Heat Pump (Thermoelectric Device)

CE20238 Chemical Engineering Skills, Practice and Design 2

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Results and Calculations

The first thing that was calculated was the work input to the cycle (W_{cycle}) This was done by using the values for heater power (Q_{in}) and cooling power (Q_{out}) are automatically obtained via the program and inserted into Equation 1 below:

$$W_{cycle} = Q_{out} - Q_{in}$$

$$\therefore W_{cycle} = 89.9 - 49.49 = 40.41W$$

This example calculation was from 5 Amps of Peltier power at temperature difference (dT) of 0.9, as will all example calculations for this section.

Once this calculation was complete, the next step was to calculate the coefficients of performance (COP) for all the different conditions that had been experimented on the Peltier device. For this, the recorded values for the Peltier power and the power input and output values were obtained, which were then used to find the COP in the heat pump (COP_{HP}) and the refrigeration system (COP_{Ref}), which can be calculated using Equations 2 and 3 as shown below:

$$COP_{HP} = \frac{Q_{out}}{W} = \frac{89.9}{56.88} = 1.58$$

$$COP_{Ref} = \frac{Q_{in}}{W} = \frac{49.49}{56.88} = 0.87$$

One the values for the Coefficient of Performance was calculated, these values were then plotted against dT, which is the temperature difference between the hot and cold reservoir temperatures, T1 – T2. This can be seen in Figure 1:

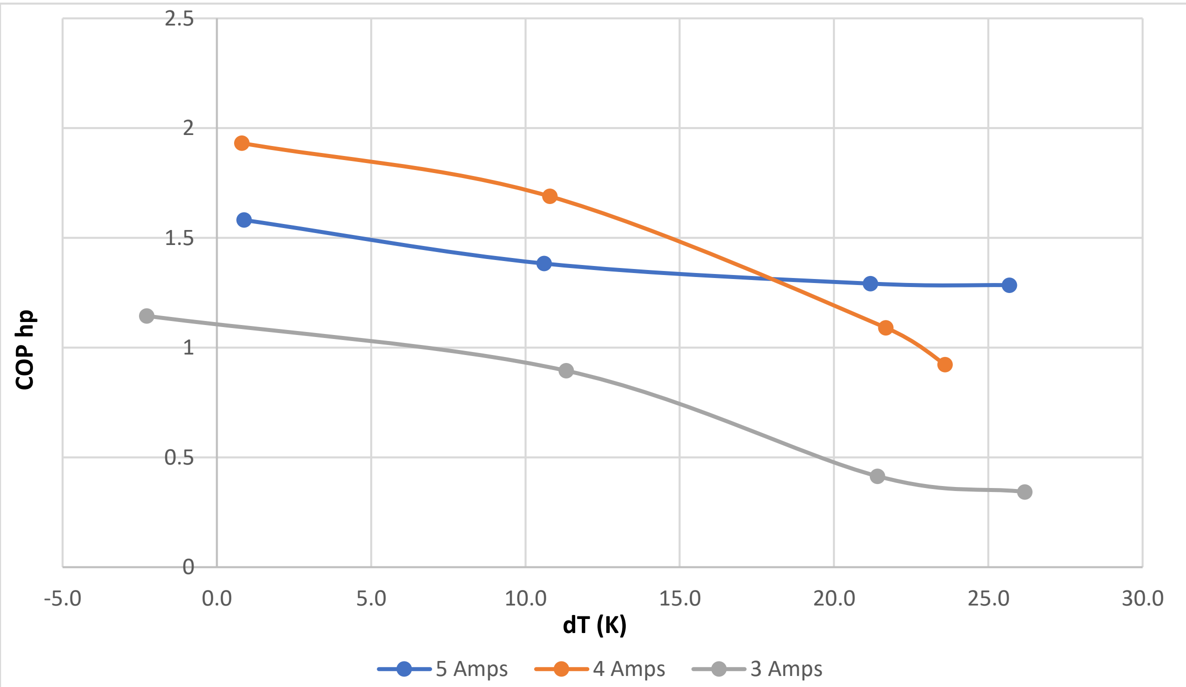

Figure 1: The relationship between the COP for the heat pump and the temperature difference (dT) for the different Peltier currents (Amps)

As well as this relationship, another graph was also plotted for the COP based on the refrigeration system, which lead to a slightly different relationship, however, the overall pattern is similar to the heat pump COP. This can be observed in Figure 2:

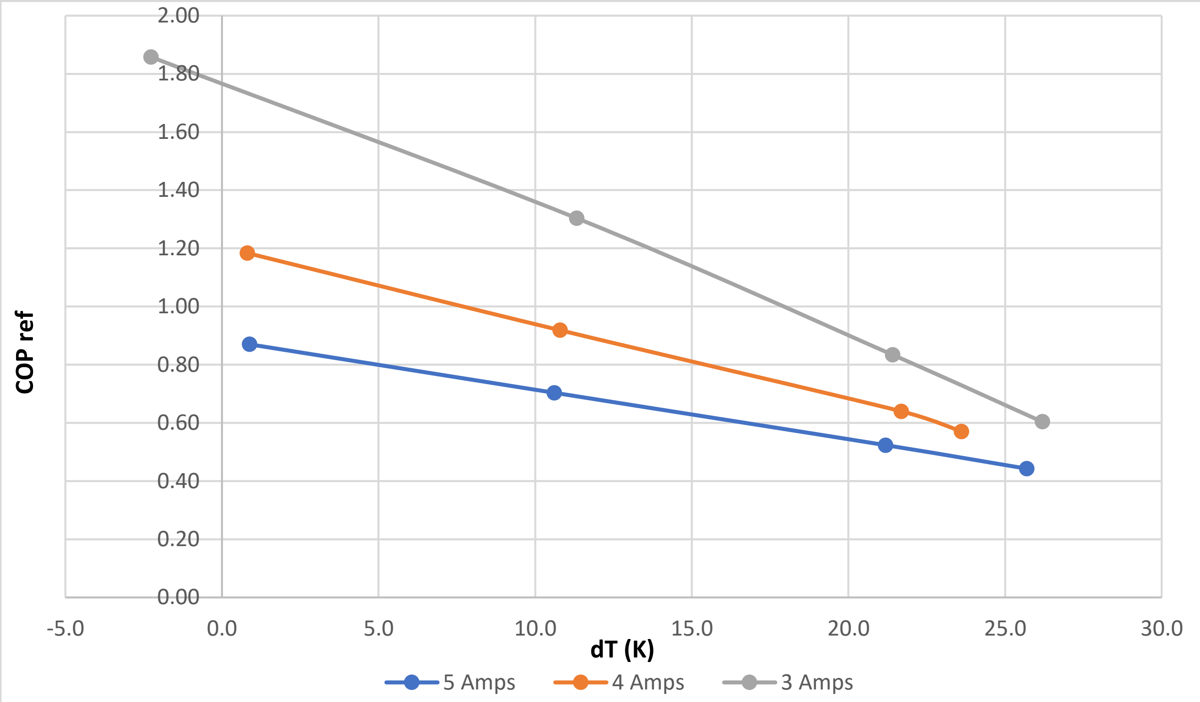

Figure 2: The relationship between the COP based on the refrigeration system and the temperature difference (dT) for the different Peltier currents (Amps)

One can initially see that the relationship for the refrigeration system is much more linear than the heat pump. The lowest current has the highest overall coefficient of performance, relative to the value of dT. When it comes to this, one can see that the greater the temperature difference, the lower the value for the COP for the refrigeration system, with the linear negative correlation.

For the COP for the heat pump, the same relationship is maintained where the greater the temperature difference, the lower the value for the COP. However, the relationship is not linear and there are gradual and sudden decreases which vary with which Peltier currents one is analyzing.

Once these graphs are produced, the next was heater power (Q_h) against dT for the different Peltier currents. Once plotted, a line of best fit was drawn for all the different currents, showing the relationship between the power and temperature difference, as can be seen in Figure 3:

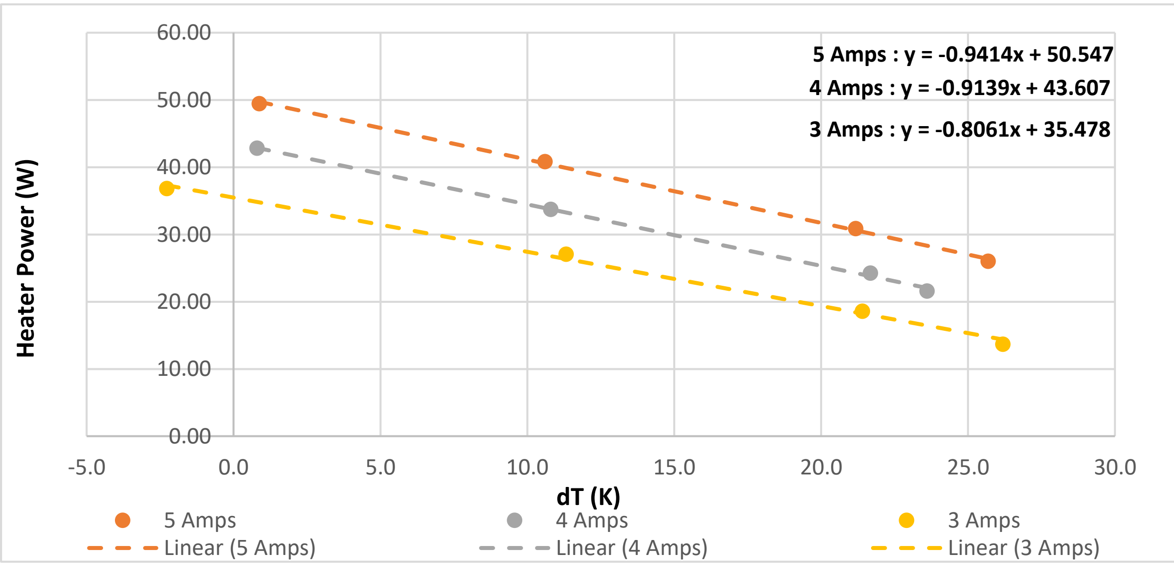

Figure 3: Relationship of Heater Power against dT for each setting of Peltier current (Amps)

Discussion

With all of the graphs produced one can initially identify that the greater the temperature difference for both the heat pump and the refrigeration system, the lower the COP values. Which then shows that there is less efficiency which can also be further seen in Figure 3, where the reason for this is due to the decreasing heater power with increasing temperature difference, especially the fact that there is a rather strong negative linear correlation with all the different Peltier currents. This linear relationship can also be seen in Figure 1.

The reason behind the relationship between COP and dT would be that the increasing temperature difference means that there is an increase in the amount of heat energy loss to the environment, meaning that less heat energy is transferred to the hot plate, meaning that the COP will be lower.

A way to increase the efficiency by increasing the heat transfer could be to increase the distance between the 2 plates, which would potentially counteract the temperature difference. This can be proven mathematically when analyzing Fourier's equation for heat transfer via conduction, where (Connor, 2019) the temperature gradient is given as $\frac{dT}{dx}$ therefore if we have a greater value of dx, we can decrease the effect of the temperature difference on the value of the heat transfer via conduction, if assumed that the value of the thermal conductivity of the plate remain constant, thereby decreasing the effect on conduction on the overall heat transfer and increasing the efficiency.

Also, at a specific point, the system will try to achieve equilibrium by moving heat in the opposite direction down the temperature gradient via convection, meaning that less heat energy is being transferred to the hot reservoir which then means that there is a less overall heat transfer. The material of the plates can be a factor that affects this and preferably a material with a lower thermal conductivity for the metal interconnect plates that are attached to the n-type and p-type semiconductors. The n-type and p-type semiconductors are the negative and positive electrodes, respectively. The suggested materials to use for the 2 plates were (*How do thermoelectric coolers (TEC) work | II-VI Incorporated*, 2021) Solid solutions of bismuth telluride, antimony telluride, and bismuth selenide are the preferred materials for Peltier effect devices because they provide the best performance from 180 to 400 K.

Also, when looking at the COP graph for the heat pump, Figure 1, one can see that the Peltier current with the highest COP is 4 Amps until around a temperature difference of 16K, where it then crosses over with the line that represents 5 Amps and drops to a COP value of 0.109, when at 5 Amps it is at 1.29. However, in the overall picture, the 4 Amp current is the most efficient one for low to medium temperature differences. In the COP for the refrigeration however, the most efficient overall current is the 3 Amp current and there is not crossing over of any of the lines for the 3 different conditions.

The reason behind this varying COP for the various Amps of currents could be that the assumption of a steady-state heat transfer is an impractical one, this is because the ideal conditions required to achieve a steady-state heat transfer is impossible to achieve in these lab conditions and therefore would be an inaccurate representative of the experiment that was undergone and therefore would have deviations of results from the ideal ones.

One of the main reasons why steady-state heat transfer could not be achieved was the fluctuations in the control of the conditions system. One of which is the flow-rate of the water between the 2 plates, the flow rate was fluctuating around the values that were calculated from the Peltier current, multiplied by 9, which would give the necessary flow rate in m^3/min. These values consisted of 45, 36 and 27 m^3/min and when looking at the raw data collected by the program, one can see the significant fluctuations around these values. At all 4 different conditions of the 5 Amp Peltier current trials, the ideal flowrate was 45 m^3/min, however, in all of the trials, the values were, at highest 69 m^3/min and at 48 m^3/min at the lowest, therefore the flowrate never stabilised at the ideal value. The same patterns can be seen with all of the other trials with different conditions.

The reasoning for the lack of control for the systems could be the accuracy of the temperature and pressure sensors, meaning that the flow rate and the temperature values could not be identified to an adequate accuracy, therefore the system may have tried to control the wrong conditions, due it processing the wrong conditions as the correct ones.

A good advantage of the Peltier effect in heat pumps is that it allows for heating up of devices that do not have any moving parts, therefore, these devices are much less likely to fail compared to the more conventional heaters. Another benefit of these heat pumps is that they require no maintenance meaning that it is easy to keep them in good condition.

The main advantages of the Peltier heat pumps include (O'Driscoll, 2019) quiet and free of vibrations as they don't contain moving parts, location isn't an issue and they can be moved so are suitable for portable units, can be small and lightweight, safe to use as no flammable or ozone-depleting refrigerants are required and economical to produce.

On the other hand, they are (O'Driscoll, 2019) generally slower than in compressor-cooling systems, complex, multistage systems are required for larger temperature differentials, can't provide low temperatures (below 10°C) and not very energy-efficient compared to compressor-based systems, therefore the lack of efficiency in a Peltier device would make it a less useful device and as alternative, a compressor-based system would be preferred by sacrificing the mobility of the Peltier device.

Some applications may include preheating swimming pools for adequate conditions for public use, cooling drinks such as water and beverages, dehumidifiers, circuit cooling in devices and refrigeration systems on vehicles such as cars, boats, planes, etc.

References

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