Experimental Results Confirming Improved Performance of Systems Using Thermal Isolation

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Abstract

Results are presented of a design verification study demonstrating the system efficiency increase in thermoelectric systems that utilize thermal isolation. Three devices ranging from 40 to 2500 watts of electrical input power are described. Test results for these devices are compared to the theoretical best values for conventional thermoelectric systems.

Demonstrated performance gains are at least 50% greater than the theoretical best coefficients of performance (COP) for conventional systems. Measured performance ranges from 60 to 90% of the theoretical COP for thermal isolation geometries. Loss mechanisms that reduce the performance from theoretical values are discussed.

Introduction

To verify the increase in performance predicted by the theory of Bell[1], several devices with thermal isolation were constructed and tested. As shown in Figure 1, these devices were made from one or more standard 40 mm x 40 mm thermoelectric modules that were placed between heat exchangers. The heat exchange fluid was water or ethanol.

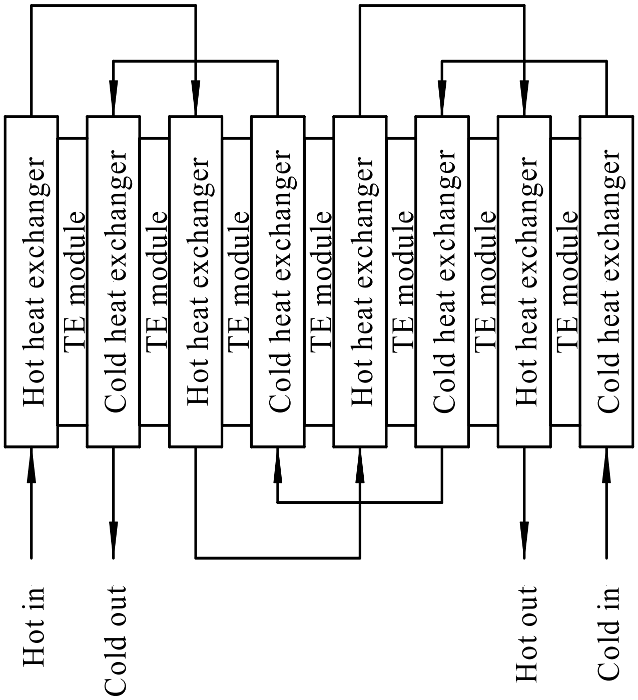

Figure 1. Test specimen schematic, cross-flow connections.

Three devices are reported on here. A single-module device (20 to 40 W) was constructed to represent a conventionally constructed system without thermal isolation and was compared directly against a 7-module (200 to 400 W) device. In both cases, the heat exchangers were soldered to the thermoelectric modules. A 35-module (1 to 2.5 kW) device was constructed using thermal grease between the thermoelectric modules and the heat exchangers. During testing, these devices were enclosed in an insulated box to minimize heat transfer losses to the laboratory environment.

Tests were conducted with both cross- and parallel-flow connections. Note that in cross flow mode, the inlets are on the ends to minimize losses. In parallel mode, only the cold inlet was on the end. The incoming fluids were near room ambient. Temperatures were measured with thermocouples or thermistors. Flow rates were measured by weighing a timed amount of effluent. Flow rates were adjusted to equalize the hot and cold side temperature differences. The thermoelectrics were powered electrically both in series and in parallel – no significant difference in performance was expected or seen.

Results

Figures 2 through 6 show the comparison of the one and seven module devices. Each of the figures shows the experimental data points and the theoretical maximum performance achievable at one stage (lowest solid curve), seven isolated stages (middle curve), and an infinite number (highest curve) of isolated stages. Each test was performed with equal temperature changes in the hot side and cold side heat exchange fluids. Thus the total temperature difference achieved is the sum of the two.

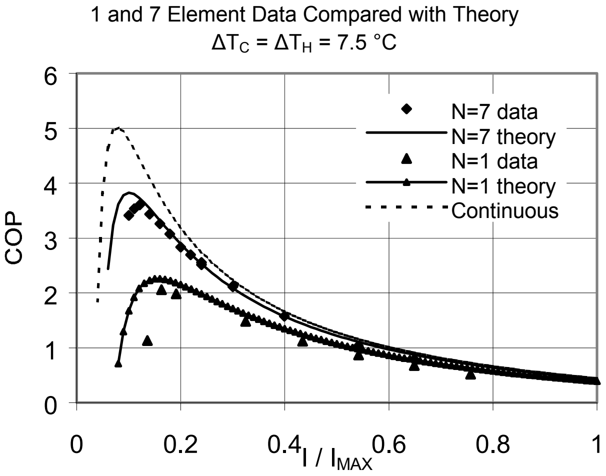

Figure 2. 1 and 7 element efficiency improvement at total temperature difference of 15 °C

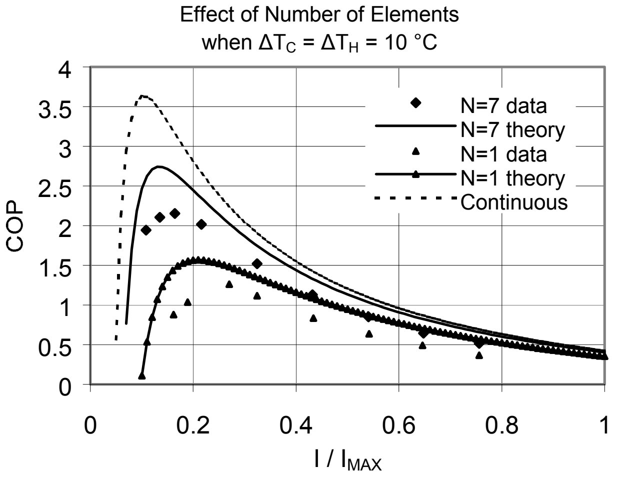

Figure 3. 1 and 7 element efficiency improvement at total temperature difference of 20 °C

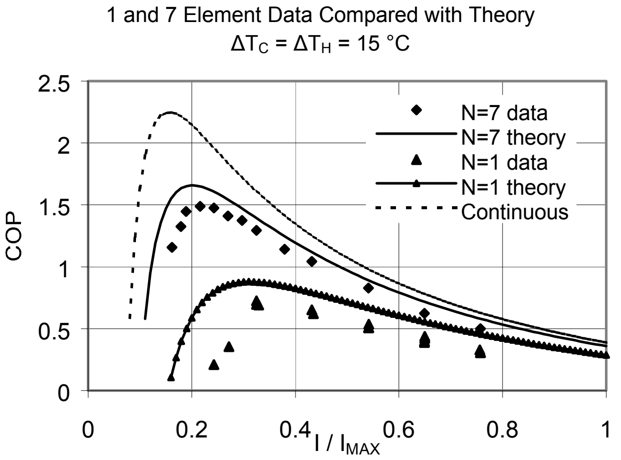

Figure 4. 1 and 7 element efficiency improvement at total temperature difference of 30 °C

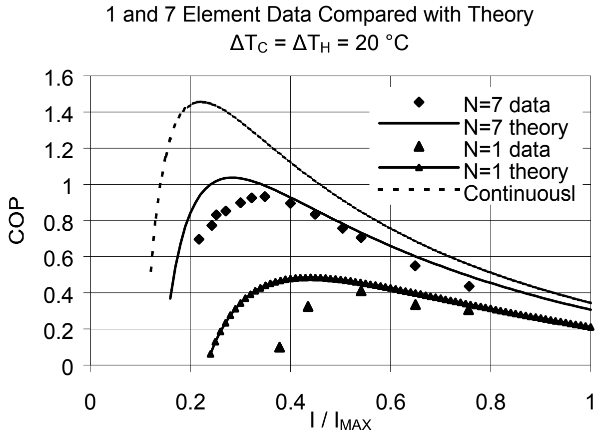

Figure 5. 1 and 7 element efficiency improvement at total temperature difference of 40 °C

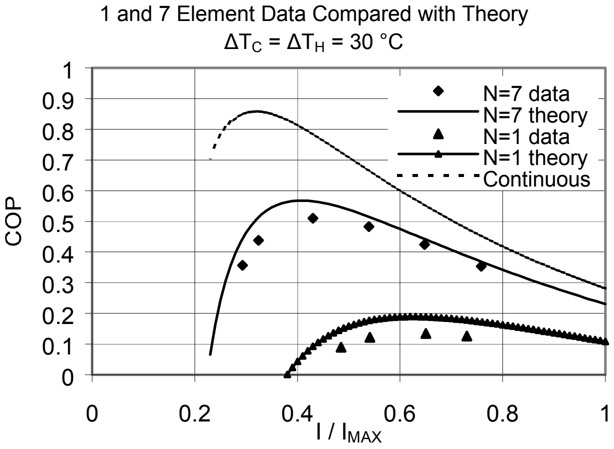

Figure 6. 1 and 7 element efficiency improvement at total temperature difference of 60 °C

In every case, the theoretical maximum performance curve is approached closely for larger currents. The peak in the experimental data is typically 80 to 90% of the peak for theory, but occurs for slightly higher current.

A 35-element device was also constructed, but with thermal greased instead of soldered thermal interfaces between the thermoelectric modules and the heat exchangers. Results from a selection of tests with this device are shown in Figures 7 and 8. The performance of this device in terms of its approach to the theoretical curve is similar to that of the smaller devices. Note, however, that the theoretical curve for 35 elements is very close to that for the continuous case. Thus, in a practical sense, devices consisting of the order of 35 elements exploit the principle of thermal isolation quite well.

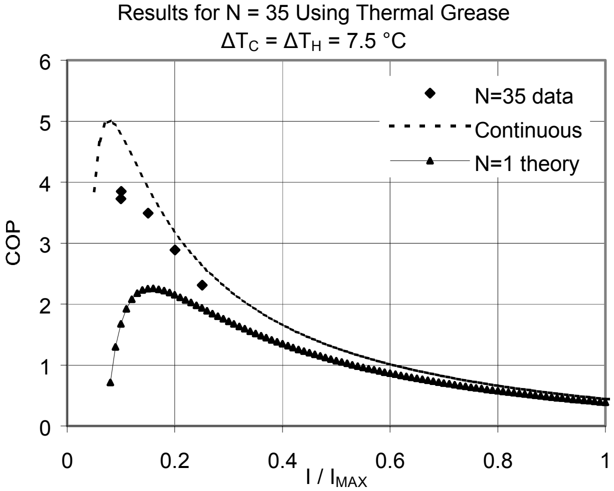

Figure 7. 35 element efficiency improvement at a total temperature difference of 15°C

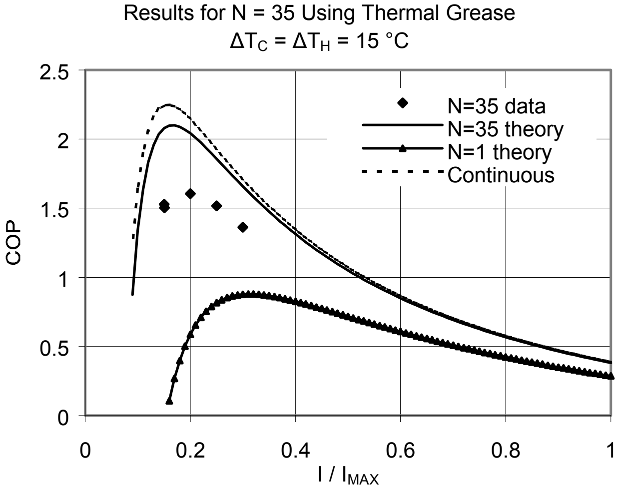

Figure 8. 35 element efficiency improvement at a total temperature difference of 30 °C

A limited number of tests were carried out with the 7 element device connect in parallel flow mode. The results are compared with the cross-flow data in Figure 9. The parallel flow performance is less than that for cross flow, due, in part, to the test conditions in which all of the TE modules do not have the same properties. For optimum performance, Bell's theory requires that module resistance or current be a function of the temperature difference across the module. This condition is closely approximated by that present in the cross flow test with all temperature differences equal and all currents equal. However, in the parallel flow test the currents were equal and therefore not balanced to the changing temperature differences across the modules. Nevertheless, the performance did increase, as was expected.

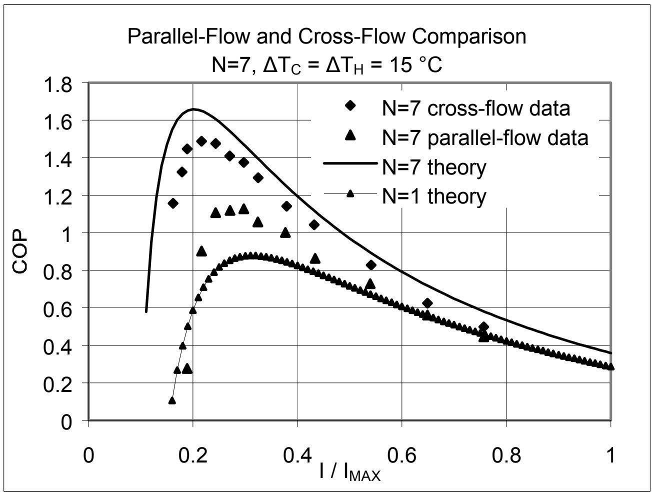

Figure 9. Comparison of cross and parallel flows at a total temperature difference of 30 °C

Conclusions

Performance gains in efficiency for devices employing thermal isolation in the direction of flow were at least 50% greater than the theoretical best for conventional systems at the peak of the COP curve. Compared with practically achievable performance for conventional systems, the isolated element devices were even somewhat better. When compared against the theoretical curve for thermal isolation, the experimental devices achieved over 65% (parallel flow case) and 80% to 90% (cross flow case) of the predicted best.

Acknowledgments

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References

1. Bell, L. E., "Use of Thermal Isolation to Improve Thermoelectric System Operating Efficiency," *Proceedings 21st International Conference on Thermoelectrics*, Long Beach, CA, August 2002.