Tasty and Safe: Heat Transfer in Orange Juice

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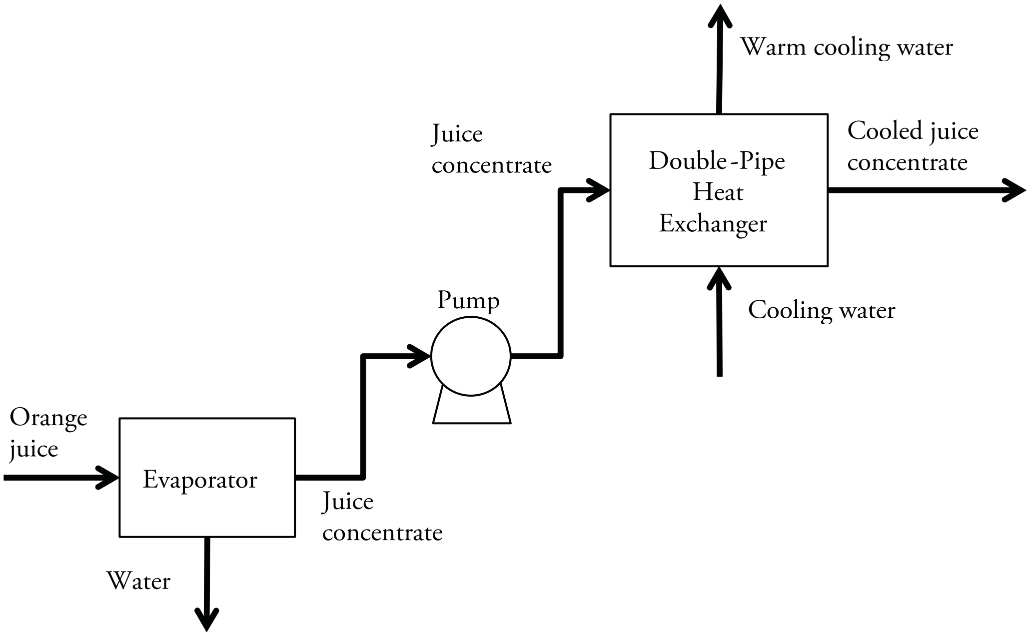
Part I – Think Before You Buy

A beverage company produces orange juice concentrate. A diagram of the evaporation and cooling process is shown below. The juice is concentrated in the evaporator after pasteurizing, then the concentrate is cooled for packaging and storage.

The current heat exchanger in the process is old and inefficient. However, it is a necessary par of the process: orange juice must be pasteurized to destroy pathogenic and spoilage microorganisms. The company decides that they have enough money in the budget to purchase a new heat exchanger. As the process engineering team for the company, your group is in charge of designing the new heat exchanger.



Questions

For the following scenarios, describe your approach for finding the desired quantity. Include in your descriptions the formulas, assumptions, and data needed for the solution. Write any equations in terms of variables only. Do not try to solve for actual values!

1. What is the energy balance for the heat exchanger given the inlet temperatures of concentrate and water, and the desired outlet temperature of concentrate?
2. What is the length of the double-pipe heat exchanger?

Part II – Staying on Spec

The company wants to produce orange juice concentrate with a moisture content no greater than 54% wet basis. 5 kg/s of concentrate enters the heat exchanger at 72°C. The concentrate must then be cooled to 20°C so it can be packaged.

Properties of the fluids (assume they are constant with temperature):

	Concentrate	*Water*	*Units*
C_p	2.919	4.195	kJ/kg K
k	0.425	0.577	W/m K
μ	0.413	0.001296	Pa s
ρ	1400	999.7	kg/m^3

Questions

1. Draw and label a diagram of the system.
2. Write the appropriate mass and energy balances for the system in terms of variables only.
3. How much cooling water is needed if the cooling water enters at 5°C and no more than a 10°C rise in water temperature is desired?

Part III – Choices, Choices…

Your team found that the amount of cooling water needed for cooling the juice is about 18 kg/s. The current heat exchanger uses 25 kg/s of cooling water. This convinces management that the heat exchanger needs to be replaced.

The team is considering an insulated double-pipe heat exchanger made of stainless steel. The ID of the inner and outer pipes are 4 cm and 12 cm, respectively, and the inner pipe has a wall thickness of 1 cm. There are four options for the heat exchanger setup.

1. Juice outside, water inside, cocurrent flow.
2. Juice inside, water outside, counter-current flow.
3. Water outside, juice inside, cocurrent flow.
4. Water inside, juice outside, counter-current flow.

Questions

1. Which setup will you pick? Explain your reasoning.
2. Calculate the log mean temperature difference in your selected heat exchanger setup.
3. One team member contacted the heat exchanger manufacturer for information on heat transfer efficiency. He was told that with his products, he should expect to have an overall heat transfer coefficient in the inner pipe of 2500 W/m^2 K. If this is the case, how long does the heat exchanger need to be?
4. The existing heat exchanger is 15 feet long. Will the heat exchanger you designed fit into this space? If not, how can you make it fit while maintaining the inlet and outlet temperatures of the orange juice? Discuss the various options available.
5. What are some other options for heat exchangers (aside from a double-pipe heat exchanger)? What type of heat exchanger would you recommend based on your product? Explain your answer. You do not need to perform any calculations, just discuss your approach.
6. If you were going to use a plate heat exchanger and the overall heat transfer coefficient was given to you, how would you figure out how many plates you need to achieve the desired temperature change in the orange juice? Explain your answer.