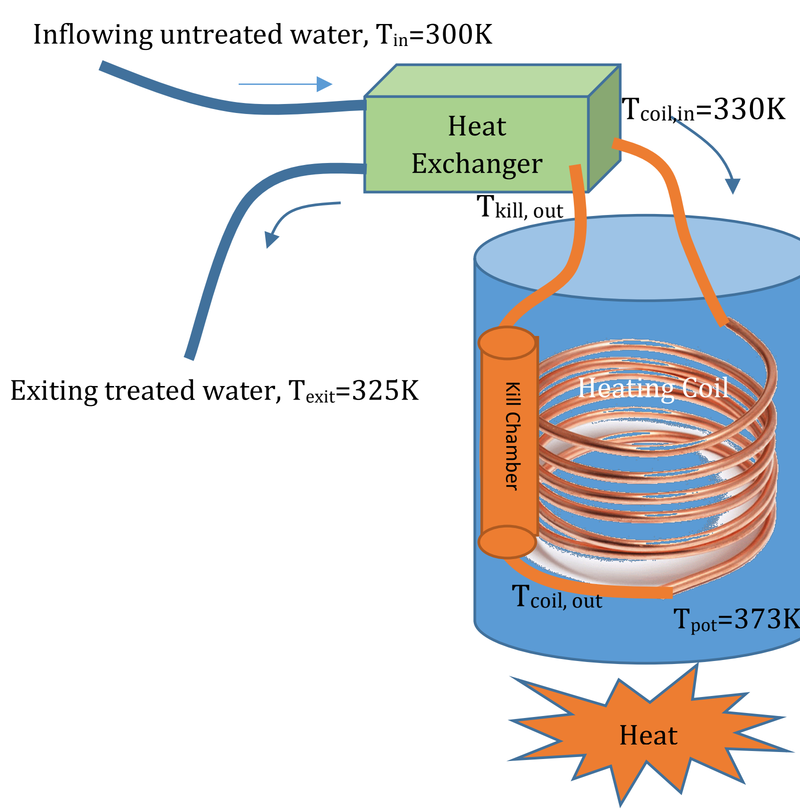
ME 332 Design Project 2
Dr. MacCarty, Fall 2021

Due Nov 22nd at 8am on Canvas. 10% late penalty per day for up to 5 days

Today 1.2 billion people in the developing world boil their water over campfires to kill pathogens like e.coli and viruses and then cool it to a safe temperature before consuming. This process is incredibly time consuming, energy-intensive, and creates significant emissions that harm environment and health. While people bring water to a full boil to use nucleate bubbles as an indicator that the water has been purified, pasteurization of these pathogens actually occurs at a much lower temperature. Research has shown that these pathogens are killed when held at only 77˚C for at least 15 seconds. Furthermore, once the water has reached this temperature, the energy can be recuperated and used to preheat the incoming water using a heat exchanger for added efficiency. Using these methods, the Water Purifier designed by our colleagues at InStove uses 97% less energy to purify water than traditional boiling on an open fire. For more information on this product and associated research in Dr. MacCarty's lab at OSU, see the last page of this document, and/or listen to the **OSU Engineering Out Loud Podcast** episode from 10/31/18 at https://engineering.oregonstate.edu/s7-e4-clean-water-solution-developing-world.

In this project, you will design and model a heat transfer and exchange system for the InStove water purifier. This system consists and a heat exchanger paired with a coil of copper tubing immersed in a pot of boiling water used to bring flowing water up to pasteurization temperature (77˚C), then pass it to a larger diameter section called a "kill chamber" that holds the water at or above 77˚C for at least 15 seconds before passing it back through the heat exchanger to recuperate the heat and return the water to a cool temperature where it then exits the system ready for use. Your task is to determine the required length of the coil and heat exchanger to achieve this objective.



Operating conditions are as follows:

- The temperature of the water entering the system is T_{in}=300K
- The temperature of the water exiting the system is T_{exit}=325K
- The temperature of the boiling water in the pot is held constant at 373 K
- You may assume constant properties (for water at an appropriate average temperature), fully developed flow, and no losses from the pot.
- The nominal flow rate of the water is 10liters per minute.
- The heating coil is made of ½" ID copper pipe.
- The heat exchanger is a concentric tube heat exchanger with the hot water flowing on the inside tube which is made of the same ½"ID copper pipe as the coil that has a 0.001 m wall thickness. The outer tube holds the incoming cool water and its diameter is sized to provide the same velocity water flow as the inner tube and is well insulated on the outside.
- The temperature of the water entering the heating coil (and leaving the heat exchanger's cold side) is $T_{coil,in}$=330 K.

Determine:

- For the copper coil
    - The convective heat transfer coefficient, h_{coil}, into the water as it passes through the ½" ID copper tube immersed in the pot of boiling water which provides a constant surface temperature
    - The length of tube needed, L_{coil}, to bring the water that has left the heat exchanger to the pasteurization temperature of 77°C
- For the heat exchanger
    - Design a concentric tube heat exchanger with the ½" ID copper pipe (with 0.001 m wall thickness) as the inner tube to achieve the desired objectives.
        - Size the outer tube diameter to provide the same fluid velocity as the inner tube.
        - Report in performance values for this heat exchanger in terms of inner and outer tube heat transfer coefficients, diameters, heat exchanger length, and U_o on the provided spreadsheet.
        - When designing the size of the heat exchanger tubing, what should you consider to optimize performance, and what trade-offs might exist? List at least three.
    - If fouling occurs over time in the heat exchanger, what will happen to the performance? What should the new length of the HX be to account for fouling? Calculate the effect of fouling in the heat exchanger over time using ***the average fouling factor for river water*** found in the textbook. You should use the same fouling factor on both sides of the heat exchanger, since the same water is flowing on both sides.
- For the overall system
    - Determine the rate of heat needed to be replaced in the pot by the fire, as well as the energy required per liter of clean water produced.
    - Compare the energy required to produce a clean liter of water with the pasteurizer to the amount of energy required to bring a liter of water from T_{in} to T_{boil}.
    - What will happen if the flow rate deviates from the nominal value? How should the design be adapted to ensure that the system performs as needed for variations in these and other relevant operational parameters?

- Generate two graphs. One should be of the heat exchanger length (y-axis) vs. flow rate (x-axis). A second should be any design and dependent variables of interest relevant to designing the system.
- Comment on how the design could be optimized. Consider how the system should operate with a factor of safety to ensure only safely pasteurized water exits the system under a variety of in-field conditions. What in-field conditions might change and how could the design be modified to accommodate potential deviations from anticipated conditions? List at least three deviations and design responses to ensure that only clean water is exiting the system.

Deliverables:
Rather than a report, the results of this project will be shared via numerical and short answer questions. The expected essay questions and file uploads are detailed in the provided Project #2 spreadsheet template.

Grading Matrix:

- Correct properties (10%)
- Correct numerical answers (65%)
- Short answer discussions (10%)
- Graphs (10%)
- Code upload (5%)

Group Work:
You are welcome but not required to work with <u>one</u> partner in completing this assignment. However, you and partner are to do your work individually (i.e. you cannot copy from other groups or from previous classes). You will submit one set of deliverables for the two of you.

Hints:

1. Start early. Analysis, coding, and debugging takes time.
2. You may check your answers with the instructor or TAs. This is highly encouraged to identify errors in methods or coding.
3. Anticipate referencing multiple chapters from the book.
4. You may assume constant water properties, and it is best to evaluate them at the average of the inlet and pasteurization temperatures. You may use property values for copper at 300K.
5. The HX will fit the special case where C_c=C_h since the same supply of water is flowing on both sides at the same mass flow rate, so take care with how you calculate your log-mean temperature difference.
6. When using the Dittus-Boelter equation, be sure to choose the correct exponent for the Pr term, depending on whether the outer surface is providing heating or cooling. Note it is specified that in the concentric tube heat exchanger, the hot fluid flows on the inside tube.
7. Assume the boiling water is providing a constant surface temperature at the outer surface of the heating coil. In reality this would be a convective flux, but we do not have sufficient correlations to determine the value of h on the outside of the tube at this point.
8. Be very careful with cross sectional area versus perimeters in your calculations, and be aware of the tube wall thickness when necessary.
9. The problem can be solved using Excel, a coding package, or Engineering Equation Solver (EES). EES is highly recommended since it is very user-friendly for this type of simultaneous equation solving.
10. You do not need to analyze the kill chamber in this simplified problem. However, you should be aware that it is there and the temperature will continue to rise after leaving the coil and

before exiting the pot, as you'll find in later calculations for the temperature entering the heat exchanger on the hot side. In the diagram this is shown as $T_{kill,out}$ and is greater than $T_{coil,out}$.

11. Your calculations should show less energy saving than the 97% listed in the project statement. In the simplified project, a concentric tube heat exchanger is used instead of a more effective compact heat exchanger. So the temperature of the water leaving the system in the real product is even lower, representing greater energy savings.