Optimising Thermoelectric Cooler Modules in a System

Introduction

The aim of this document is to provide better understanding of the data provided in the datasheet for thermoelectric cooler (TEC) or Peltier devices and how it may be used to understand and optimise a TEC in a system.

Example graphs are presented from ET-127-10-13-RS, but the explanations are applicable to all single stage TECs. The datasheets present equivalent data at three different fixed hot side temperatures (T_h = 25, 50 and 75°C) to illustrate the impact this has on performance: over this range, higher hot side temperatures normally lead to improved performance. This document will focus on examples at 25°C hot side.

Heat Flow

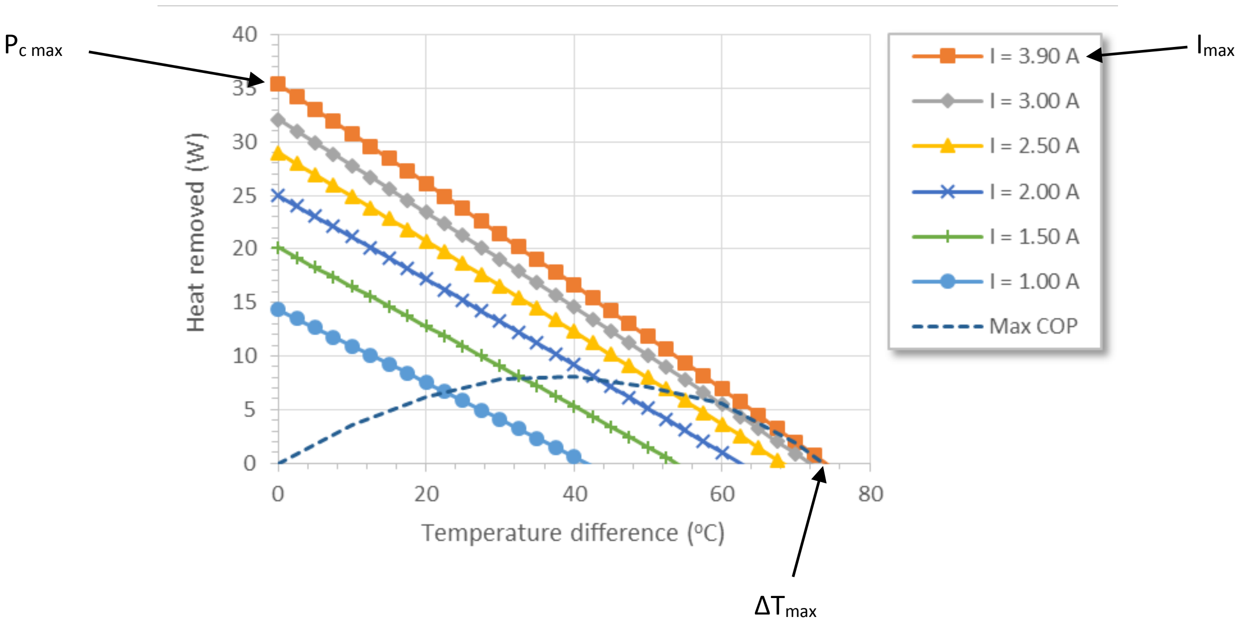

Figure 1: *Heat removed (Pc) vs Temperature difference at T_h = 25 °C*

Figure 1 shows the heat removed, P_c, against the temperature difference across the module at a range of different currents. This graph is important to use in determining the performance in your system. It is clear that the larger temperature difference that the module has to work against, the smaller the quantity of the heat removed from the cold side. For example, if a full system results in a

30 °C temperature difference across the module, the maximum cooling power can be read off the graph as a maximum of 21 W at a current of 3.9 A. It is important to estimate the temperature difference expected across the module, as the actual P_c in use can be significantly less than $P_{c\,max}$. The heat removed must compensate for any heat sources on the module cold side, and any thermal losses through contact with ambient air or insulation, or through clamping bolts etc. In addition the heat removed must be sufficient to provide an adequate transient response.

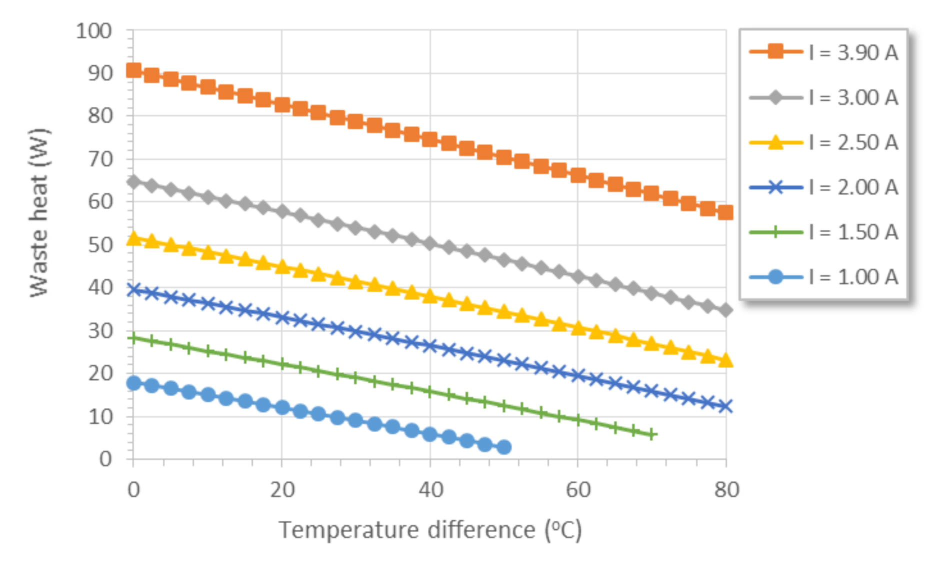

Figure 2: *Waste heat (Q_h) vs Temperature difference*

Figure 2 shows the waste heat, Q_h, against the temperature difference across the module at a range of different currents. This graph shows the amount of heat that must be dissipated from the hot side of the module. The waste heat is approximately given by the sum of the heat removed (Pc) and the electrical power into the module (IV):

$$Q_h = P_c + IV.$$

Therefore the waste heat is always higher than the heat removed, and can be significantly higher, especially at higher temperature differences and higher currents. For example, at a 30 °C temperature difference, at $I = I_{max} = 3.9\ A$, 79W of heat energy is dissipated from the hot side, significantly more than the 21 W of cooling provided by the cold side under these conditions. The quantity of waste heat can therefore serve as a guide to select a suitable heat sink or other heat transfer means on the hot side. Since the heat flow on the hot side is always higher than on the cold side, issues with a system can often be due to unintended additional thermal resistances added on the hot side.

This data can be used more quantitatively, to estimate the temperature difference seen by the module in a system. For example if other components such as a heat sink add a thermal resistance R_h on the hot side, they will result in an additional temperature loss T_h - T_{amb} in the system, as shown in Figure 3.

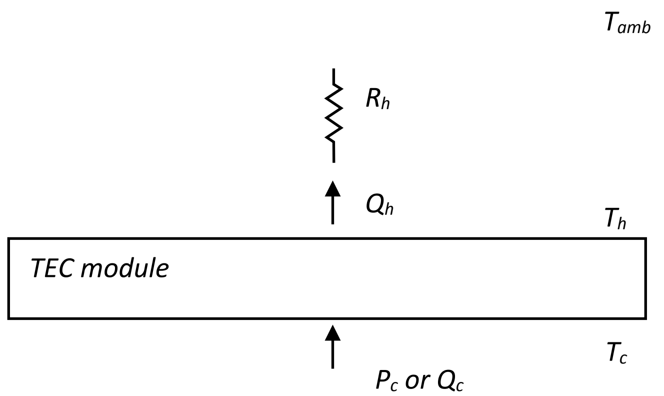

Figure 3: *TEC diagram including hot side thermal resistance.*

Using approximate knowledge of the heat out of the TEC, Q_h, can aid in estimating this temperature loss by using the equation:

$$T_h - T_{amb} = Q_h * R_h \ .$$

Continuing the example of using the TEC at 30 ^oC across the module and at a current *Imax*, a forced convection heat sink with a thermal resistance $R_h = 0.25\ ^oC/W$ is used. The additional system temperature drop $T_h - T_{amb} = R_h * Q_h = 0.25 * 79 = 20\,^oC$. Therefore, even though the module is generating a 30 ^oC temperature difference, the temperature drop between the cold side of the module and the ambient air (T_{amb}) is only $T_{amb} – T_c = \Delta T – (T_h – T_{amb}) = 30 – 20 = 10\ ^oC$.

The heat flow out of the module has a significant impact on the overall system performance as it has reduced the overall system temperature difference from 30 ^oC at the module level to 10 ^oC at the system level. Therefore it is usual to run the module at a current less than I_{max}, e.g. ~70% of I_{max}. This reduction in I_{max} only results in a small reduction in the cooling power (P_c) and the achievable module temperature differences, but produces a much larger reduction in the waste heat (Q_h).

This reduction in Q_h results in a better system performance. Note that there is an optimum, as if the current is reduced too much, the loss in module cooling power dominates, reducing system performance. The exact optimum current point depends on the module and system. The variation of the cooling power and waste heat with current can be seen more quantitatively in Figure 4 and Figure 5 (not published in standard datasheets).

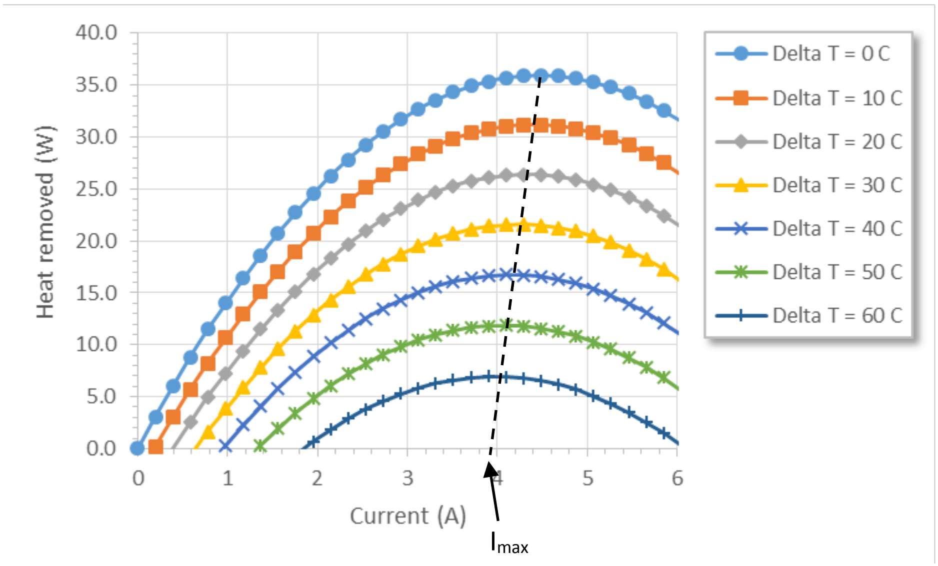

Figure 4: *Heat removed (P_c) vs current*

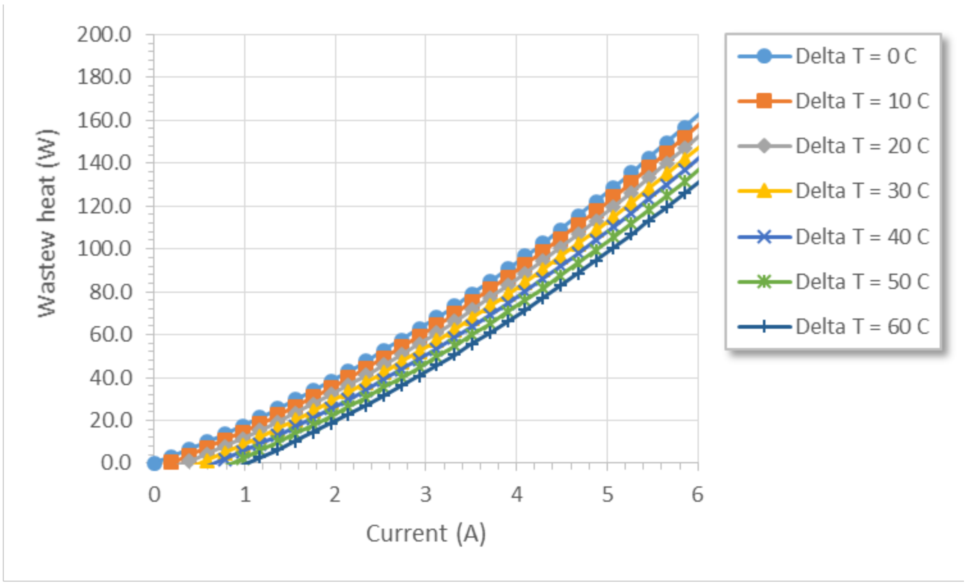

Figure 5: *Waste heat (Q_h) vs current*

Note that this non-linearity in the heat pumped vs current means that pulse width modulation (PWM) control may need additional smoothing before its input into the TEC, or it may reduce the TEC performance. This occurs as for example the average heat pumped and average waste heat is different if the module is run at I_{max} for half the time or $I_{max}/2$ all the time.

Electrical Characteristics

TEC voltage vs current characteristics are shown in Figure 6. The characteristics are dependent on the temperature difference as well as the mean module temperature. Therefore, for example, driving the module at a constant voltage from an initial zero temperature difference will result in a drop in current as a temperature difference across the module develops. This temperature difference dependence can be also be useful to troubleshoot a system. If, with a set voltage the current drawn is much smaller than expected (or equivalently the voltage is much higher than expected with a fixed current system), this suggests that the temperature difference across the module is much higher than expected, suggesting problems with thermal interfaces or other system issues. This can be separated from module issues by checking the AC resistance of the module in the 'off' state.

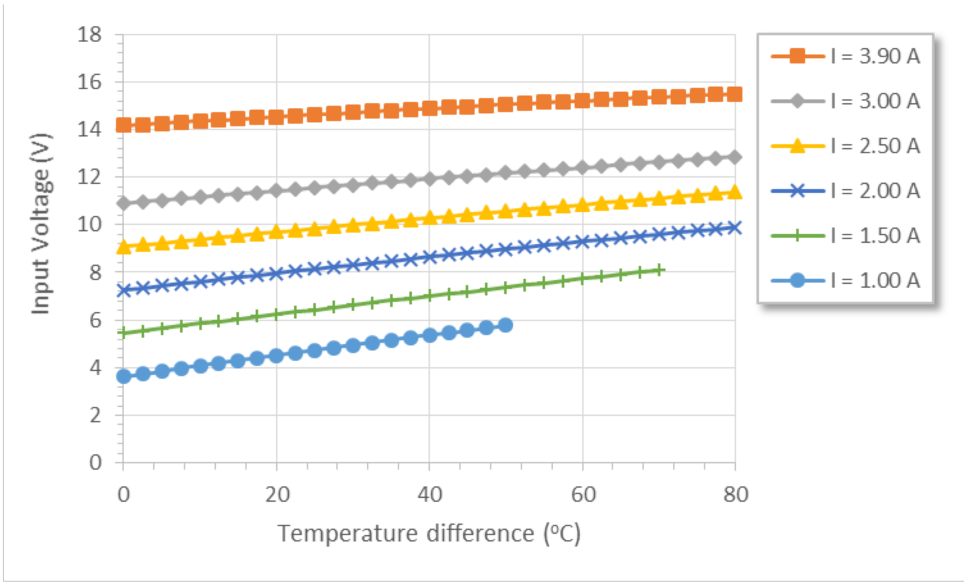

Figure 6: *TEC voltage vs TEC current*

Reversing a module

A thermoelectric single stage module can be electrically driven in reverse to reverse the heat flow direction. The performance will be almost completely identical apart from a small loss due to additional heat losses down the wires. Note that the temperature rating of either side of the module may be different in some cases. A high number of thermal cycles of the module can degrade device lifetime unless the module has been specifically designed for cycling applications (e.g. ETC or APHC in the part number).

A thermoelectric module may also be used as a heater when it pumps heat (i.e. using Q_h). Since it is a heat pump it can even achieve higher heat flow into the hot side than the inputted electrical energy. Heating is generally easier than cooling with a thermoelectric module. Typically a thermoelectric module is used instead of a resistive heater when fast ramp rates and stable temperatures are required, sue to the low thermal mass of the thermoelectric and its ability to actively heat and cool.

A thermoelectric module however has a lower maximum temperature rating than electrical resistance heaters so is not suitable for high temperatures or very high heat flows into large thermal masses.

Coefficient of Performance (COP)

The final graph (Figure 7) in the datasheet shows the coefficient of performance (*COP*). This is defined for cooling applications, as:

$$COP = \frac{Heat\ pumped}{Electrical\ input\ power} = \frac{P_c}{I * V}$$

It can be seen that the COP is maximised at low temperature differences and low to medium currents provided that the current is sufficient to achieve the required temperature difference. Figure 1 also shows what current (and associated P_c) the maximum *COP* occurs at when you have fixed the temperature difference. It does not show the value of the *COP* at that maximum. A high *COP* is desirable to reduce electricity usage and reduce the waste heat produced, but there is often a balance between efficiency and achievable pumping power or temperature difference.

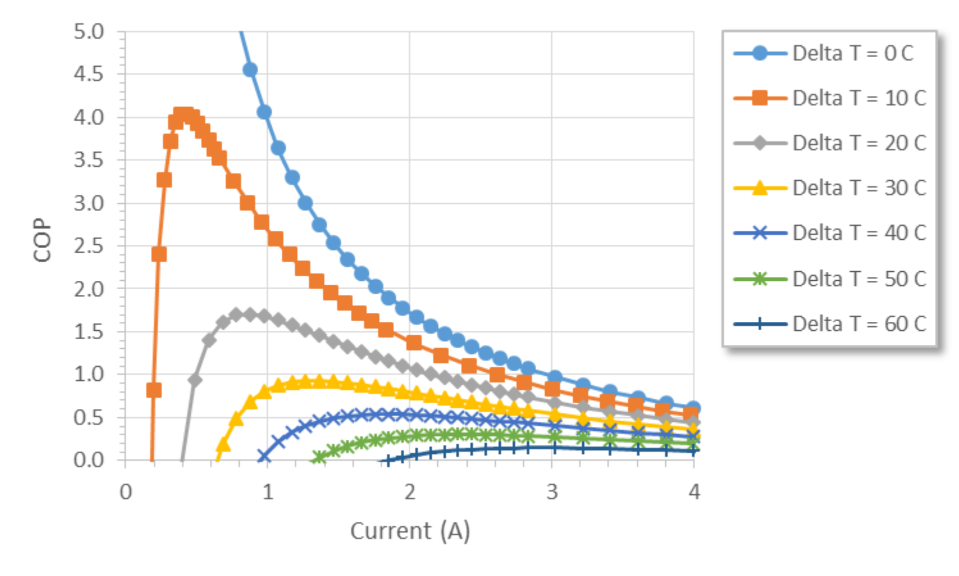

Figure 7: *Coefficient of performance vs current.*