Development of a Scalable 10% Efficient Thermoelectric Generator

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Build on Recent Successes

Materials:

ZT substantially greater than unity has been demonstrated at places such as Michigan State, Research Triangle Institute (RTI), and MIT Lincoln Labs.

Segmentation devices have successfully been demonstrated at Jet Propulsion Laboratory (JPL).

Thermodynamics and Heat Transfer:

Thermal isolation in the direction of flow that can improve cooling/heating performance by a factor of two.

High power density designs that require 1/6 the thermoelectric (TE) material usage of conventional designs.
TGM Development Methodology

Model, design and build fractional generator, first with low temperature TE material followed by high temperature TE material and finally segmented TE material

Validate performance model under varying operating conditions

Replicate fractional generator to scale up to >500 watts for low temperature TE material followed by similar scale up for high temperature (20W) and segmented TE materials

Integrate fractional generators with heat exchangers on the hot and cold side

Test and revalidate the performance model at varying operating conditions
Low Temperature Bi$_2$Te$_3$ Subassembly

Low temperature device built to continue learning process while high temperature material systems are being developed

Bi$_2$Te$_3$ thermoelectric generator module (TGM) output nominally targeted at > 500 watts

- Hot side fluid: oil, inlet temperature = 200 to 250°C
- Cold side fluid: water or glycol/water, inlet temperature = -5 to 30°C
Test Results of Single Module

$\left( T_h = 190^\circ C, \text{water bath} = 20^\circ C \right)$

Peak Power = .969893
Solid Model Isometric & Cross Section Views

- Expansion bellows
- Cold manifold
- Hot manifold
- TE circuit between hot and cold manifolds
Thermoelectric Subassemblies
Assembled Single Hot Plate TE Generator
Generator Test Setup
Test Results
Maximum Open Circuit Voltage > 12V

Power Gen
One Fifth Device

Current (Amps)

Voltage (V)

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Maximum Open Circuit Voltage > 12V
Test Results

Maximum Peak Power of 130W

Power Gen
One Fifth Device

200C_-5C
190C_-5C
180C_-5C
170C_-5C
160C_-5C
160C_-6C
160C_-15C
160C_-25C
131C_-5C
113C_-5C
98C_-4C

Test Results
Maximum Peak Power of 130W
Peak Test Results Compared to Simulations
Measured to simulated values vary by < 5%

Single plate
(interfacial resistance = 2μΩcm²,
hot volume flow = 8 gpm (Xceltherm 600),
cold volume flow = 8.85 lpm (water or glycol/water))
Materials for segment layers are chosen to maximize ZT over each element’s exposed temperature range.

Materials of choice currently include p- and n-type skutterudite and Bi$_2$Te$_3$ as well as TAGS and n-type PbTe.

Ref: Modified from - http://www.its.caltech.edu/~jsnyder/thermoelectrics/
TE Couple Configuration
Alternatives with Segmented Elements

Traditional configuration

Alternative “Y” configuration
TGM Design Objectives

State-of-the-art thermoelectric materials
Thermally isolated elements in the direction of flow
High power density design
Segmented elements to maximize ZT over entire temperature range
Ability to adjust segment thicknesses to increase TE material compatibility within elements
Use “Y” configuration to accommodate differing element thicknesses and differing thermal expansion coefficients
Use non-rigid joints to reduce the effects of thermal expansion mismatch
High Temperature TGM
Developmental Prototype (20W)

TGM subassembly
(cartridge heaters on hot side- full scale TGM will use hot gas heat exchangers)

Solid model of fractional TGM in its test fixture
20W Generator Build

Completed halves of the 20W device, prior to the final assembly

Final assembled 20W device, plumbed and ready for testing
Test Results for the 20W Generator

20W generator performance
(cold bath = 20C, six TAGS/PbTe couples, couple has 4 elements per side)
(element dimensions = 3 x 3 x 2 mm)
(test #1 = solid, test #2 = dotted)
Segmented TAGS/PbTe-BiTe Couple

BiTe (0.6 mm)
PbTe (2mm)
TAGS (2mm)
BiTe (0.6 mm)
10% Efficiency Demonstration

Performance is reproducible after thermocycling

Segmented Couple Performance
Marlow TAGS (Ti5Si3 metalization), PbTe, Bi2Te3
4 p-type, 6 n-type, TAGS (3 x 3 x 2mm), PbTe (3 x 3 x 2mm), Bi2Te3 (3 x 3 x 0.6mm)
segments soldered together, alumina silica fiber paper insulation
01/10/07

![Graph showing efficiency vs. temperature difference with legend](image)
**Next Steps**

Complete assembly and testing of full-scale low temperature generator

Evaluate new design concepts that enhance performance and structural integrity of the device over the usage temperature range and during thermal cycling

Test fractional-scale prototype segmented element devices to analyze problem areas in the design, validate the model, and develop different segmentation techniques

Continue working with and testing new TE materials and new TE material combinations to push towards increasing average ZT

Continue working with partners to reduce interfacial resistance to 0.1 $\mu\Omega cm^2$ at room temperature

Continue working on reducing heat losses from the system

Build full-scale high temperature TGM device using segmented elements
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