An Air-Breathing, Portable Thermoelectric Power Generator
Based on a Microfabricated Silicon Combustor

by

Christopher Henry Marton

The global consumer demand for portable electronic devices is increasing. The emphasis on reducing size and weight has put increased pressure on the energy and power densities of available power storage and generation options, which have been dominated by batteries. The energy densities of many hydrocarbon fuels exceed those of conventional batteries by several orders of magnitude, and this gap motivates research efforts into alternative portable power generation devices based on hydrocarbon fuels. Combustion-based power generation strategies have the potential to achieve significant advances in the energy density of a generator, and thermoelectric power generation is particularly attractive due to the moderate temperatures which are required.

In this work, a portable-scale thermoelectric power generator was designed, fabricated, and tested. The basis of the system was a mesoscale silicon reactor for the combustion of butane over an alumina-supported platinum catalyst. The reactor was integrated with two commercial bismuth telluride thermoelectric modules and two air-cooled, light-weight heat sinks to form the generator. A model-based design process was used for the reactor system to ensure sufficient thermal isolation from the environment and adequate catalyst contact time, without the imposition of a large flow resistance that would have prevented the use of ambient air as the oxidant.

The system was used to produce 5.8 W of electrical power with a chemical-to-electrical conversion efficiency of 2.5% (based on lower heating value). The energy and power densities of the demonstrated system were 321 Wh/kg and 17 W/kg, respectively. The pressure drop through the system was 258 Pa for the flow of 15 liters per minute of air, and so the parasitic power requirement for air-pressurization was very low. The demonstration represents an order-of-magnitude improvement in portable-scale electrical power from thermoelectrics and hydrocarbon fuels, and a notable increase in the conversion efficiency compared with other published works.

The system was also integrated with thermoelectric-mimicking heat sinks, which imitated the performance of high-heat-flux modules. The combustor provided a heat source of 206 to 362 W to the heat sinks at conditions suitable for a portable, air-breathing TE power generator. The combustor efficiency when integrated with the heat sinks was as high as 76%. Assuming a TE power conversion efficiency of 5%, the design point operation would result in thermoelectric power generation of 14 W, with an overall chemical-to-electrical conversion efficiency of 3.8%.

Thesis Supervisor: Klavs F. Jensen
Title: Department Head, Chemical Engineering
        Warren K. Lewis Professor of Chemical Engineering
        Professor of Materials Science and Engineering