The 2014 Joseph W. Richards Summer Research Fellowship – Summary Report

Thermogalvanic Waste Heat Recovery in Transportation Energy Systems

by Andrey Gunawan

Waste heat recovery remains an inviting subject for research. Solid state thermoelectric devices have been widely investigated for this purpose, but their practical application remains challenging due to high cost and the inability to fabricate them in geometries that are easily compatible with heat sources. An alternative to solid-state thermoelectric devices are thermogalvanic cells.[1-7] The temperature difference between the hot and the cold electrodes creates a difference in electrochemical potential of the redox couples at the electrodes. Once connected to a load, electrical current and power is delivered, converting thermal energy into electrical energy. The aim of this summer project is to extend ongoing research to study the feasibility of incorporating thermogalvanic systems into automobiles.

A climate-controlled wind tunnel (Fig. 1) was built to provide equivalent conditions to the ambient air stream under the car. Temperature was controlled using a window air conditioner, while an air mover drove the flow up to 6 m s^{-1}. A heat gun provided the equivalent of a low-temperature exhaust gas stream (~110 °C). The annular cell was bound by concentric copper pipes (electrodes) and CPVC bulkheads; all sealed with silicone. K-type thermocouples were attached with epoxy onto electrode surfaces to measure the electrode temperature, which were monitored and recorded by a Campbell Scientific CR23X Micrologger. The cell potential (E) was probed using a Fluke 8846A Digital Multimeter. An Elenco RS-500 resistor box (R_{ext}) was connected in parallel to measure power output, $P = E^2/R_{ext}$.

A 0.7 M $CuSO_4$ aqueous electrolyte was used, with 0.1 M H_2SO_4 as the supporting electrolyte. The T_{cold} was varied based on the quad-monthly average ambient air temperature ($T_{ambient}$) in Phoenix, AZ of 31.6, 22.5, and 14.1 °C. Because thermal resistance from the hot air stream to the inner copper pipe is large relative to the thermal resistance of the cell, the T_{hot} was measured to be less than the hot air stream's temperature. Reducing this resistance would greatly improve the system performance. The experimental values of T_{hot} and T_{cold} are shown next to their resultant plots in Fig. 2. These results showed that higher $T_{ambient}$ yielded a higher P, because of the higher average cell temperature, $T_{avg} = (T_{hot} + T_{cold})/2$. This trend agreed with our previous study.[8] Since the resistor could only be

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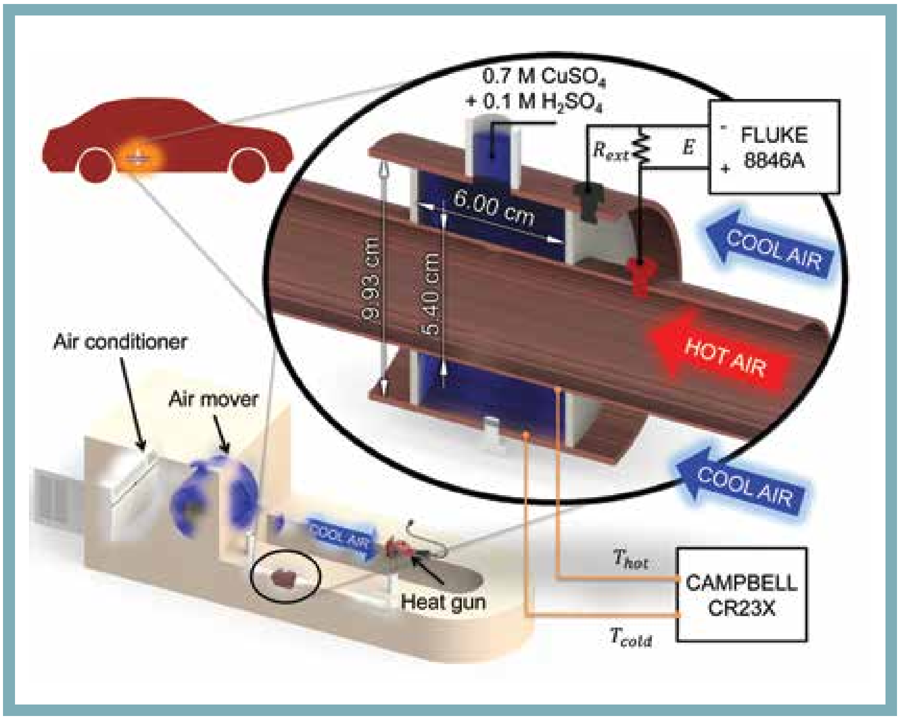

Fig 1. *3D CAD drawings of the wind tunnel and the cross-sectional diagram of the annular Cu/Cu^{2+} thermogalvanic cell.*

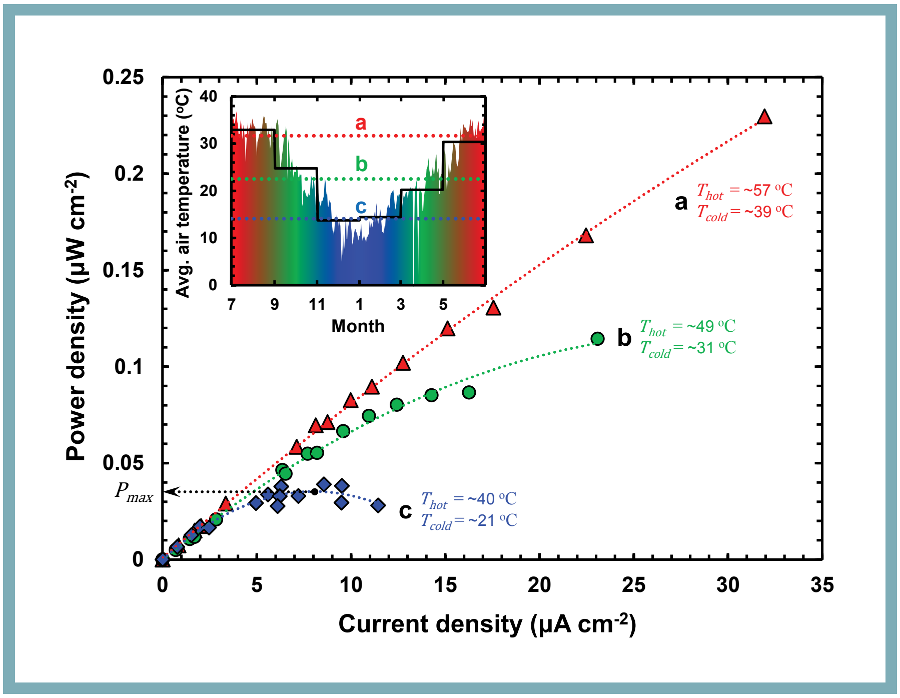

Fig 2. *Power density vs. current density curves for the annular Cu/Cu^{2+} thermogalvanic cell tested at the three ambient temperatures of (a) 31.6, (b) 22.5, and (c) 14.1 °C. T_{hot} and T_{cold} are the temperatures of the hot and cold electrodes, respectively, as shown in Fig. 1. The inset shows historical data of average ambient air temperature in Greater Phoenix area, AZ from July 1, 2013 to June 30, 2014, which is imported from the Arizona State University Weather Station;[9] solid and dotted lines indicate bi-monthly and quad-monthly average air temperatures, respectively.*

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varied down to 1.1 Ω, we could not show the maximum power output (P_{max}) for $T_{ambient}$ values of 31.6 and 22.5 °C. Nevertheless, the magnitude of the P and P_{max} was consistent with our previous observations.[1,8]

We have demonstrated that the liquid electrolyte enables a thermogalvanic device to conform to the shape of automotive exhaust pipes much more readily than a solid-state thermoelectric device. Expensive, cleanroom-based manufacturing processes are not required for constructing the cell, resulting in potentially lower production costs than high-performance solid-state thermoelectrics. Future studies will focus on improving the experimental setup by enhancing the air-side heat transfer, incorporating a flow cell, and increasing the electrode surface area to increase the sites available for reaction, thereby helping generate more power.

Acknowledgment

The author gratefully acknowledges ECS for the Joseph W. Richards Summer Fellowship and Professor Patrick Phelan for his invaluable support and guidance throughout the project. In addition, the author wishes to thank Professor Candace Chan for her steadfast encouragement and recommendation in earning this fellowship, Nicholas Fette for his great assistance and fruitful discussions on the project, and Professor Daniel Buttry for all helpful conversations and suggestions regarding the electrochemistry aspect of the project. Additional support from the National Science Foundation through Award CBET-1236571 is also gratefully acknowledged.

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