COMSOL CONFERENCE 2018 BOSTON

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COMSOL Multiphysics® Simulation of TEGs for Waste Thermal Energy Harvesting

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Agenda

- Purpose
- Thermoelectric Generator
- Research Approach
- COMSOL Modules
- System Components
- TEG Module Comparison
- Simulation
- Results
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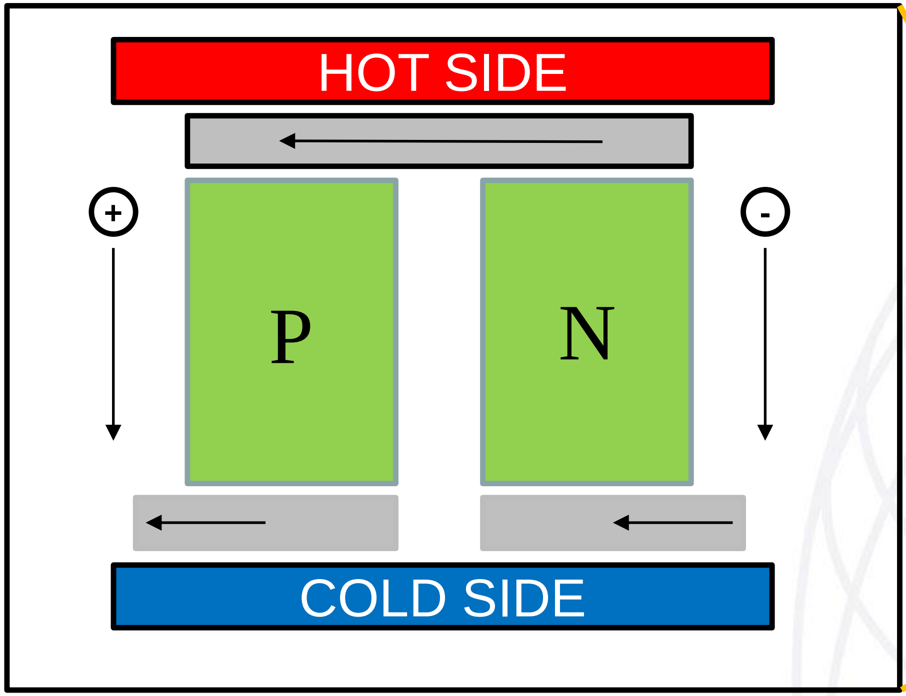
- Conclusion

Purpose

- The Department of Defense is looking at several energy initiatives to reduce the reliance on fossil fuels and increased efficiency within the branches of the military.
- Considering the amount of energy wasted to heat in combustion engines, combat, and communications systems, it is natural to attempt to re-capture some of this energy and put it to beneficial use to increase operational efficiency.
- Ultimately, this research will help determine if waste heat recovery with thermoelectric generators (TEG) from a generator or an engine is feasible, and to what degree.

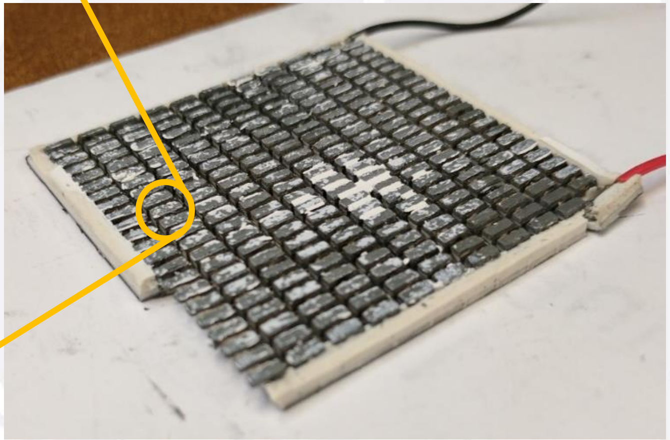
Thermoelectric Generation

- **Seebeck Effect**
  - **Creates voltage when exposed to a temperature differential**



⊕ Positive Charge Carrier (hole)

⊖ Negative Charge Carrier (electron)



Research Approach

- Develop a model in COMSOL to simulate a potential prototype system of a TEG array on the muffler of a portable generator to predict the potential temperature difference between TEG sidings.
  - COMSOL Modules
  - Geometry
  - Boundary Conditions
  - Simulation

COMSOL Modules

- Heat Transfer Module
  - Heat Transfer in Fluids : Shows how heat spreads through system components
  - Laminar Flow: Simulates the movement of fluid
  - Nonisothermal Flow: combined Laminar Flow and Heat Transfer in Fluids
    - Simulated varying temperatures

- AC/DC and Heat Transfer Module
  - Electric Currents interface and Heat Transfer in Solid interface
    - Simulated the thermoelectric effect

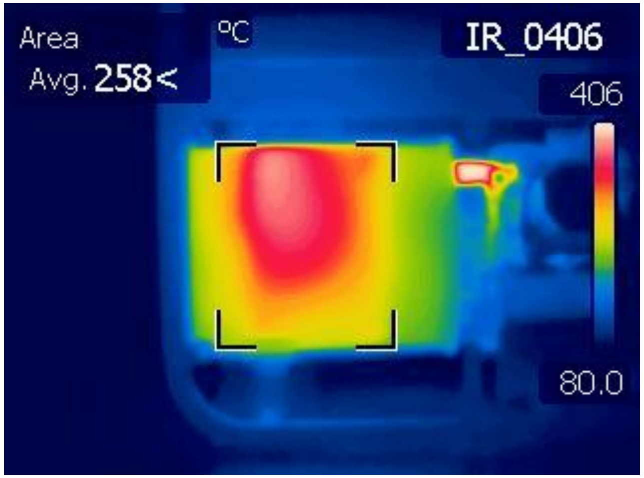
Muffler

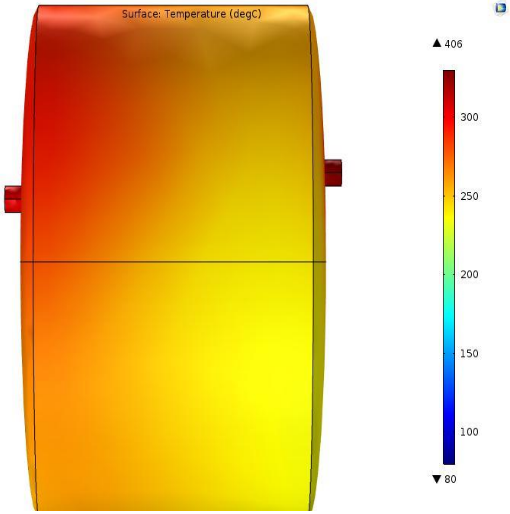
Overview

- Muffler of a commercial gasoline powered generator
  - Carbon steel
  - Interior assumed to be hollow

Boundary Conditions

- FLIR camera: inflow temperature and average surface temperature
  - 10 minutes steady state operation
    - Inflow temp: 406°C
      -Heat Transfer of Fluids interface
    - Avg. surface temp: 258°C
      -Lamar Flow interface adjusted until the muffler matched 258°C. Resulted in an inlet flow of $0.0117\,\frac{m^3}{s}$.





Water Block

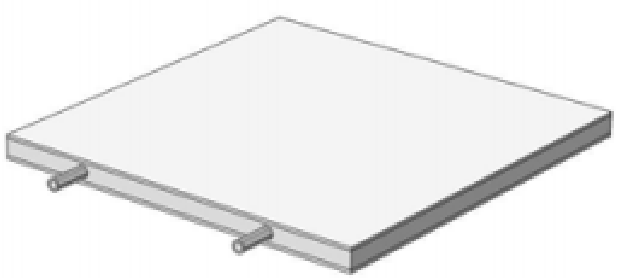
Overview

- Two nozzles constructed to simulate a water cooling system
- Thin aluminum walls designed to force the water to spread evenly throughout the block

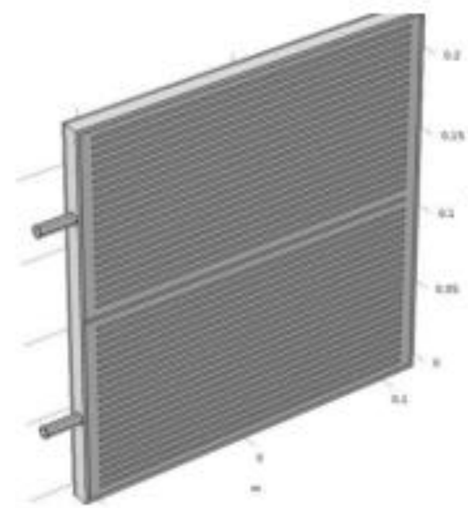
Boundary Conditions

- To simulate a cooling system chiller:
  - Heat Transfer in Fluids interface
    - Water temperature: 19°C
    - Pressure: 60 Psi
  - Laminar Flow interface
    - Inlet flow rate: 0.00014 $\frac{m^3}{s}$

Exterior



Interior



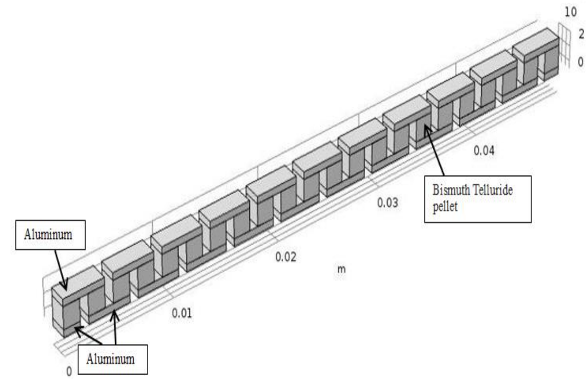
TEG

Overview

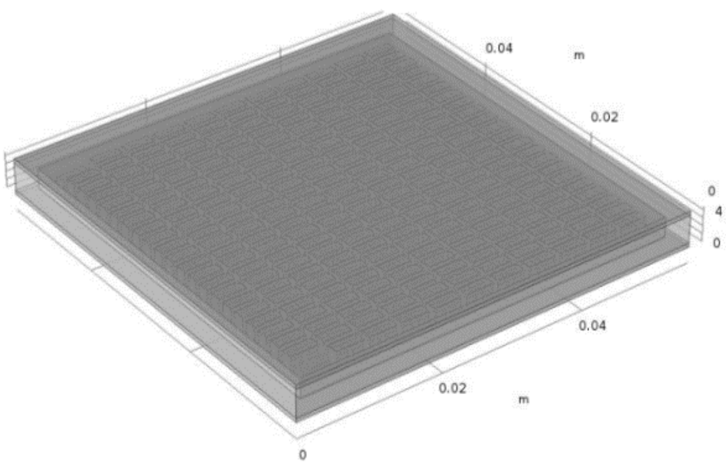
- Commercial TEG
  - Bi_2Te_3
  - Aluminum
  - Silicone based adhesive

Complex Design

- 22 rows of Bi_2Te_3 pellets with 11 pairs in each
- Aluminum plates surround pellets
- Hollow boxes of silicone

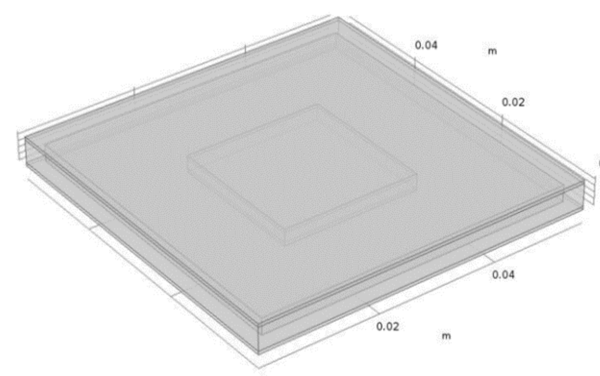


Complex Design



Simplified Design

- Same external dimensions as complex
- Same volume of Bi_2Te_3, aluminum, and silicone that was inserted into 2 blocks



TEG Model Comparison

- Each TEG design placed in block of air at ambient temperature
  - One side of the TEG heated from 100-180 °C at 20° C increments
  - Opposite side of TEG temperature measured

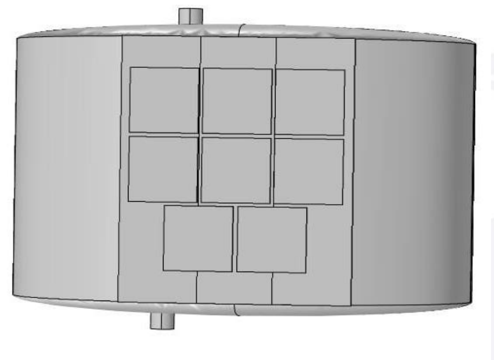
Temperature Input (°C)	Complex TEG Temperature (°C)	Simplified TEG Temperature (°C)
100	373.04	373.04
120	393.00	393.01
140	412.97	412.97
160	432.93	432.92
180	452.88	452.88

- Key Takeaways:
  - Same thermal conduction between designs
  - Simplified design computation was 9 times faster at 3 seconds per simulation
  - Simplified TEG design used in overall system design

Simulation Results

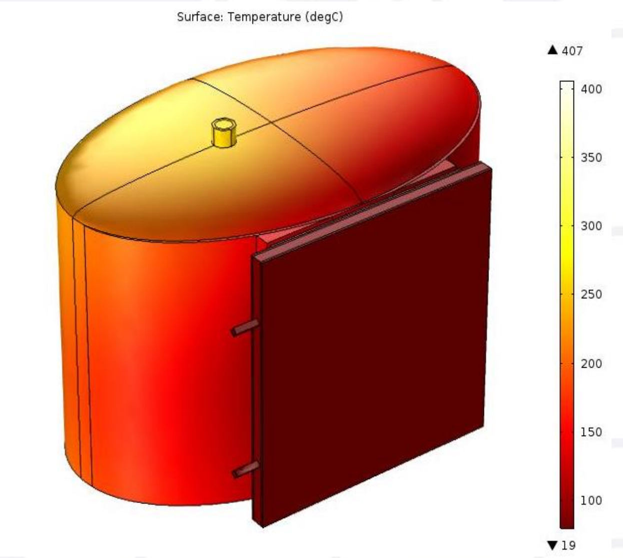
- Fist Simulation: Aluminum top sheet 5 mm wide:

TEG	Hot Side Temp (°C)	Cold Side Temp (°C)	Temp Difference (°C)
1	89.26	37.47	51.79
2	70.68	34.26	36.42
3	71.01	34.27	36.74
4	77.27	34.94	42.33
5	58.50	31.06	27.44
6	62.3	31.35	30.95
7	67.82	33.58	34.24
8	60.24	30.99	29.25
Average Temp Difference			36.15



- Second Simulation: Aluminum top sheet 3 mm wide:

TEG	Hot Side Temp (°C)	Cold Side Temp (°C)	Temp Difference (°C)
1	91.00	39.51	51.48
2	72.74	36.18	36.56
3	72.87	35.83	37.04
4	79.61	36.93	42.68
5	61.52	33.09	28.43
6	66.30	33.45	32.84
7	74.65	36.32	38.37
8	66.29	33.53	32.76
Average Temp Difference			37.52



Future Work

Future work in the research will include the following:

- Compare COMSOL model output to tabletop prototype
- Apply temperature differences determined in COMSOL to predict voltage and output power of TEG array
- Determine most efficient TEG array arrangement in series, parallel, or combination
- Investigating IR signature reduction aspects

Conclusion

- COMSOL verified physical characteristics of TEG, water block, and muffler
- Two simulations conducted to determine hot and cold side temperature for each TEG
  - 5.0 mm plate: 36.15 °C
  - 3.0 mm plate: 37.52 °C
- Findings will be utilized in further modeling, design, and construction of TEG array prototype

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Acknowledgements

NPS Systems Engineering Department
Advisors:

Dr. Anthony Pollman (USMC, Ret.)
Dr. Dragoslav Grbovic

Office of Naval Research
Neptune II

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Questions?