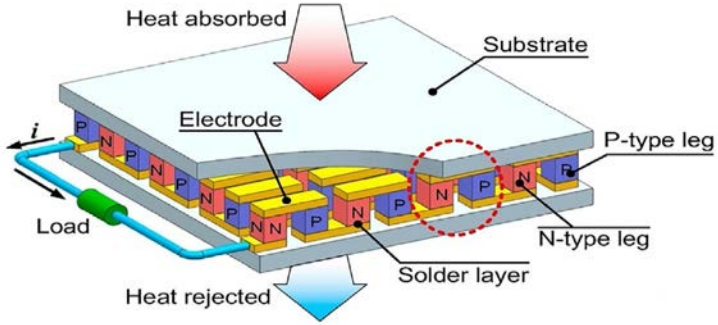
$$zT = \frac{S^2 \sigma \bar{T}}{k}$$

σ: electrical conductivity
k: thermal conductivity
$\bar{T}$: average temperature

Seebeck coefficient (S):

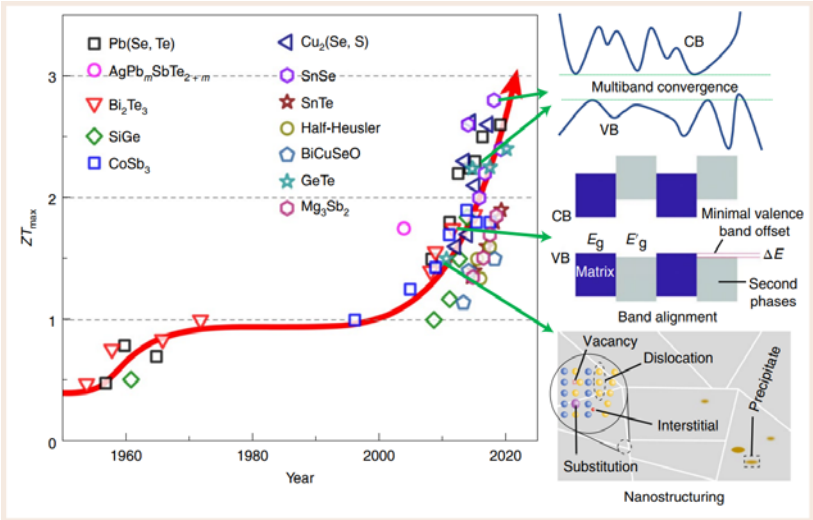
$$S = -\frac{\Delta V}{\Delta T}$$

ΔV: electric potential
ΔT: temperature difference



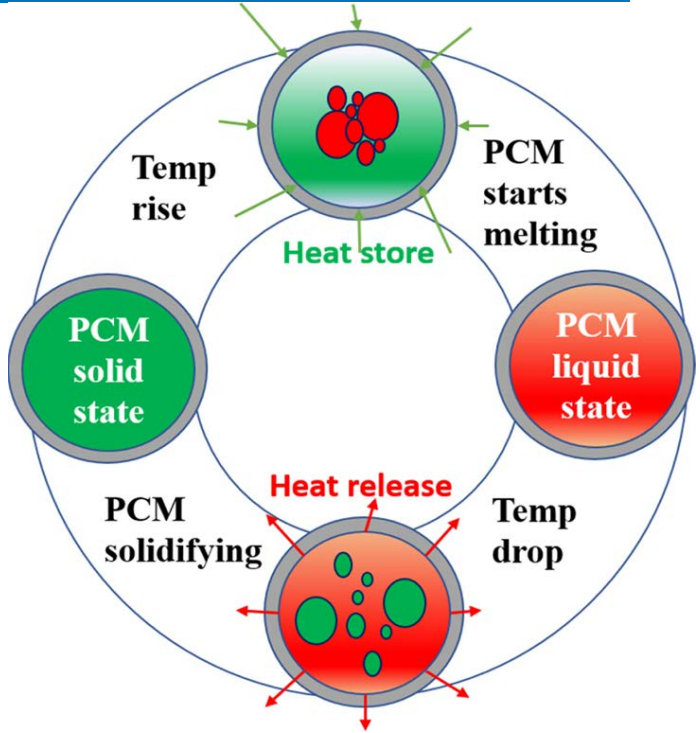
Thermoelectric generator [1]

Value of zT with time (with advancement of nanoparticles) [2]



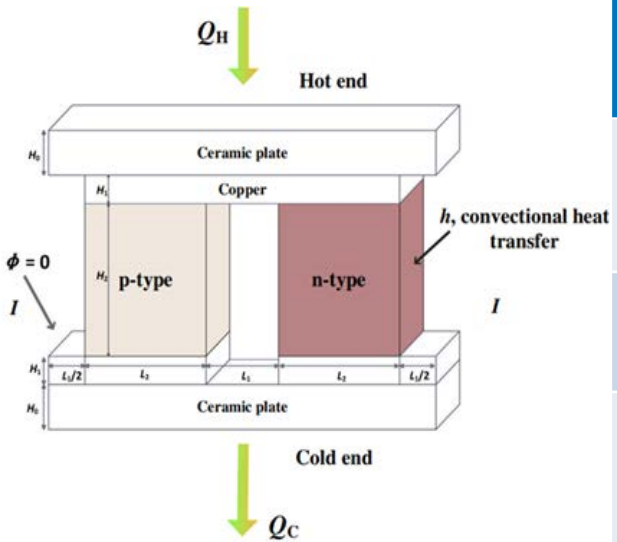
Phase Change Material (PCM)

- Phase Change Material (PCM) is a substance that absorbs and releases thermal energy during phase transitions, typically from solid to liquid and vice versa.
- These materials are widely used for thermal energy storage (TES) applications due to their ability to store and release large amounts of latent heat at a nearly constant temperature.
- There are three types of PCMs:
  - Organic PCM
  - Inorganic PCM
  - Eutectic PCM



Melting & Solidification Process [3]

Selection of TEGs & PCM



Schematic of TEG

Selected TEGs - Bi_2Te_3

Parameters	Semiconductor		Connector (Cu)	Ceramic plate
	Constant Property	Variable Property		
k $(WK^{-1}m^{-1})$	$k_p = k_n$ 1.54	$k_p = k_n$ $0.000029T^2 - 0.019593T + 4.809677$	350	130
ρ $(\Omega\ m)$	$\rho_p = \rho_n$ 1.03×10^{-5}	$\rho_p = \rho_n$ $10^{-6}(0.043542T - 2.754139)$	1.695×10^{-9}	-
α $(V\ K^{-1})$	$\alpha_p = \alpha_n$ 2.0×10^{-5}	$\alpha_p = \alpha_n$ $10^{-6}(-0.002025T^2 + 1.423448T - 44.953611)$	6.5×10^{-6}	-

Thermophysical Properties of Bismuth Telluride (Bi_2Te_3)

Cont..

S. No.	PCMs	Melting Point (℃) (Solid/Liquid)	Latent Heat (kJ/kg)	Thermal Conductivity (W/m.K) (Solid/liquid)	Specific Heat (kJ/kg K) (Solid/liquid)	Density (kg/m³) (Solid/Liquid)
(Summer Season)						
1.	PureTemp 18	16/18	192	0.25/0.15	1.47/1.74	950/860
2.	PureTemp 20	18/20	171	0.23/0.14	2.07/2.15	950/860
3.	PureTemp 23	21/23	201	0.25/0.15	1.84/1.99	910/830
4.	CrodaTherm 19	18/19	175	0.23/0.16	2.5/1.8	911/850
5.	CrodaTherm 21	19/21	190	0.18/0.15	2.3/1.9	891/850
6.	CrodaTherm 24	22/24	184	0.22/0.16	3.7/2.2	906/843
7.	RT 18 HC	16/18	260	0.2/0.2	2	880/770
8.	RT 21 HC	19/21	190	0.2/0.2	2	880/770
9.	RT 22 HC	20/22	190	0.2/0.2	2	760/700
10.	RT 24 HC	22/24	200	0.2/0.2	2	800/700

Selected PCMs

Validation

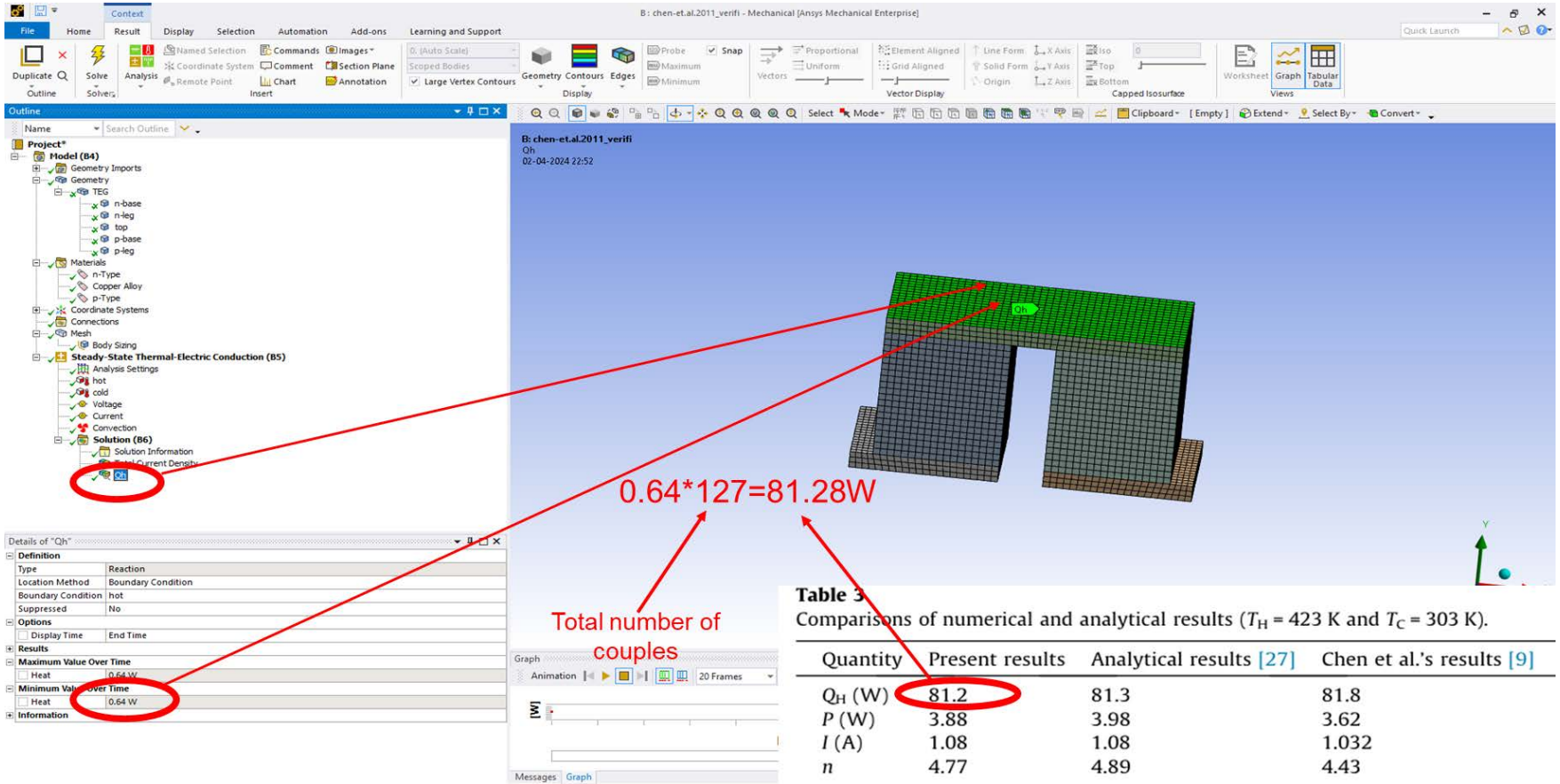
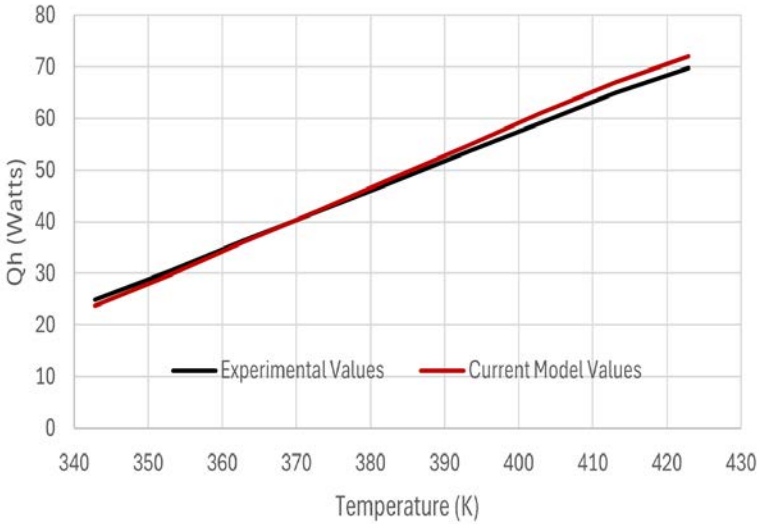
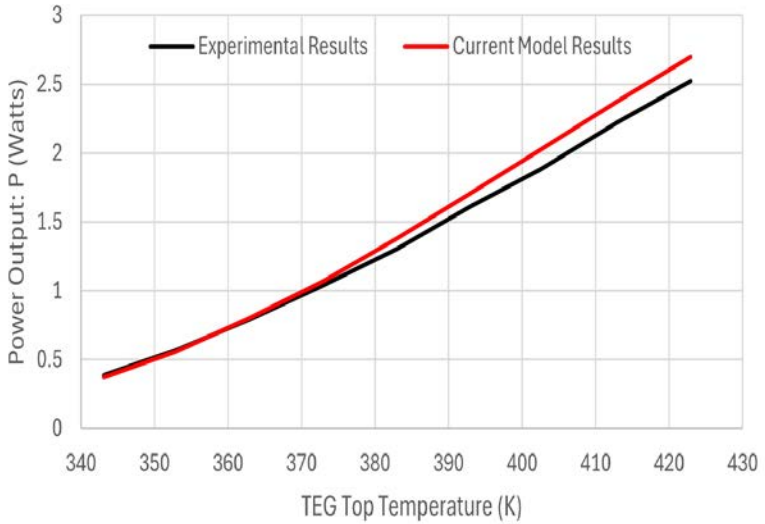


Table 3
Comparisons of numerical and analytical results (T_H = 423 K and T_C = 303 K).

Quantity	Present results	Analytical results [27]	Chen et al.'s results [9]
Q_H (W)	81.2	81.3	81.8
P (W)	3.88	3.98	3.62
I (A)	1.08	1.08	1.032
n	4.77	4.89	4.43

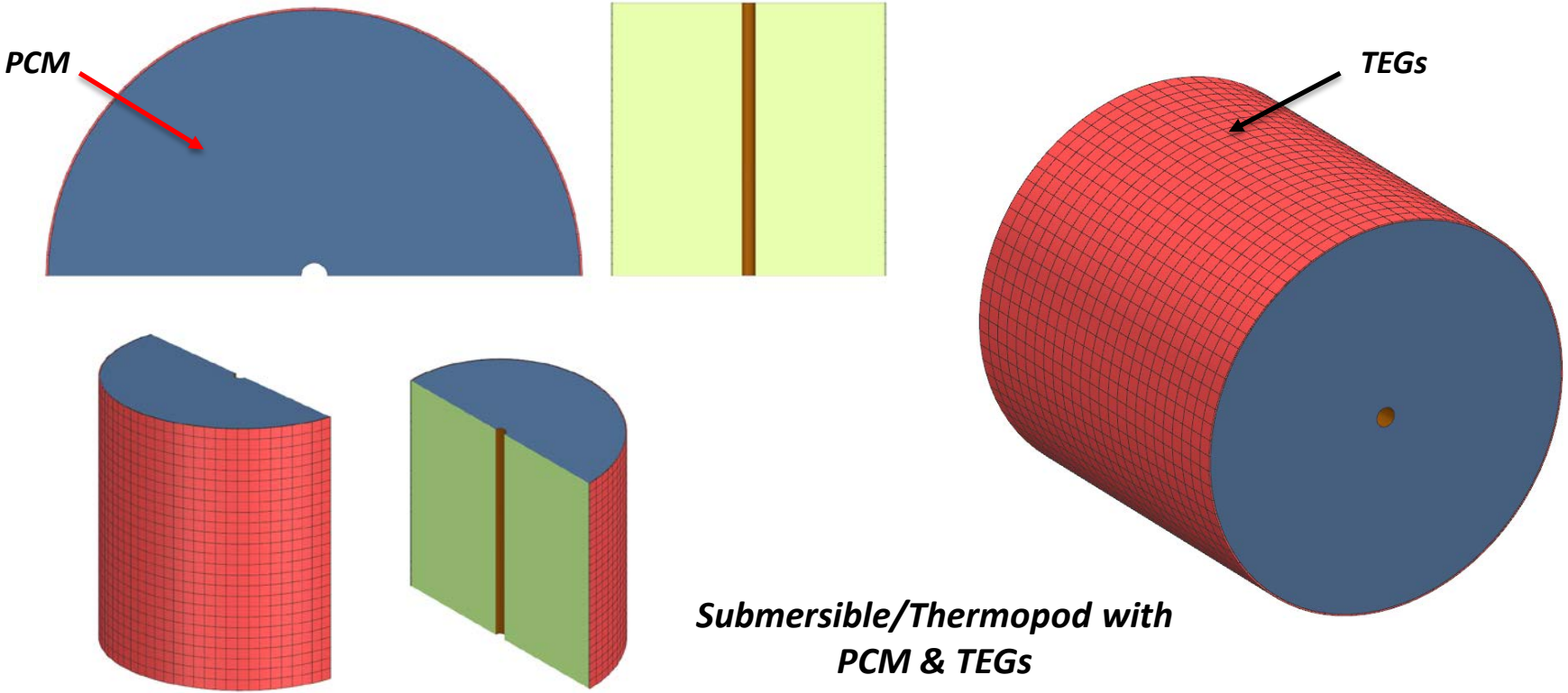
Cont..





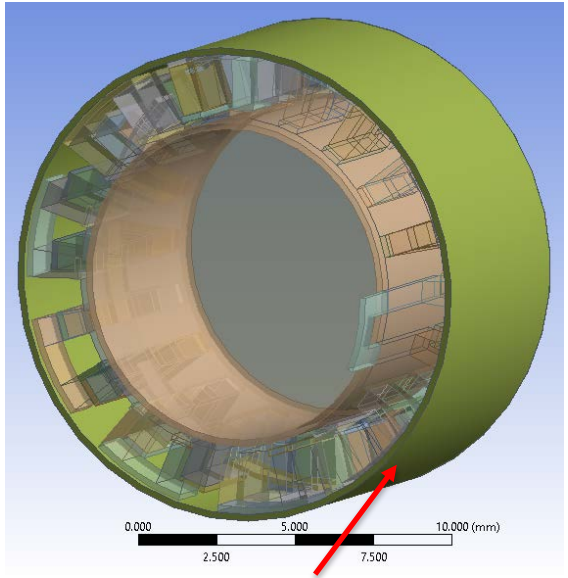
- Heat transfer from the heat source to the hot junction and power generation for a single thermoelectric device.
- Maximum relative error of 7.48% at 422 K

Modeling of Submersible/Thermopod

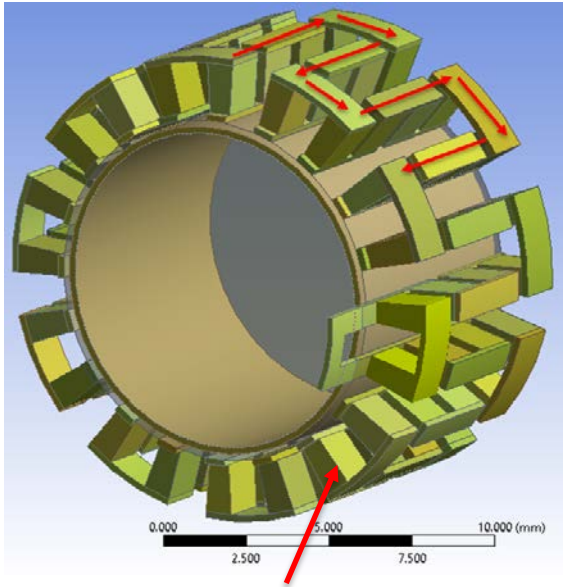


Submersible/Thermopod with PCM & TEGs

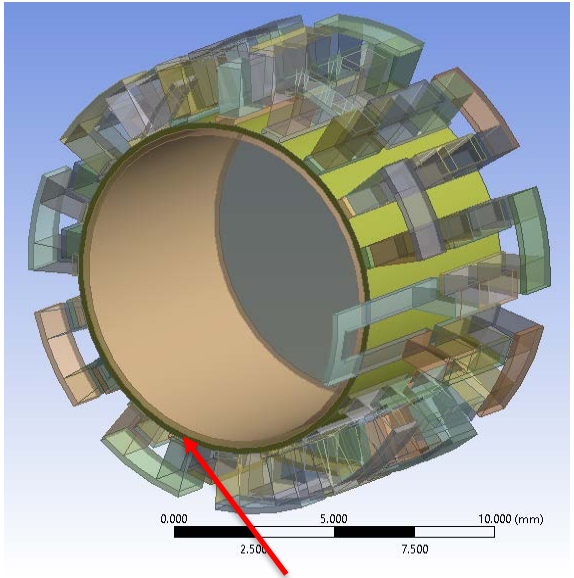
Cont..



Ceramic outer layer

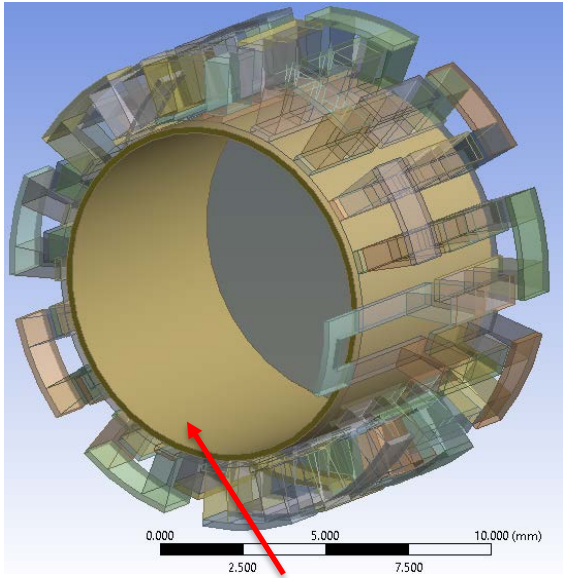


TEGs Couples

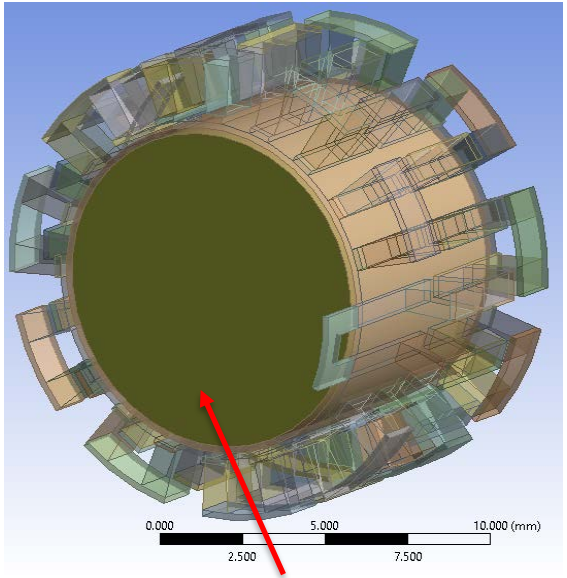


TEGs Couples

Cont..

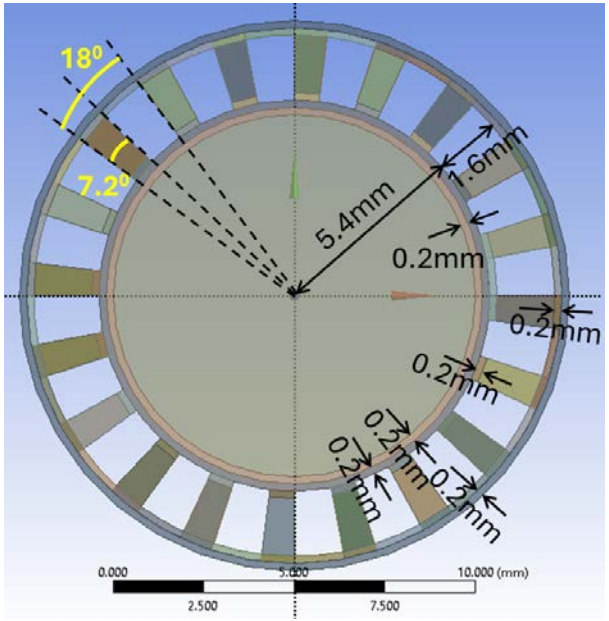


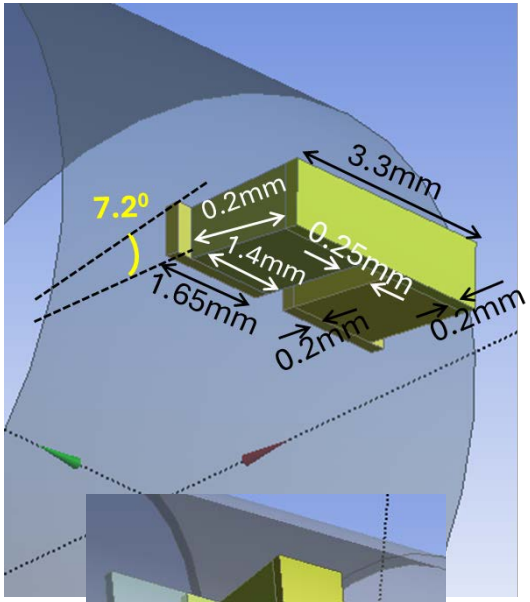
Copper Cylinder

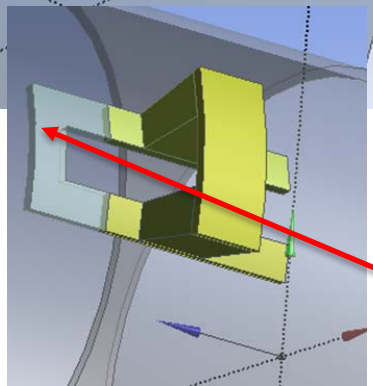


PCM

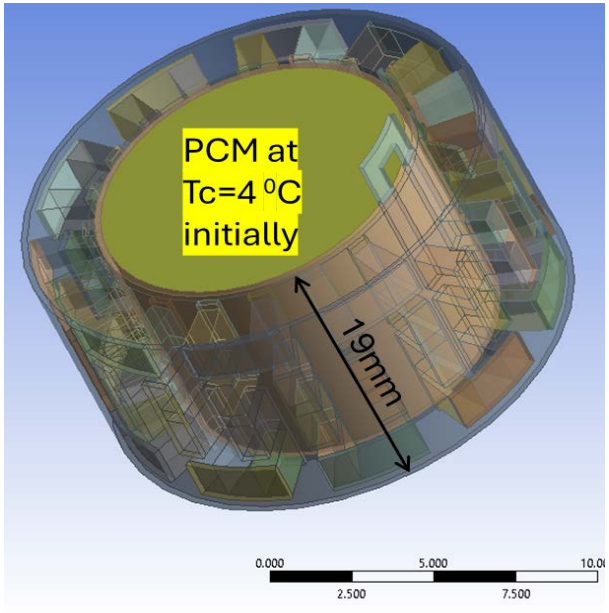
Geometrical Details



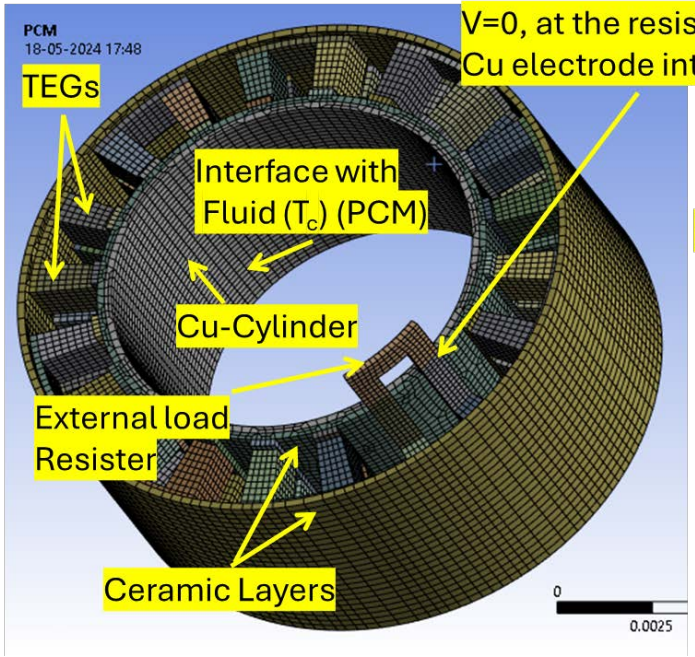




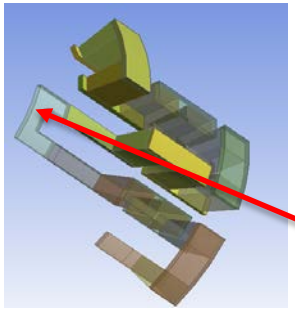
External Resistor/Load

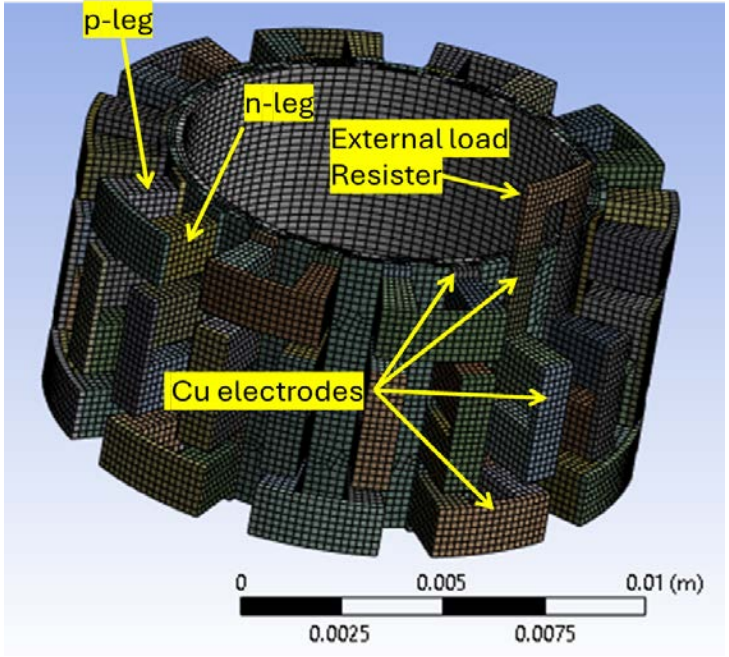


Meshing & Boundary Conditions



Hot wall T_h=25 ^{0}C

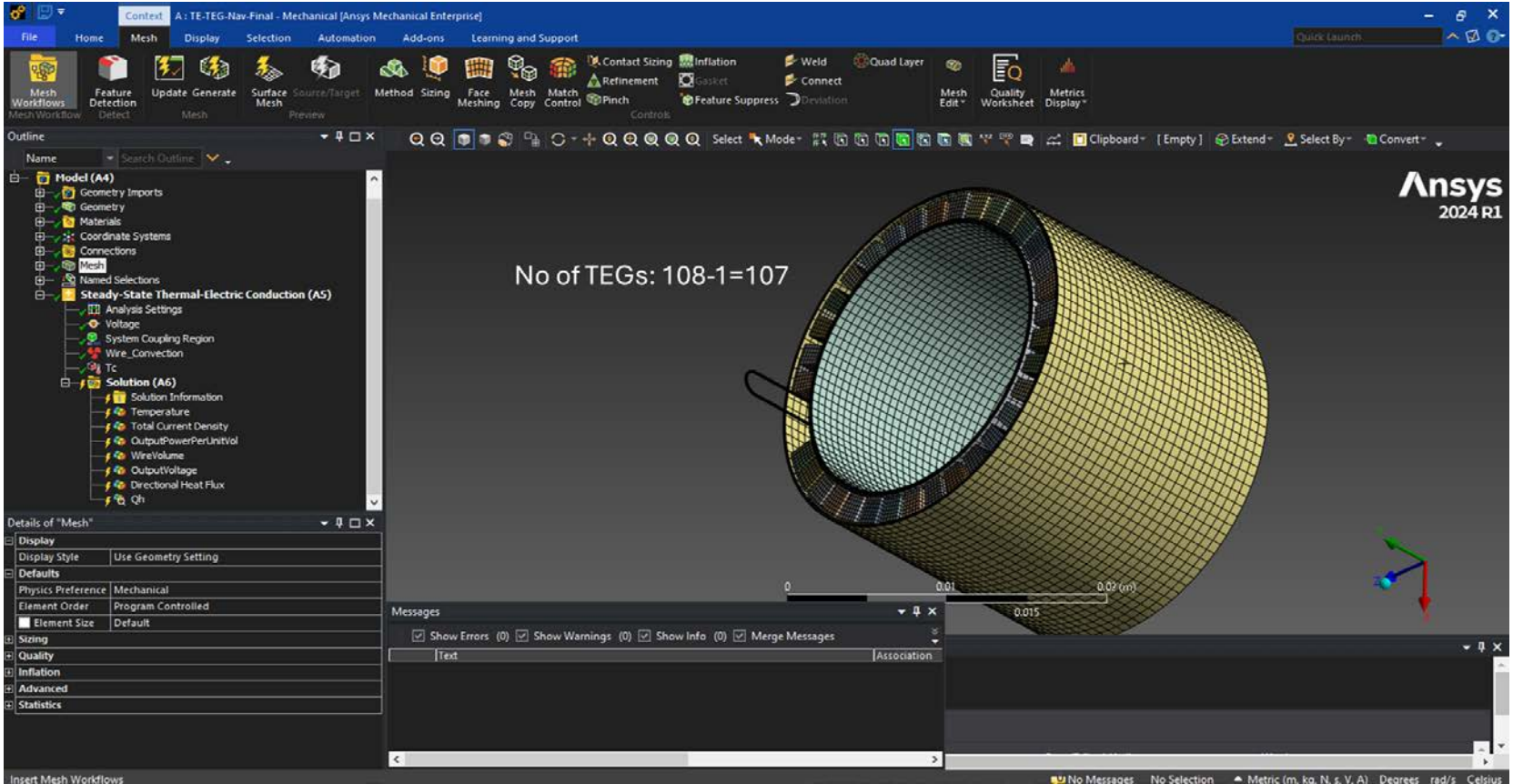




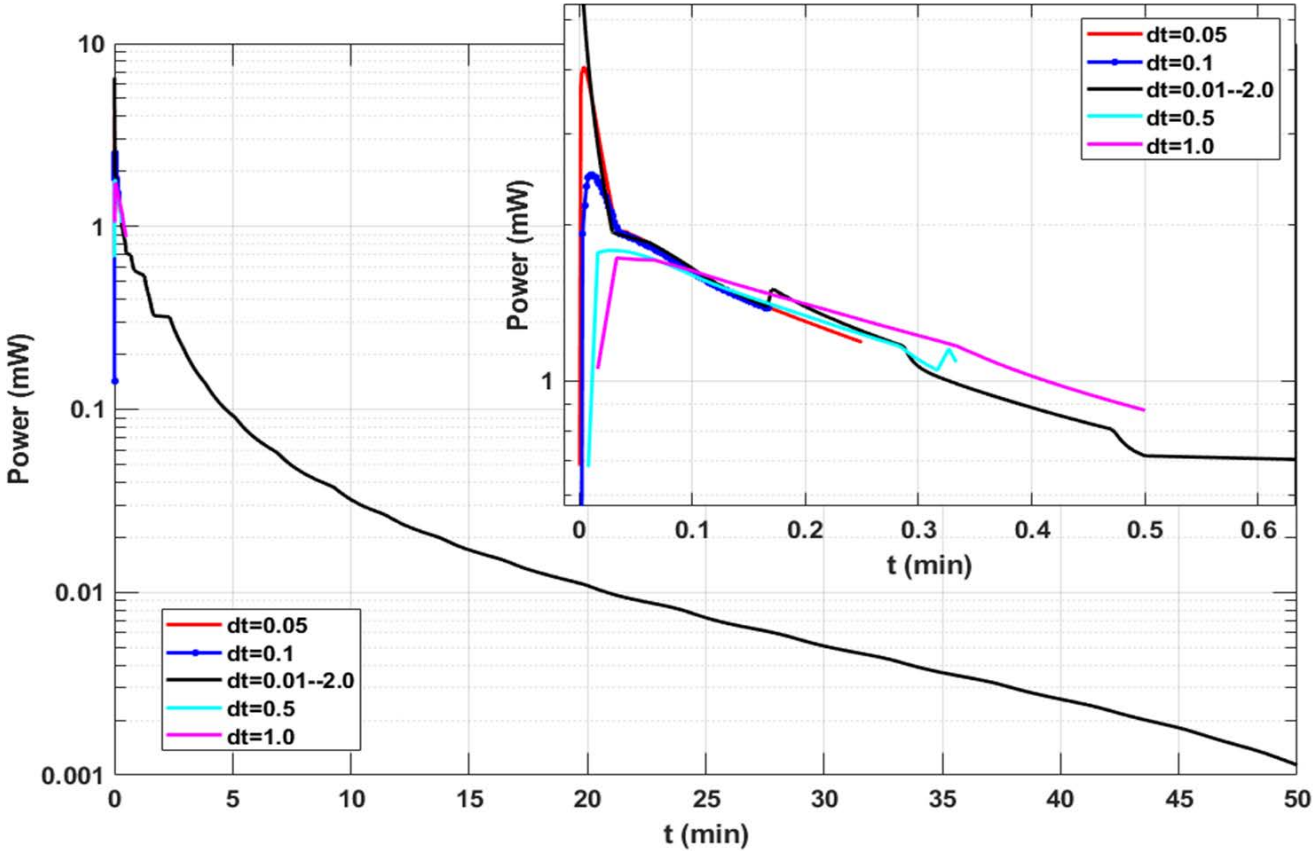
External Resistor/Load

- There are 107 TEGs couples in the entire geometry.

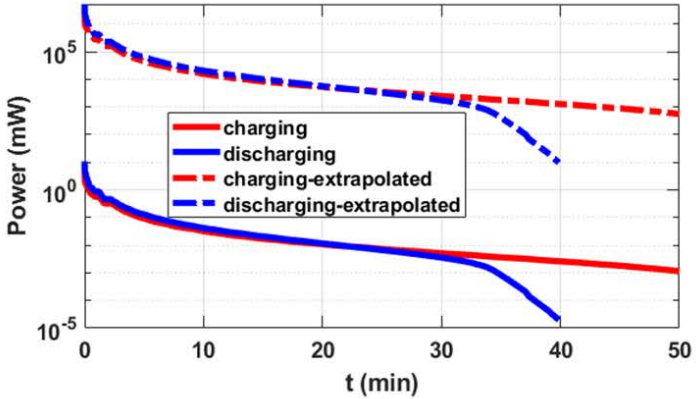
Cont..

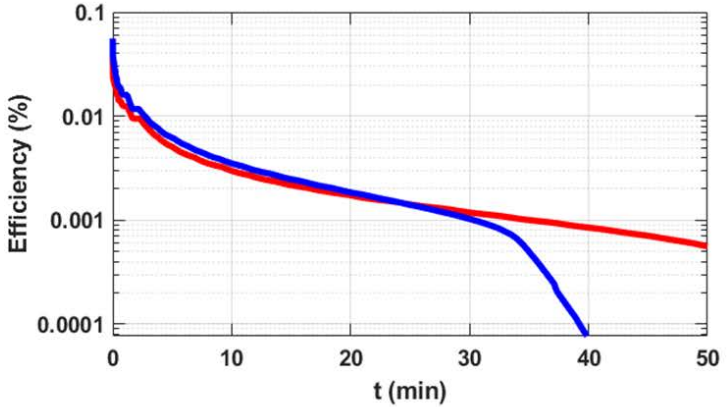

A : TE-TEG-Nav-Final - Mechanical [Ansys Mechanical Enterprise]
Ansys
2024 R1
No of TEGs: 108-1=107
Model (A4)
Geometry Imports
Geometry
Materials
Coordinate Systems
Connections
Mesh
Named Selections
Steady-State Thermal-Electric Conduction (A5)
Analysis Settings
Voltage
System Coupling Region
Wire_Convection
Tc
Solution (A6)
Solution Information
Temperature
Total Current Density
OutputPowerPerUnitVol
WireVolume
OutputVoltage
Directional Heat Flux
Qh
Details of "Mesh"
Display
Display Style
Use Geometry Setting
Defaults
Physics Preference
Mechanical
Element Order
Program Controlled
Element Size
Default
Sizing
Quality
Inflation
Advanced
Statistics
Messages
Show Errors (0)
Show Warnings (0)
Show Info (0)
Merge Messages
Text
Association

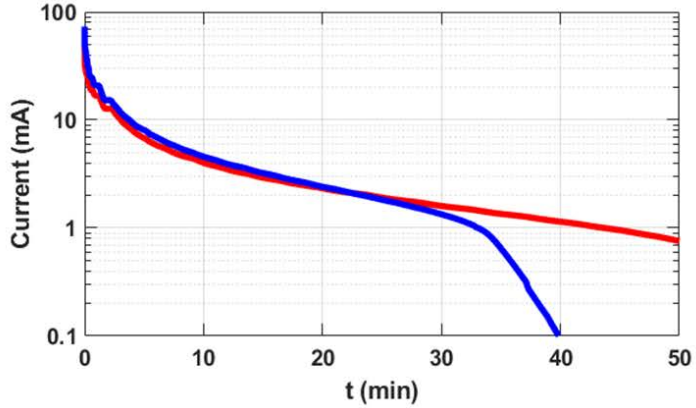
Time Independence Study

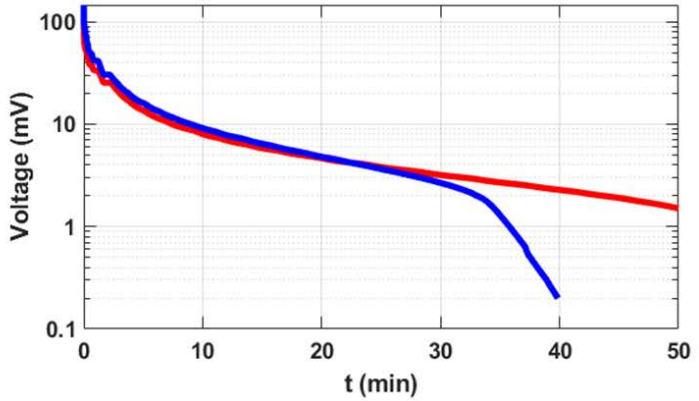


Results

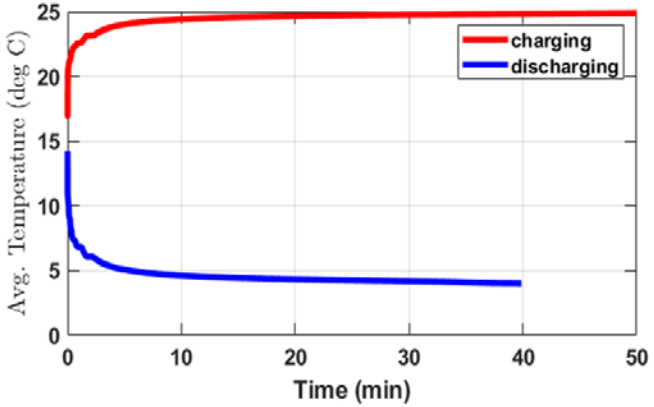

Power (mW)
10^{5}
10^{0}
10^{-5}
charging
discharging
charging-extrapolated
discharging-extrapolated
0
10
20
30
40
50
t (min)

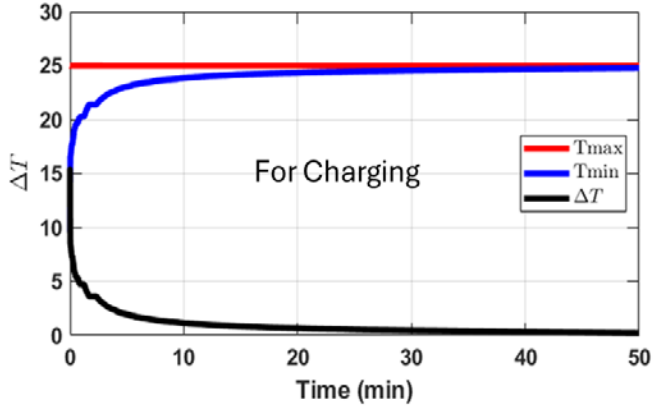

Efficiency (%)
0.1
0.01
0.001
0.0001
0
10
20
30
40
50
t (min)

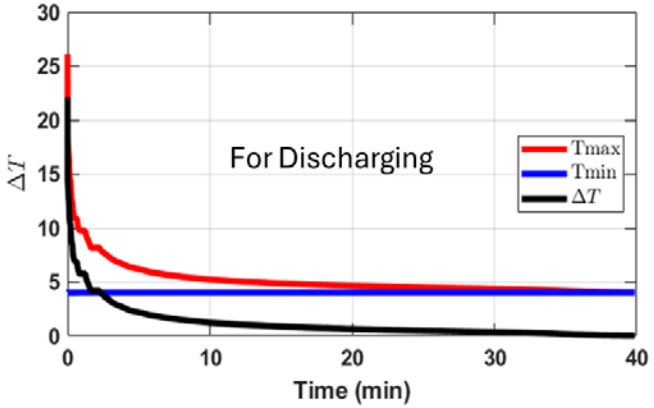

Current (mA)
100
10
1
0.1
0
10
20
30
40
50
t (min)

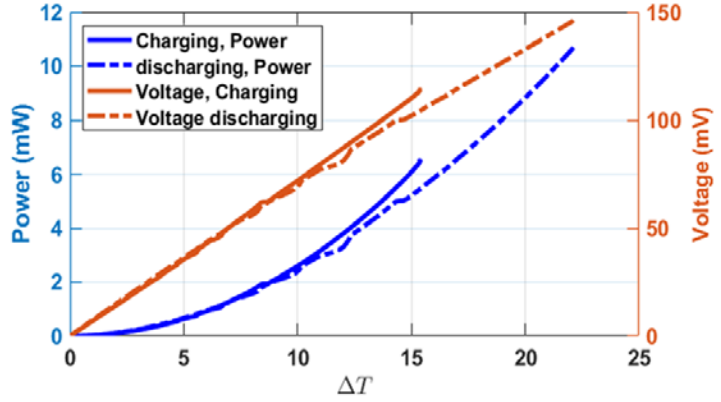

Voltage (mV)
100
10
1
0.1
0
10
20
30
40
50
t (min)

Cont..

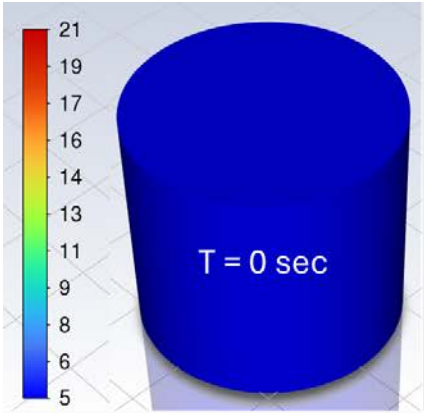

charging
discharging
Avg. Temperature (deg C)
Time (min)

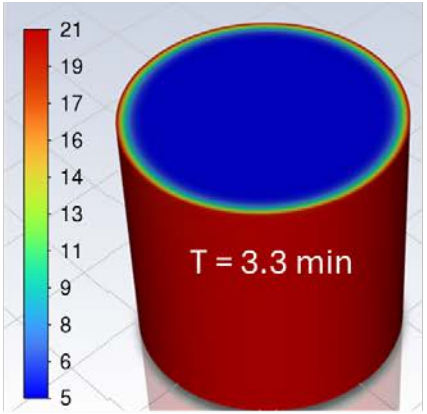

For Charging
Tmax
Tmin
ΔT
Time (min)

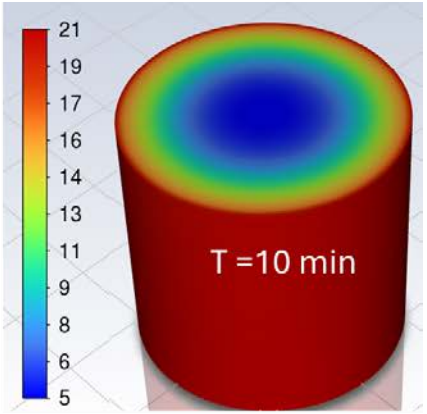

For Discharging
Tmax
Tmin
ΔT
Time (min)

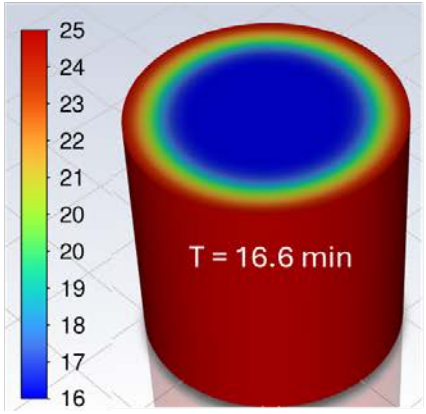

Charging, Power
discharging, Power
Voltage, Charging
Voltage discharging
Power (mW)
Voltage (mV)
ΔT

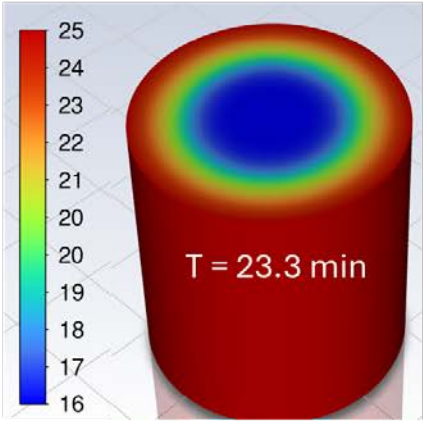
Temperature Contour (Charging)

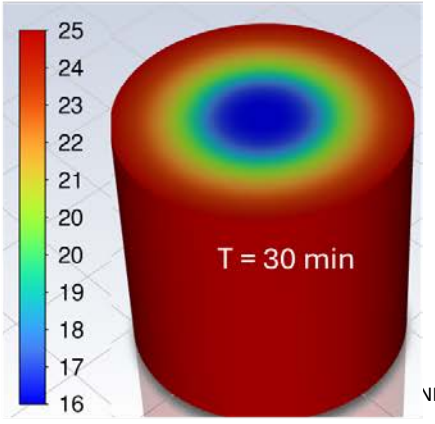




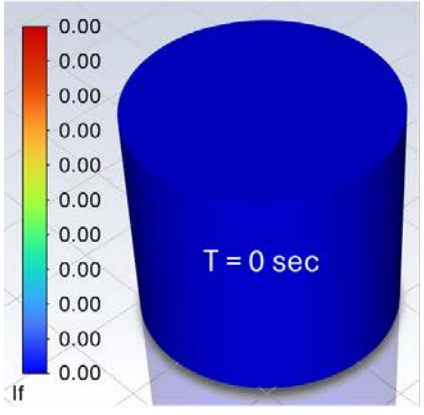


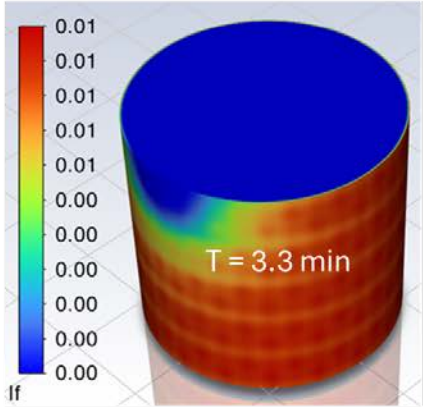


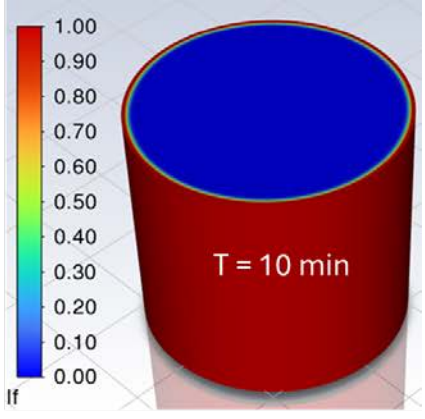


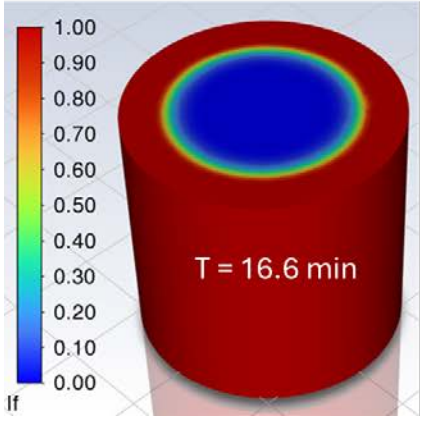


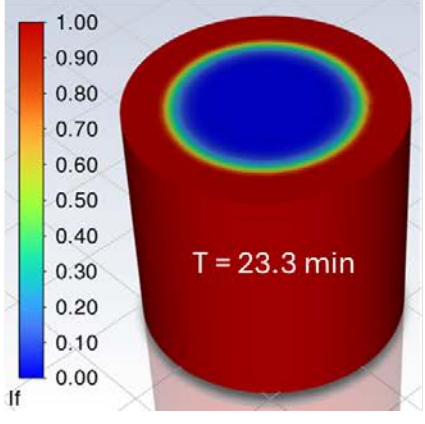
Melt Fraction (Charging)

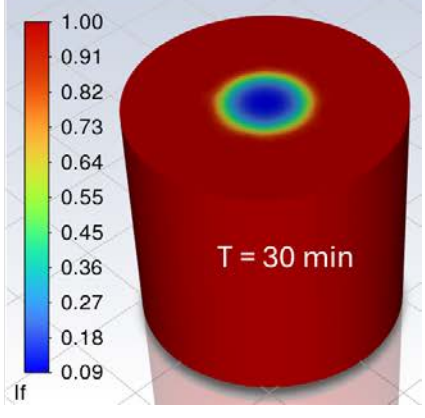




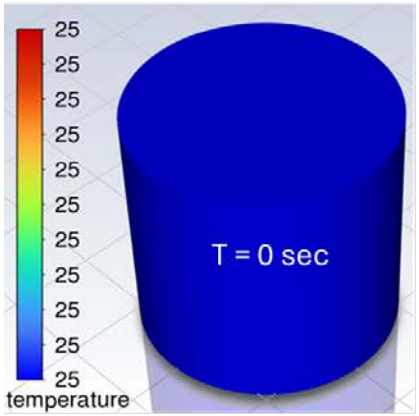


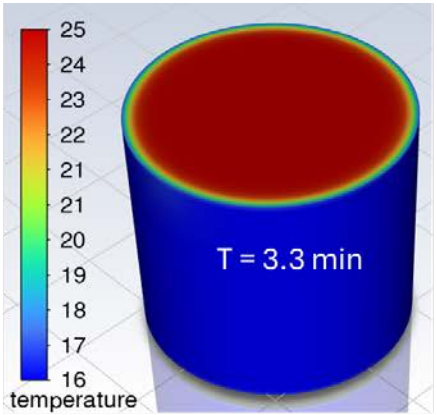


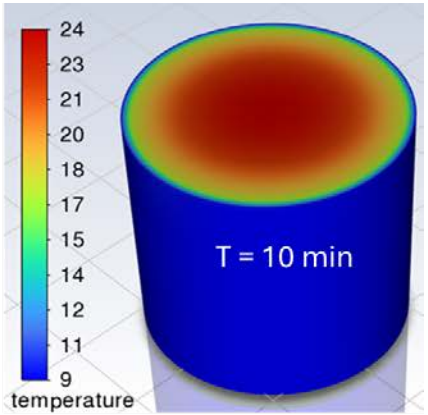


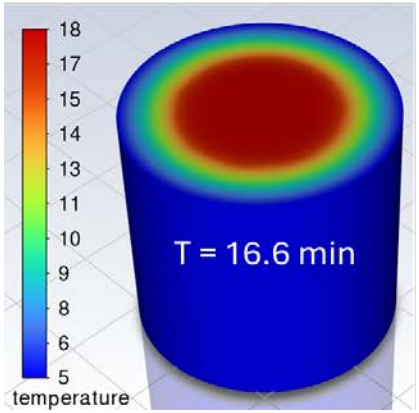


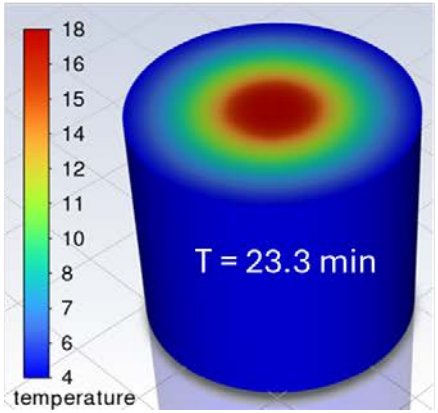
Temperature Contour (Discharging)

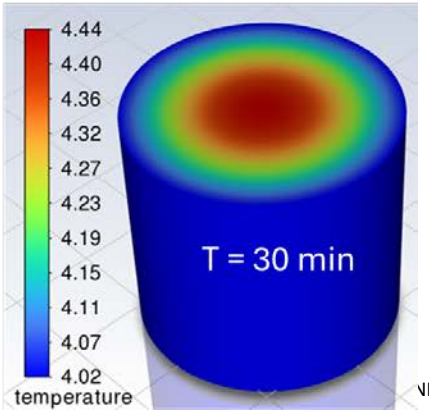




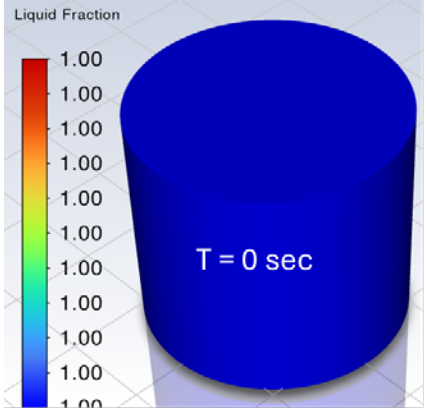


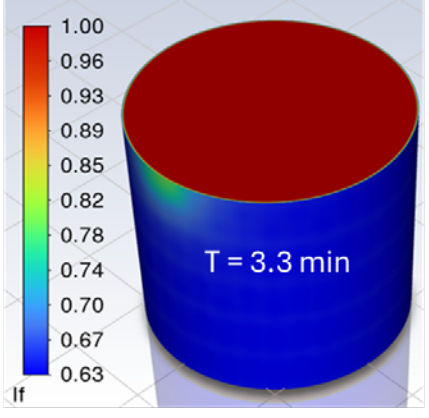


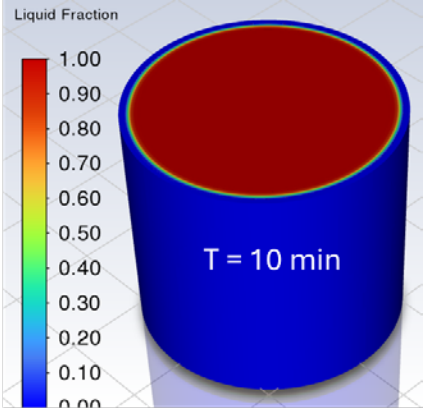


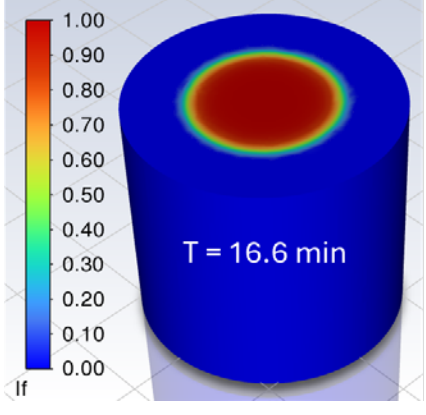


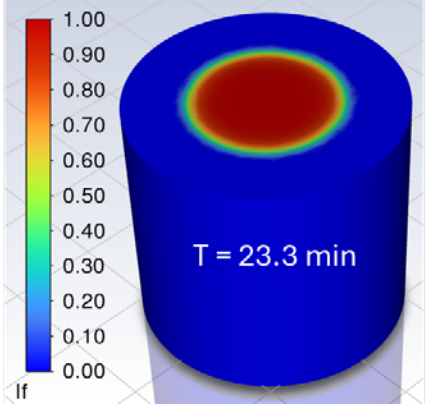
Melt Fraction (Discharging)

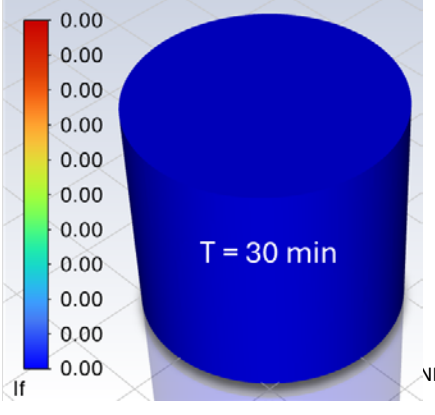












Conclusion

- Different PCMs serves more effectively at different locations and seasons.
- Based on the initial analysis, we can generate the around 100 to 150 kWh power per year from a single Thermopod.
- Design optimizations can further increase the power production from a submersible/Thermopod.
- The whole system will produce between 1 to 5 MWh per year.

References

1. Samson Shittua, Guiqiang Lia, Xudong Zhaob, Xiaoli Maa, Review of thermoelectric geometry and structure optimization for performance enhancement, Applied Energy 268 (2020) 115075.
2. Qingyu Yan, and Mercouri G. Kanatzidis, High-performance thermoelectrics and challenges for practical devices, Nature Materials, VOL 21,May 2022, 503–513.
3. Suhanyaa S. Magendran, Fahad Saleem Ahmed Khan, N.M. Mubarak, Mahesh Vaka, Rashmi Walvekar, Mohammad Khalid, E.C. Abdullah, Sabzoi Nizamuddin, Synthesis of organic phase change materials (PCM) for energy storage applications: A review, Nano-Structures & Nano-Objects, Volume 20, October 2019, 100399.
4. Experimental data taken from: M. Chen, L.A. Rosendahl, T. Condra. A three-dimensional numerical model of thermoelectric generators in fluid power systems. International Journal of Heat and Mass Transfer 54 (2011) 345–355.

Thank You!

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