1. (50 points) A countercurrent, double-pipe heat exchanger is used to heat the feed to a reactor. The reactants pass through the inside of the double-pipe heat exchanger, and a heat-transfer fluid flows through the outside of the double-pipe heat exchanger. Both streams are in turbulent flow (see figure below).

A decision is made to double the flow rate $m=2.1 \text{ kg/s}$ of the inside stream (the reactor feed stream that is being heated) to become $m_{\text{new}}=4.2 \text{ kg/s}$. The inlet temperature of the inside stream $T_1=21^\circ \text{C}$ is not changed and the inlet temperature $T'_2=95^\circ \text{C}$ and flow rate of the heat-transfer fluid $m'=3.07 \text{ kg/s}$ are not changed either. The system is allowed to come to steady state. Please answer the following.

a) Is the new value of the inner-stream outlet temperature ($T_2$) higher, lower, or is it the same as it was before this change in flow rate is made? Please explain briefly (provide one or two sentences with the appropriate equations).

b) **Bonus 5 points** Is the new value of the overall heat transfer coefficient of the heat exchanger ($U$) higher, lower, or is it the same as it was before this change in flow rate is made? Please explain briefly (provide one or two sentences with the appropriate equations).
2. (50 points) A 1-2 shell-and-tube heat exchanger is installed in a process as shown below. The overall heat transfer coefficient for this unit is \( U = 270 \, \text{W/m}^2 \, \text{K} \) and \( Q = 36,000 \, \text{W} \) of heat are transferred to the cooler stream at steady state. To obtain the desired operating temperatures shown below the figure, what does the heat-transfer area need to be?

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\begin{align*}
T_{ci} &= 25^\circ C \\
T_{co} &= 105^\circ C \\
T_{hi} &= 201^\circ C \\
T_{ho} &= 153^\circ C
\end{align*}
\]