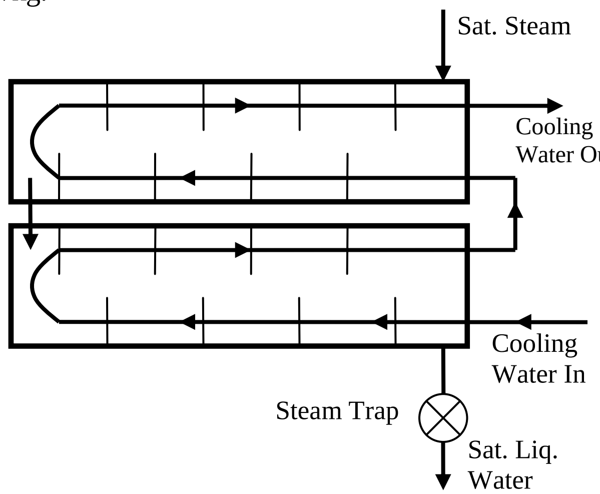
Problem Set # 11

Given: Mon., Nov. 26 **Recommended Completion Date:** Mon., Dec. 03
Do not submit for grading

Problem 1: Consider a clean two-shell-pass four-tube-pass heat exchanger as shown in the figure below. Saturated steam at 125°C is condensed on the outside surface of the tube. Cooling water is pumped through the tube at the rate of 2.5 kg/s. The inlet temperature of the cooling water is 20°C, and the rate of condensation of the steam is 0.3 kg/s. The specific heat of water is 4180 J/kg-°C, and the latent heat of condensation for steam (at 125°C), is $h_{fg} = 2.2\times10^6$ J/kg.

a) Based on total surface area of A = 4.807 m^2, what is the overall heat transfer coefficient?
b) After 3 years of operation, the original values of the saturated steam temperature; cooling water mass flow rate, temperature, and specific heat; and surface area remain essentially unchanged. But, scaling inside the heat exchanger causes its effectiveness to drop to ε = 0.50. Calculate the corresponding rate of condensation of steam.
c) What is the fouling factor after three years of operation?



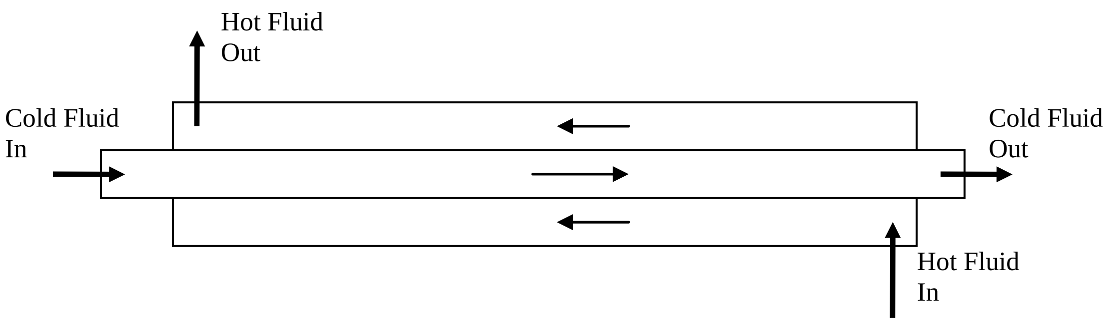
Ans.: a) 2000 W/m^2-°C; b) 0.2494 kg/s; c) 1.638×10^{-4} m^2-°C/W.

Problem 2: A brand new counter-flow double-pipe heat exchanger has a total heat transfer area of A = 1.6 m^2. For this brand new heat exchanger, the following operating data are available:

$\dot{m}_c = 0.5$ kg/s; $c_c = 4000$ J/kg-°C; $T_{c,i} = 20$°C; $T_{c,o} = 50$°C; $T_{h,i} = 200$°C; $T_{h,o} = 80$°C

For this brand new heat exchanger, (a) calculate the effectiveness, and (b) the overall heat transfer coefficient.

After five years of operation, the hot and cold fluid mass flow rates, the total surfaces area for heat transfer, the specific heats of the hot and cold fluids, and the inlet temperatures of the hot and cold fluids remain essentially the same as in the brand new heat exchanger. However, due to fouling of the heat exchanger, there is a 10% reduction in the total rate of heat transfer from the hot to cold fluid streams, and, as a result, the temperatures at the exit of the heat exchangers also change. (c) Calculate the effectiveness of the fouled heat exchanger; (d) what is the fouling factor?

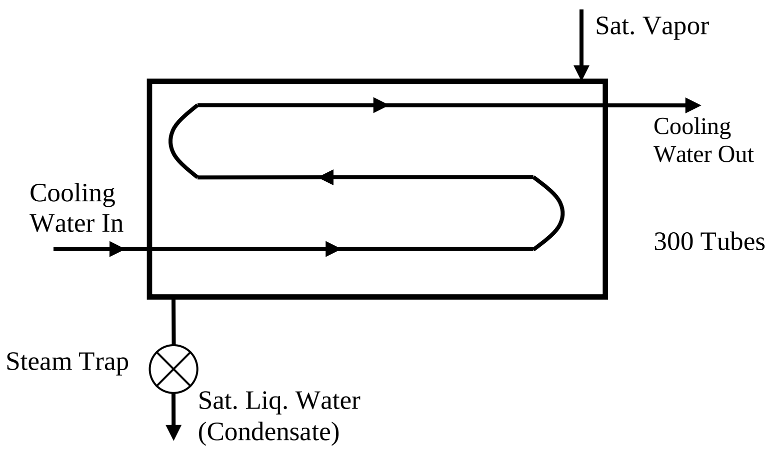


Ans.: a) 66.67%; b) 381.8 W/ m^2-°C; c) 60.0%; d) 5.81×10^{-4} m^2-°C/W.

Problem 3: A shell and tube heat exchanger (one shell pass, three tube passes) is to be designed to condense 3.0 kg/s of a saturated vapor at 40°C. The latent heat of condensation for this vapor is h_{fg} $=2.1\times10^6$ J/kg. Condensation occurs on the outside surfaces of the tubes, and corresponding convection coefficient is h_o = 12500 W/m^2-°C. The condenser is supplied with cooling water, which enters the tube at 20°C. The desired exit temperature of the cooling water is 30°C. The tubes are smooth and thin walled: D_o =0.023 m and D_i = 0.02 m. The thermal conductivity of the pipe material is k_{pipe} = 200 W/m-°C. A total of 300 tubes are used. The properties of the cooling water may be assumed constant at the following values:

$$\rho = 1000 \text{ kg/m}^3;\ c_p = 4200 \text{ J/kg-°C};\ \mu = 9.0\times 10^{-4} \text{ kg/m-s};\ k = 0.6\text{W/m-°C}.$$

a) What is the total rate of heat transfer that is required to obtain the desired rate of condensation?
b) What is required total mass flow rate of the cooling water?
c) What is the average velocity of the water in the tubes?
d) What is the overall heat transfer coefficient for this heat exchanger?
e) What is the total length of each tube?
f) After four years of operation, the saturated vapor temperature, the mass flow rate and inlet temperature of the cooling water, and the heat exchanger geometry remain unchanged, but fouling causes the rate of condensation to drop to 2.0 kg/s. What is the fouling factor?



Ans.: a) 6.3×10^6 W; b) 150 kg/s; c) 1.592 m/s; d) U_i =4347.1 W/ m^2-°C (based on internal pipe surface); e) 5.33 m; f) $R_{i,foul} = 1.636\times10^{-4}$ m^2-°C/W (based on internal pipe surface).

Selected Problems from the Textbook

Please do the following problems:

6th Edition: **11.4, 11.16, 11.34**

or

7th Edition: **11.4, 11.18, 11.39**