1 Sample calculations

$$R = 10\,\mathrm{mm}$$

$$k = 16.3\,\mathrm{W\,m^{-1}\,K^{-1}}$$

$$c = 460\,\mathrm{J\,kg^{-1}}$$

$$\rho = 8500\,\mathrm{kg\,m^{-3}}$$

$$\alpha = 0.45 \times 10^{-5}\mathrm{m^2\,s^{-1}}$$

1.1 High speed

When $t = 36\,\mathrm{s}$:

$$T_\infty = T_1 = 84.39$$

$$T_c = T_3 = 82.38$$

$$T_i = T_{3@t=0\,\mathrm{s}} = 30.36$$

$$\begin{aligned}\theta &= \frac{T_c - T_\infty}{T_i - T_\infty} \\ &= \frac{82.38 - 84.39}{30.36 - 84.39} \\ &= \frac{67}{1801} \\ &\approx 0.037 \text{ (same as computed value)}\end{aligned}$$

$$\begin{aligned}F_o &= \frac{\alpha t}{R^2} \\ &= \frac{(0.45 \times 10^{-5})(36)}{(0.01)^2} \\ &= 1.62 \text{ (same as computed value)}\end{aligned}$$

From the chart, $\frac{1}{\mathrm{Bi}} = 0.61$:

$$\begin{aligned}h &= \frac{\mathrm{Bi}\ k}{R} \\ &= \frac{\left(\frac{1}{0.61}\right)(16.3)}{0.01} \\ &= \frac{163000}{61} \\ &\approx 2672.13 \text{ (same as computed value)}\end{aligned}$$

1.2 Low speed

When $t = 36$ s:

$$T_\infty = T_1 = 83.21$$

$$T_c = T_3 = 80.52$$

$$T_i = T_{3@t=0\,\mathrm{s}} = 33.23$$

$$\begin{aligned}\theta &= \frac{T_c - T_\infty}{T_i - T_\infty} \\ &= \frac{80.52 - 83.21}{33.23 - 83.21} \\ &= \frac{269}{4998} \\ &\approx 0.054 \text{ (same as computed value)}\end{aligned}$$

$$\begin{aligned}F_o &= \frac{\alpha t}{R^2} \\ &= \frac{(0.45 \times 10^{-5})(36)}{(0.01)^2} \\ &= 1.62 \text{ (same as computed value)}\end{aligned}$$

From the chart, $\frac{1}{\mathrm{Bi}} = 0.79$:

$$\begin{aligned}h &= \frac{\mathrm{Bi}\ k}{R} \\ &= \frac{\left(\frac{1}{0.79}\right)(16.3)}{0.01} \\ &= \frac{163000}{79} \\ &\approx 2063.29 \text{ (same as computed value)}\end{aligned}$$

2 Discussion

The following four points is required to discuss:

a) T_1, T_2, and T_3 versus time at different pump rates;
b) The non-dimensional temperature difference, θ versus time at different pump rates;
c) The effect of pump rates on the heat convection coefficient (h);
d) The heat convection coefficient (h) versus time.

2.1 T_1, T_2, and T_3 versus time at different pump rates

Overall, when the pump speed is high, all the temperatures T_1, T_2, and T_3 are generally higher than when the pump speed is low.

For the graph of T_1 against time, the temperatures are relatively constant for both low-speed and high-speed pump rates due to the water bath maintaining the temperature, which was kept constant for both setups.

For the graph of T_2 against time, for both the low-speed and high-speed pump rates, the temperature increased at a decreasing rate until it reached a constant value.

For the graph of T_3 against time, both the low-speed and high-speed pump produced a graph that increased at a decreasing rate, but the initial rate of increase is much higher than that of the graph of T_2 against time. This is due to the larger temperature difference initially, which results in a much greater rate of heat transfer.

2.2 The non-dimensional temperature difference, θ versus time at different pump rates

The non-dimensional temperature difference, θ versus time decreased at a decreasing rate until it reached a constant value after $t = 64$ s. The high-speed pump had a higher rate of decrease than the low-speed pump. This suggests that the rate of heat transfer is higher for the high-speed pump than it is for the low-speed pump. This is due to higher flow velocity, increasing the turbulence of the water, which increases the Reynolds number, resulting in a higher rate of heat transfer by convection.

2.3 The effect of pump rates on the heat convection coefficient (h)

The heat convection coefficient was higher for the high-speed pump rate compared to the low-speed pump rate, up until about 55 s. This can be attributed to a higher rate of heat transfer by convection as the flow rate of water in the cylinder is higher, and hence more turbulent.

2.4 The heat convection coefficient (h) versus time

The heat convective coefficient for both the low-speed and high-speed pumps decreases at a decreasing rate until it reaches a constant value. In theory, the heat convective current should be constant since the pump rate, which affects the flow rate, is kept constant throughout the experiment. This decrease in the heat convection coefficient is due to the Biot number not being known, and hence needs to be derived from the Heisler charts using the Fourier number and the temperature difference to obtain the inverse of the Biot number. Since the temperature difference decreases over time, it is expected that the Biot number obtained from this method will also decrease with time, which explains the decreasing h values. If Biot number is calculated using the θ and Fourier number values for the entire duration of the experiment, then the h values would remain constant as expected.