How Thermoelectric Coolers Work

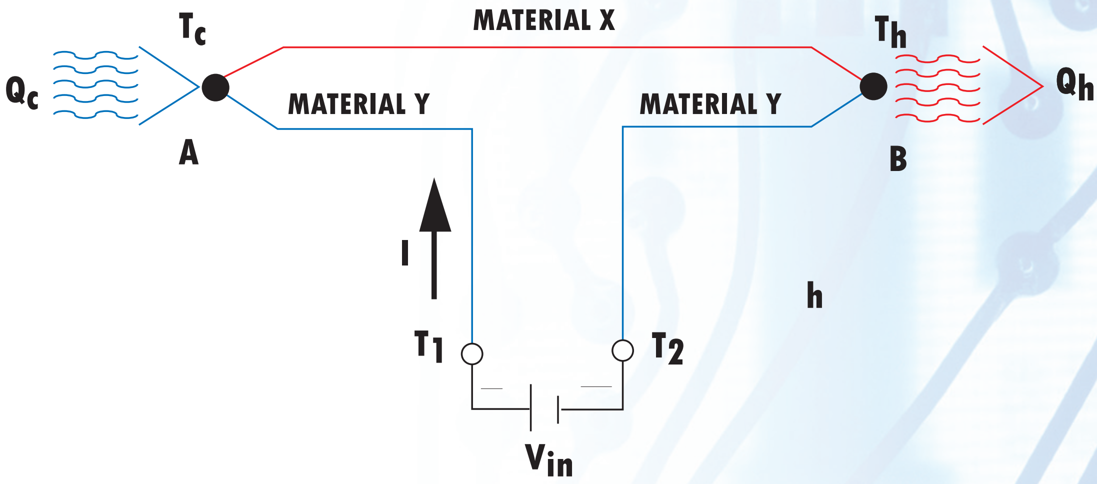

Figure 1. Circuit diagram demonstrating Peltier effect [1].

Thermoelectric Coolers (TECs) are essentially small heat pumps that can heat or cool both components and systems with low power dissipation. This ability, coupled with their high reliability (projected 200,000 hours MBTF), makes TECs an ideal method for precisely controlling thermal systems. TECs are also very effective for applications where sub-ambient cooling is required.

The fundamental principal behind the operation of TECs is the Peltier effect. This is demonstrated in Figure 1:

Two dissimilar conductive materials are joined together to form a circuit with a junction at points A and B. When a current is passed through the circuit as shown, the result is a relative temperature difference between the two junctions and a net heat transfer between the cold junction A and the hot junction B [1].

Using this principle, a working TEC module can be created from semiconductor materials. Bismuth telluride (Bi_2Te_3) is the primary thermoelectric material of choice, but other materials are available for specialized applications. Different conductive materials are created by doping the semiconductor to create what are commonly referred to as P-type and N-type materials [2].

P-type material has an electron deficit, while N-type material has an electron surplus. When electric current flows from the P to the N material at a common temperature junction, the electrons jump to a higher energy level, absorbing heat energy in the process. This creates the TEC cold junction. The reverse is true when the current flows from the N-type to P-type material. In this case, the electrons must drop to a lower energy state, releasing heat energy in the process and creating the hot junction of the TEC.

To make a working TEC, these P and N modules are linked electrically in series and thermally in parallel. They are assembled between two ceramic substrates. The cross-section in Figure 2 shows how a typical TEC is constructed and used.

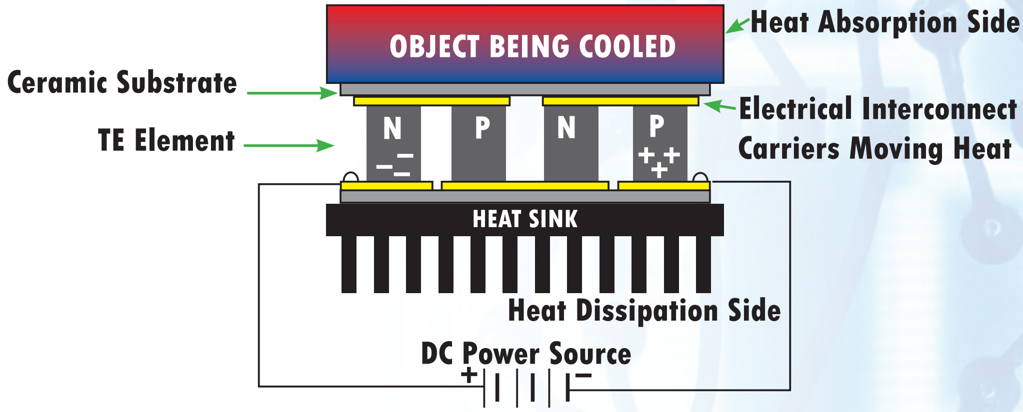

Figure 2.
Cross-section of a typical TEC with heat sink [1].

In practical applications, TECs are used with heat sinks to more effectively dissipate heat from hot junctions and thus increase their efficiency.

A general mathematical model can be constructed to describe TEC performance, using the governing equations below [1], [3]

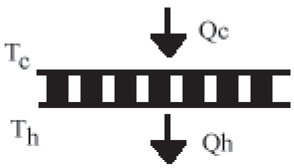

Figure 3.
Schematic of a TEC showing important variables [1].

The temperature (T) difference between the hot and cold side of the TEC can be expressed as:

$$\Delta T = T_h - T_c$$

Where ΔT is the temperature difference, T_h is the hot side junction temperature, and T_c is the cold side junction temperature of the module. All temperatures are expressed in K (absolute temperature).

The heat pumping capacity then becomes:

$$Q_c = (\alpha \cdot Tc \cdot I) - (0.5 \cdot I^2 \cdot \beta) - (\varepsilon \cdot \Delta T)$$

Where Q_c is the heat pumping capacity of the TEC in Watts, α is the Seebeck coefficient in Volts/K, β is the module resistance in Ohms, ε is the module thermal conductance in W/K, and I is the current through the module in Amps. The Seebeck coefficient, module thermal resistance and module thermal conductance are all temperature-dependent properties specific to each TEC. They can be determined through experimentation or by contacting the TEC manufacturer.

For a given ΔT and I, the required TEC supply voltage (V_{in}) becomes:

$$V_{in} = (\alpha \cdot \Delta T) + (I \cdot \beta)$$

The total input power (P_{in}) to the TEC is then:

$$P_{in} = V_{in} \cdot I$$

Finally, the TEC heat rejection (Q_h) is:

$$Q_h = P_{in} + Q_c$$

If the current flow through the TEC is reversed, it will effectively operate as a heater. In this case, the heat rejection becomes:

$$Q_h = (\alpha \cdot T_h \cdot I) + (0.5 \cdot I^2 \cdot \beta) - (\varepsilon \cdot (T_h - T_c))$$

The efficiency of TECs is generally greater in the heater mode because of the I^2R heating in the module. The theoretical ΔT limit for TECs is 65 to 70°C; however, in practical applications, multi-stage TECs should be considered if a ΔT of 55°C or greater is required.

There are a number of practical considerations and limitations with TECs. These include, but are not limited to, the following:

>> TECs are driven by the temperature differences between their hot and cold sides. Therefore, it is important to consider the desired temperature difference before selecting or implementing the TEC.

>> When TECs are used for sub-ambient cooling, it is important to consider the effects of condensation on the TEC and surrounding components.

>> The preferred method of attachment is to clamp the TEC between a heat sink and the component to be cooled or heated. TECs can also be soldered or epoxied in place, if care is taken to consider thermal expansion and contraction of the materials involved.

>> The use of high-performance thermal interface materials is recommended to minimize interfacial resistances and maximize TEC efficiency [1], [2].

>> TECs have shown to be most effective for spot cooling. For system level applications with larger power dissipation, experimental testing is highly recommended to validate the effectiveness of a TEC-based cooling system design prior to product release.

References:

1. Thermoelectric Technical Reference, FerroTec Corporation, 2001-2006.

2. Godfrey, S., Melcor Corporation, An Introduction to Thermoelectric Coolers, Electronics Cooling, September 1996.

3. Kraus, A. and Bar-Cohen, A., Thermal Analysis and Control of Electronic Equipment, McGraw Hill Book Company, pp. 441-452, 1983.