PELTIER HEAT PUMP

PRINCIPLE
The cooling capacity, heating capacity and efficiency rating of a Peltier heat pump are determined under different operating conditions.

EQUIPMENT
Thermogenerator
Flow-through heat exchanger
Air cooler
Heating coil with sockets
Distributor
Rheostat, 33 Ohm, 3.1 A
Connecting plug, 2 pcs.
Power supply, universal
Digital multimeter
Stopwatch, digital, 1/100 sec.
Cold/Hot air blower, 1700 W
Lab thermometer, -10...+100 °C
Thermometer, -10...+50 °C
Heat conductive paste, 50 g

THEORY
When an electric current flows through a circuit composed of two different conductors, heat will be liberated at one junction and absorbed at the other; depending on the direction in which the current is flowing (Peltier effect). The quantity of heat $Q$ liberated per unit time is proportional to the current $I$:

$$\frac{Q}{t} = \frac{P}{t} = \pi \cdot I = \alpha \cdot T \cdot I$$

where $\pi$ is the Peltier coefficient, $\alpha$ the Seebeck coefficient and $T$ the absolute temperature.
If an electric current $I$ flows in a homogeneous conductor in the direction of a temperature gradient $dT/dx$, heat will be absorbed or given out, depending on the material (Thomson effect):

$$P_T = \tau \cdot I \cdot \frac{dT}{dx}$$

where $\tau$ is the Thomson coefficient.

The direction in which the heat flows depends on the sign of the Thomson coefficient, the direction in which the current flows and the direction of the temperature gradient.

**Fig. 1** Construction of a Peltier semiconductor element. In practice several elements are generally connected in series (electrically) and in parallel (thermally).

**Fig. 2** Power balance flow chart in a Peltier component. (The example illustrated is for the case where $P_T > 0$)
If an electric current $I$ flows in an isothermal conductor of resistance $R$, we have the Joule effect:

$$P_J = R \cdot I^2$$

Because of heat conduction, heat also flows from the hot side (temperature $T_h$) to the cold side (temperature $T_c$):

$$P_L = L \frac{A}{d} (T_h - T_c)$$

where $L$ is the conductivity, $A$ the cross-sectional area and $d$ the thickness of the Peltier component.

Writing $\Delta T = T_h - T_c$, we obtain for the heat capacity of the pump on the cold side (the cooling capacity):

$$-P_c = \alpha T_c I \pm \frac{\tau I \Delta T}{2d} - \frac{1}{2} I^2 R - \frac{L \cdot A \cdot \Delta T}{d}$$

and, for the heat capacity of the pump on the hot side (the heating capacity):

$$+P_h = \alpha T_h I \pm \frac{\tau I \Delta T}{2d} + \frac{1}{2} I^2 R - \frac{L \cdot A \cdot \Delta T}{d}$$

The electric power supplied is

$$+P_{el.} = \alpha I \Delta T + RI^2 + \frac{\tau I \Delta T}{2d} = U_p \cdot I_p$$
SET-UP AND PROCEDURE

Fig. 3 General set-up for various sections of the experiment

Fig. 4 Set-up for determining cooling capacity
1) **To determine the cooling capacity $P_c$ of the pump as a function of the current and to calculate the efficiency rating $\eta_c$ at maximum output.**

   a) Set up the experiment according to Fig. 4 and Fig. 5. Ensure that readings on both sets of ammeter and voltmeter for the cold side and hot side are zero, i.e. the rheostat is at its original position (arrow pointing at “starting position” on the apparatus), and the voltage and current settings on the universal power supply are at zero. Fill the water bath to about 3/4 full; there is no need to fill the water bath all the way to the brim. Additionally, check to make sure that the polarity of the pump is correct, i.e. the red terminal is + and the blue terminal is - , as shown in Fig. 4.

   b) Turn on the tap where the water hose connects it to the hot side. Make sure that water flows into and out of the hot side with no leakage through the heat exchanger. Using the glass beaker and stopwatch provided, set the flow rate of water from the tap at approximately 200ml in 30s. There is no need to further adjust the flow of water at any point of the experiment; keep the flow constant. Then place the thermometers in the respective holes on the pump. Note that $T_h$ should be higher than $T_c$ (since water from the tap is warmer than the water in the water bath) after allowing the readings on both thermometers to settle down after a few minutes.

   c) Now, switch on the universal power supply (switch at the back of the front panel with the knobs). Turn and adjust the current knob to 5A. This value should stay fixed/constant and not to be adjusted throughout the experiment. Additionally, take note that this value is NOT $I_P$. The value of $I_P$ required is displayed on the ammeter (the same applies to experiments 2, 3 and 4), which is still zero now.
d) Then adjust the rheostat slowly and in small steps, until the current displayed on the ammeter $I_H$ is 1.5A. This current value is the required value of $I_H$ to be recorded. Additionally, record down the corresponding voltage $U_H$ displayed on the voltmeter (the same applies to experiments 2, 3 and 4). Wait for approximately 30mins for the water bath to heat up, and it should be observed that $T_c$ has increased by about 1°C to 2°C above $T_h$.

e) Adjust the voltage on the universal power supply until the current displayed on the ammeter $I_p$ is 0.5A. Ensure that $T_c$ is approximately equal to $T_h$ after waiting approximately 20mins for both temperatures to equilibrate, since it is necessary to allow time for temperature changes to occur. Otherwise, increase or reduce $I_p$ between 0.1A and 0.2A until both $T_c$ and $T_h$ are approximately equal to each other. Record down $I_p$ and the corresponding voltage $U_p$ displayed on the voltmeter (the same applies to experiments 2, 3 and 4).

f) Repeat steps (d) and (e) for $I_H = 2.0A, 2.5A, 3.0A, 3.5A$ and $4.0A$. Instead of waiting for 30mins for the water bath to heat up at these values of $I_H$, the waiting time may be reduced to about 20mins. Additionally, $I_p$ may need further fine-tuning, if required, for both $T_c$ and $T_h$ to achieve temperature equilibrium.

g) Determine the maximum $P_c$ from $P_H (= U_H I_H)$ vs $I_p$ plot and the efficiency rating $\eta_c$ at maximum $P_c$.

$$\eta_c = \frac{P_c}{P_{el}} = \frac{P_H}{U_p I_p}$$

2) To determine the heating capacity $P_h$ of the pump and its efficiency rating $\eta_h$ at constant current and constant temperature on the cold side.

a) Remove the heating coil from the water bath as it is no longer required. Reverse the operating current (i.e. reverse the electrical polarity of the pump) so that the water in the bath now heats up. Ensure that the current knob on the universal power supply is at 5A. This value should stay fixed/constant and not to be adjusted throughout the experiment.

b) Measure the rise in the temperature of water $T_h$ at constant current $I_p = 4.0A$, obtained by adjusting the voltage knob on the power supply. Record down $I_p, U_p$ and $T_c$. 
c) Calculate the total heat capacity $C_{\text{tot}}$ from the following data and the measured mass of the water.

\[ m_w = \text{(to be measured by student)}, \quad c_w = 4182 \frac{J}{\text{kgK}} \]
\[ m_{\text{Br}} = 0.0983 \text{ kg}, \quad c_{\text{Br}} = 381 \frac{J}{\text{kgK}} \]
\[ m_{\text{Cu}} = 0.712 \text{ kg}, \quad c_{\text{Cu}} = 383 \frac{J}{\text{kgK}} \]

\[ C_{\text{tot}} = m_w c_w + m_{\text{Br}} c_{\text{Br}} + m_{\text{Cu}} c_{\text{Cu}} \]

where $m_w$ = mass of the water in the water bath, $c_w$ = specific heat capacity of the water, $m_{\text{Cu}}$ = mass of a copper block, $c_{\text{Cu}}$ = specific heat capacity of copper, $m_{\text{Br}}$ = mass of the brass bath and $c_{\text{Br}}$ = specific heat capacity of brass.

d) Plot the graph of $T_\text{h}$ vs time $t$ at constant $I_p$ and determine its initial slope $dT_\text{h}/dt$.

e) Calculate the pump heating power $P_h$ and the corresponding efficiency rating $\eta_H$.

\[ P_h = C_{\text{tot}} \frac{dT_\text{h}}{dt} \]

\[ \eta_H = \frac{P_h}{P_{\text{el}}} = \frac{P_h}{I_p \overline{U}_p} \]

where $\overline{U}_p$ is the mean pump voltage.
3) To determine $P_h$, $\eta_h$ and $P_c$, $\eta_c$ from the relationship between temperature and time on the hot and cold sides.

a) Remove the pump in the set-up for experiments 1 and 2 and replace it with another pump fitted with water baths on both sides, as shown in Fig. 6, provided for the experiment. **PLEASE DO NOT DISMANTLE THE FLOW-THROUGH HEAT EXCHANGER from the previous pump.** Ensure that the polarity is correct when connecting the pump to the set-up (i.e. the red terminal is + and the blue terminal is - ), and similarly place the thermometers in the respective holes on the pump. Also ensure that the current knob on the universal power supply is at 5.0A. This value should stay fixed/constant and not to be adjusted throughout the experiment.

b) Fill water baths on both sides of the pump with same amount of water of the same temperature. With the current $I_p = 4.0A$ (constant and obtained by adjusting the voltage knob on the power supply) measure the changes in the temperature of the two water baths, i.e. $T_h = f(t)$, $T_c = f(t)$, $I_p$ and $U_p$.

c) Plot the graphs of $T_h$ and $T_c$ vs $t$ at constant $I_p$ and determine their initial slopes $dT_h/dt$ and $dT_c/dt$.

d) Calculate the total heat capacities of both the hot and cold sides, $C_{Htot}$ and $C_{Ctot}$.

e) Calculate the pump heating power $P_h$, cooling power $P_c$ and their efficiency ratings $\eta_h$ and $\eta_c$. 

Fig. 7   Pictorial set-up for experiment 3
4) To investigate the temperature behaviour when the pump is used for cooling, with the hot side air-cooled.

   a) Replace the water bath on the hot side of the pump that is used in experiment 3 with an air cooler shown in Fig. 8. Refrain from touching the underside of the air cooler which has thermal paste applied on it. Set $I_p = 2.0A$, by adjusting the voltage knob on the power supply. Measure the temperature of the cold side as a function of time, with the cooler

   i) in static atmospheric air, and
   ii) force-cooled with a blower.

   b) Plot and comment on the measured results. Determine the maximum temperature difference $T_h - T_c$ for (i).

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**Fig. 8** Air cooler for experiment 4

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