13-95 Cold water is heated by hot water in a heat exchanger. The net rate of heat transfer and the heat transfer surface area of the heat exchanger are to be determined.

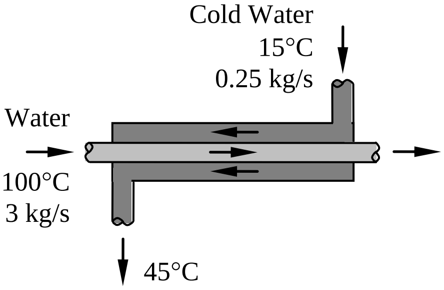
Assumptions **1** Steady operating conditions exist. **2** The heat exchanger is well-insulated so that heat loss to the surroundings is negligible and thus heat transfer from the hot fluid is equal to the heat transfer to the cold fluid. **3** Changes in the kinetic and potential energies of fluid streams are negligible. **4** The overall heat transfer coefficient is constant and uniform. **5** The thickness of the tube is negligible.

Properties The specific heats of the cold and hot water are given to be 4.18 and 4.19 kJ/kg.°C, respectively.

Analysis The heat capacity rates of the hot and cold fluids are

$$C_h = \dot{m}_h C_{ph} = (0.25 \text{ kg/s})(4180 \text{ J/kg.°C}) = 1045 \text{ W/°C}$$

$$C_c = \dot{m}_c C_{pc} = (3 \text{ kg/s})(4190 \text{ J/kg.°C}) = 12{,}570 \text{ W/°C}$$



Therefore, $C_{\min} = C_c = 1045 \text{ W/°C}$

and $$C = \frac{C_{\min}}{C_{\max}} = \frac{1045}{12{,}570} = 0.083$$

Then the maximum heat transfer rate becomes

$$\dot{Q}_{\max} = C_{\min}(T_{h,in} - T_{c,in}) = (1045 \text{ W/°C})(100\text{°C} - 15\text{°C}) = 88{,}825 \text{ W}$$

The actual rate of heat transfer is

$$\dot{Q} = C_h (T_{h,in} - T_{h,out}) = (1045 \text{ W/°C})(45\text{°C} - 15\text{°C}) = \mathbf{31{,}350 \text{ W}}$$

Then the effectiveness of this heat exchanger becomes

$$\varepsilon = \frac{Q}{Q_{\max}} = \frac{31{,}350}{88{,}825} = 0.35$$

The NTU of this heat exchanger is determined using the relation in Table 13-5 to be

$$NTU = \frac{1}{C-1}\ln\left(\frac{\varepsilon - 1}{\varepsilon C - 1}\right) = \frac{1}{0.083-1}\ln\left(\frac{0.35-1}{0.35\times 0.083-1}\right) = 0.438$$

Then the surface area of the heat exchanger is determined from

$$NTU = \frac{UA}{C_{\min}} \longrightarrow A = \frac{NTU\ C_{\min}}{U} = \frac{(0.438)(1045 \text{ W/°C})}{950 \text{ W/m}^2.\text{°C}} = \mathbf{0.482 \text{ m}^2}$$

13-96 "!PROBLEM 13-96"

"GIVEN"
T_cw_in=15 "[C]"
T_cw_out=45 "[C]"
m_dot_cw=0.25 "[kg/s]"
C_p_cw=4.18 "[kJ/kg-C]"
T_hw_in=100 "[C], parameter to be varied"
m_dot_hw=3 "[kg/s]"
C_p_hw=4.19 "[kJ/kg-C]"
"U=0.95 [kW/m^2-C], parameter to be varied"

"ANALYSIS"
"With EES, it is easier to solve this problem using LMTD method than NTU method. Below, we use LMTD method. Both methods give the same results."
DELTAT_1=T_hw_in-T_cw_out
DELTAT_2=T_hw_out-T_cw_in
DELTAT_lm=(DELTAT_1-DELTAT_2)/ln(DELTAT_1/DELTAT_2)
Q_dot=U*A*DELTAT_lm
Q_dot=m_dot_hw*C_p_hw*(T_hw_in-T_hw_out)
Q_dot=m_dot_cw*C_p_cw*(T_cw_out-T_cw_in)

$T_{hw, in}$ [C]	Q [kW]	A [m^2]
60	31.35	1.25
65	31.35	1.038
70	31.35	0.8903
75	31.35	0.7807
80	31.35	0.6957
85	31.35	0.6279
90	31.35	0.5723
95	31.35	0.5259
100	31.35	0.4865
105	31.35	0.4527
110	31.35	0.4234
115	31.35	0.3976
120	31.35	0.3748

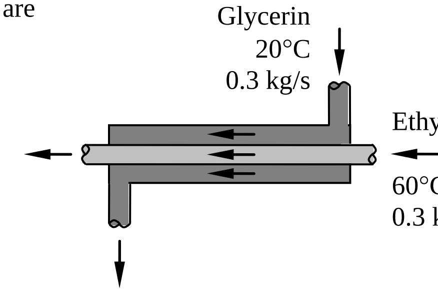
U [kW/m^2-C]	Q [kW]	A [m^2]
0.75	31.35	0.6163
0.8	31.35	0.5778
0.85	31.35	0.5438
0.9	31.35	0.5136
0.95	31.35	0.4865
1	31.35	0.4622
1.05	31.35	0.4402
1.1	31.35	0.4202
1.15	31.35	0.4019
1.2	31.35	0.3852
1.25	31.35	0.3698

13-97 Glycerin is heated by ethylene glycol in a heat exchanger. Mass flow rates and inlet temperatures are given. The rate of heat transfer and the outlet temperatures are to be determined.

Assumptions **1** Steady operating conditions exist. **2** The heat exchanger is well-insulated so that heat loss to the surroundings is negligible and thus heat transfer from the hot fluid is equal to the heat transfer to the cold fluid. **3** Changes in the kinetic and potential energies of fluid streams are negligible. **4** The overall heat transfer coefficient is constant and uniform. **5** The thickness of the tube is negligible.

Properties The specific heats of the glycerin and ethylene glycol are given to be 2.4 and 2.5 kJ/kg.°C, respectively.

Analysis (*a*) The heat capacity rates of the hot and cold fluids are



$$C_h = \dot{m}_h C_{ph} = (0.3\text{ kg/s})(2400\text{ J/kg.°C}) = 720\text{ W/°C}$$

$$C_c = \dot{m}_c C_{pc} = (0.3\text{ kg/s})(2500\text{ J/kg.°C}) = 750\text{ W/°C}$$

Therefore, $C_{\min} = C_h = 720\text{ W/°C}$

and $C = \dfrac{C_{\min}}{C_{\max}} = \dfrac{720}{750} = 0.96$

Then the maximum heat transfer rate becomes

$$\dot{Q}_{\max} = C_{\min}(T_{h,in} - T_{c,in}) = (720\text{ W/°C})(60\text{°C} - 20\text{°C}) = 28.8\text{ kW}$$

The NTU of this heat exchanger is

$$NTU = \frac{UA_s}{C_{\min}} = \frac{(380\text{ W/m}^2.\text{°C})(5.3\text{ m}^2)}{720\text{ W/°C}} = 2.797$$

Effectiveness of this heat exchanger corresponding to C = 0.96 and NTU = 2.797 is determined using the proper relation in Table 13-4

$$\varepsilon = \frac{1 - \exp[-NTU\,(1 + C)]}{1 + C} = \frac{1 - \exp[-2.797(1 + 0.96)]}{1 + 0.96} = 0.508$$

Then the actual rate of heat transfer becomes

$$\dot{Q} = \varepsilon \dot{Q}_{\max} = (0.508)(288\text{ kW}) = \mathbf{14.63\text{ kW}}$$

(*b*) Finally, the outlet temperatures of the cold and the hot fluid streams are determined from

$$\dot{Q} = C_c(T_{c,out} - T_{c,in}) \longrightarrow T_{c,out} = T_{c,in} + \frac{\dot{Q}}{C_c} = 20\text{°C} + \frac{14.63\text{ kW}}{0.72\text{ kW/°C}} = \mathbf{40.3\text{°C}}$$

$$\dot{Q} = C_h(T_{h,in} - T_{h,out}) \longrightarrow T_{h,out} = T_{h,in} - \frac{\dot{Q}}{C_h} = 60\text{°C} - \frac{14.63\text{ kW}}{0.75\text{ kW/°C}} = \mathbf{40.5\text{°C}}$$

13-98 Water is heated by hot air in a cross-flow heat exchanger. Mass flow rates and inlet temperatures are given. The rate of heat transfer and the outlet temperatures are to be determined.

Assumptions **1** Steady operating conditions exist. **2** The heat exchanger is well-insulated so that heat loss to the surroundings is negligible and thus heat transfer from the hot fluid is equal to the heat transfer to the cold fluid. **3** Changes in the kinetic and potential energies of fluid streams are negligible. **4** The overall heat transfer coefficient is constant and uniform. **5** The thickness of the tube is negligible.

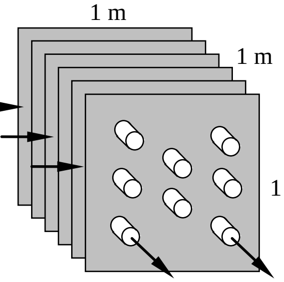
Properties The specific heats of the water and air are given to be 4.18 and 1.01 kJ/kg.°C, respectively.

Analysis The mass flow rates of the hot and the cold fluids are

$$\dot{m}_c = \rho V A_c = (1000\ \text{kg/m}^3)(3\ \text{m/s})[40\pi(0.01\ \text{m})^2/4] = 9.425\ \text{kg/s}$$

$$\rho_{air} = \frac{P}{RT} = \frac{105\ \text{kPa}}{(0.287\ \text{kPa.m}^3/\text{kg.K}) \times (130+273\ \text{K})} = 0.908\ \text{kg/m}^3$$

$$\dot{m}_h = \rho V A_c = (0.908\ \text{kg/m}^3)(12\ \text{m/s})(1\ \text{m})^2 = 10.90\ \text{kg/s}$$



The heat transfer surface area and the heat capacity rates are

$$A_s = n\pi DL = 80\pi(0.01\text{m})(1\text{m}) = 2.513\text{m}^2$$

$$C_h = \dot{m}_h C_{ph} = (9.425\ \text{kg/s})(4.18\ \text{kJ/kg.°C}) = 39.4\ \text{kW/°C}$$

$$C_c = \dot{m}_c C_{pc} = (10.9\ \text{kg/s})(1.010\ \text{kJ/kg.°C}) = 11.01\ \text{kW/°C}$$

Therefore, $C_{\min} = C_c = 11.01\ \text{kW/°C}$ and $C = \frac{C_{\min}}{C_{\max}} = \frac{11.01}{39.40} = 0.2794$

$$\dot{Q}_{\max} = C_{\min}(T_{h,in} - T_{c,in}) = (11.01\ \text{kW/°C})(30°\text{C} - 18°\text{C}) = 1233\ \text{kW}$$

The NTU of this heat exchanger is

$$NTU = \frac{UA_s}{C_{\min}} = \frac{(130\,\text{W/m}^2.°\text{C})\,(2.513\text{m}^2)}{11{,}010\,\text{W/°C}} = 0.02967$$

Noting that this heat exchanger involves mixed cross-flow, the fluid with $C_{\min}$ is mixed, $C_{\max}$ unmixed, effectiveness of this heat exchanger corresponding to C = 0.2794 and NTU =0.02967 is determined using the proper relation in Table 13-4 to be

$$\varepsilon = 1 - \exp\left[-\frac{1}{C}(1 - e^{-CNTU})\right] = 1 - \exp\left[-\frac{1}{0.2794}(1 - e^{-0.2794 \times 0.02967})\right] = 0.02912$$

Then the actual rate of heat transfer becomes

$$\dot{Q} = \varepsilon \dot{Q}_{\max} = (0.02912)(1233\text{kW}) = \mathbf{35.90\ kW}$$

Finally, the outlet temperatures of the cold and the hot fluid streams are determined from

$$\dot{Q} = C_c(T_{c,out} - T_{c,in}) \longrightarrow T_{c,out} = T_{c,in} + \frac{\dot{Q}}{C_c} = 18°\text{C} + \frac{35.90\,\text{kW}}{39.40\,\text{kW/°C}} = \mathbf{18.9°C}$$

$$\dot{Q} = C_h(T_{h,in} - T_{h,out}) \longrightarrow T_{h,out} = T_{h,in} - \frac{\dot{Q}}{C_h} = 130°\text{C} - \frac{35.90\,\text{kW}}{11.01\,\text{kW/°C}} = \mathbf{126.7°C}$$

13-99 Ethyl alcohol is heated by water in a shell-and-tube heat exchanger. The heat transfer surface area of the heat exchanger is to be determined using both the LMTD and NTU methods.

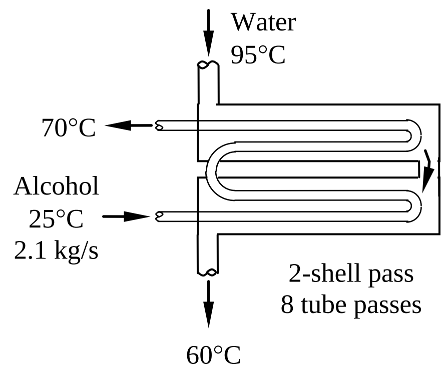
Assumptions **1** Steady operating conditions exist. **2** The heat exchanger is well-insulated so that heat loss to the surroundings is negligible and thus heat transfer from the hot fluid is equal to the heat transfer to the cold fluid. **3** Changes in the kinetic and potential energies of fluid streams are negligible. **4** The overall heat transfer coefficient is constant and uniform.

Properties The specific heats of the ethyl alcohol and water are given to be 2.67 and 4.19 kJ/kg.°C, respectively.

Analysis (*a*) The temperature differences between the two fluids at the two ends of the heat exchanger are

$$\Delta T_1 = T_{h,in} - T_{c,out} = 95°\text{C} - 70°\text{C} = 25°\text{C}$$

$$\Delta T_2 = T_{h,out} - T_{c,in} = 60°\text{C} - 25°\text{C} = 35°\text{C}$$



The logarithmic mean temperature difference and the correction factor are

$$\Delta T_{lm,CF} = \frac{\Delta T_1 - \Delta T_2}{\ln(\Delta T_1 / \Delta T_2)} = \frac{25-35}{\ln(25/35)} = 29.7°\text{C}$$

$$\left.\begin{array}{l} P = \dfrac{t_2 - t_1}{T_1 - t_1} = \dfrac{70-25}{95-25} = 0.64 \\ R = \dfrac{T_2 - T_1}{t_1 - t_1} = \dfrac{95-60}{70-25} = 0.78 \end{array}\right\} F = 0.93$$

The rate of heat transfer is determined from

$$\dot{Q} = \dot{m}_c C_{pc}(T_{c,out} - T_{c,in}) = (2.1\text{ kg/s})(2.67\text{ kJ/kg.°C})(70°\text{C} - 25°\text{C}) = 252.3\text{ kW}$$

The surface area of heat transfer is

$$\dot{Q} = UA_s \Delta T_{lm} \longrightarrow A_s = \frac{\dot{Q}}{UF\Delta T_{lm}} = \frac{252.3\text{kW}}{0.8\text{ kW/m}^2\text{.°C})(0.93)(29.7°\text{C})} = \mathbf{11.4\ m^2}$$

(*b*) The rate of heat transfer is

$$\dot{Q} = \dot{m}_c C_{pc}(T_{c,out} - T_{c,in}) = (2.1\text{ kg/s})(2.67\text{ kJ/kg.°C})(70°\text{C} - 25°\text{C}) = 252.3\text{ kW}$$

The mass flow rate of the hot fluid is

$$\dot{Q} = \dot{m}_h C_{ph}(T_{h,in} - T_{h,out}) \rightarrow \dot{m}_h = \frac{\dot{Q}}{C_{ph}(T_{h,in} - T_{h,out})} = \frac{252.3\text{ kW}}{(4.19\text{kJ/kg.°C})(95°\text{C} - 60°\text{C})} = 1.72\text{ kg/s}$$

The heat capacity rates of the hot and the cold fluids are

$$C_h = \dot{m}_h C_{ph} = (1.72\text{ kg/s})(4.19\text{ kJ/kg.°C}) = 7.21\text{ kW/°C}$$

$$C_c = \dot{m}_c C_{pc} = (2.1\text{kg/s})(2.67\text{ kJ/kg.°C}) = 5.61\text{ kW/°C}$$

Therefore, $C_{\min} = C_c = 5.61\text{W/°C}$ and $C = \dfrac{C_{\min}}{C_{\max}} = \dfrac{5.61}{7.21} = 0.78$

Then the maximum heat transfer rate becomes

$$\dot{Q}_{\max} = C_{\min}(T_{h,in} - T_{c,in}) = (5.61\text{W/°C})(95°\text{C} - 25°\text{C}) = 392.7\text{ kW}$$

The effectiveness of this heat exchanger is $\varepsilon = \dfrac{Q}{Q_{\max}} = \dfrac{252.3}{392.7} = 0.64$

The NTU of this heat exchanger corresponding to this emissivity and C = 0.78 is determined from Fig. 13-26d to be NTU = 1.7. Then the surface area of heat exchanger is determined to be

$$NTU = \frac{UA_s}{C_{\min}} \longrightarrow A_s = \frac{NTU\ C_{\min}}{U} = \frac{(1.7)(5.61\text{ kW/°C})}{0.8\text{ kW/m}^2\text{.°C}} = \mathbf{11.9\ m^2}$$

The small difference between the two results is due to the reading error of the chart.

13-100 Steam is condensed by cooling water in a shell-and-tube heat exchanger. The rate of heat transfer and the rate of condensation of steam are to be determined.

Assumptions **1** Steady operating conditions exist. **2** The heat exchanger is well-insulated so that heat loss to the surroundings is negligible and thus heat transfer from the hot fluid is equal to the heat transfer to the cold fluid. **3** Changes in the kinetic and potential energies of fluid streams are negligible. **4** The overall heat transfer coefficient is constant and uniform. **5** The thickness of the tube is negligible.

Properties The specific heat of the water is given to be 4.18 kJ/kg.°C. The heat of condensation of steam at 30°C is given to be 2430 kJ/kg.

Analysis (*a*) The heat capacity rate of a fluid condensing in a heat exchanger is infinity. Therefore,

$$C_{\min} = C_c = \dot{m}_c C_{pc} = (0.5 \text{ kg/s})(4.18 \text{ kJ/kg.°C}) = 2.09 \text{ kW/°C}$$

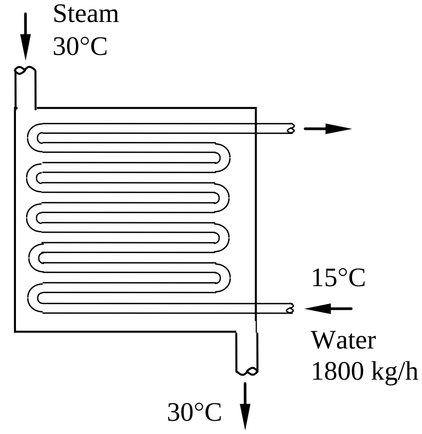
and $C = 0$

Then the maximum heat transfer rate becomes

$$\dot{Q}_{\max} = C_{\min}(T_{h,in} - T_{c,in}) = (2.09 \text{ kW/°C})(30\text{°C} - 15\text{°C}) = 31.35 \text{ kW}$$

and

$$A_s = 8n\pi DL = 8\times 50\pi(0.015 \text{ m})(2 \text{ m}) = 37.7 \text{ m}^2$$



The NTU of this heat exchanger

$$NTU = \frac{UA_s}{C_{\min}} = \frac{(3 \text{ kW/m}^2\text{.°C})(37.7 \text{ m}^2)}{2.09 \text{ kW/°C}} = 54.11$$

Then the effectiveness of this heat exchanger corresponding to $C = 0$ and NTU = 6.76 is determined using the proper relation in Table 13-5

$$\varepsilon = 1 - \exp(-\text{NTU}) = 1 - \exp(-6.76) = 1$$

Then the actual heat transfer rate becomes

$$\dot{Q} = \varepsilon \dot{Q}_{\max} = (1)(31.35 \text{kW}) = \mathbf{31.35 \text{ kW}}$$

(*b*) Finally, the rate of condensation of the steam is determined from

$$\dot{Q} = \dot{m} h_{fg} \longrightarrow \dot{m} = \frac{\dot{Q}}{h_{fg}} = \frac{31.4 \text{ kJ/s}}{2430 \text{ kJ/kg}} = \mathbf{0.0129 \text{ kg/s}}$$

13-101 "!PROBLEM 13-101"

"GIVEN"
N_pass=8
N_tube=50
T_steam=30 "[C], parameter to be varied"
h_fg_steam=2430 "[kJ/kg]"
T_w_in=15 "[C]"
m_dot_w=1800/Convert(kg/s, kg/h) "[kg/s]"
C_p_w=4.18 "[kJ/kg-C]"
D=1.5 "[cm], parameter to be varied"
L=2 "[m]"
U=3 "[kW/m^2-C]"

"ANALYSIS"
"With EES, it is easier to solve this problem using LMTD method than NTU method. Below, we use NTU method. Both methods give the same results."
"(a)"
C_min=m_dot_w*C_p_w
C=0 "since the heat capacity rate of a fluid condensing is infinity"
Q_dot_max=C_min*(T_steam-T_w_in)
A=N_pass*N_tube*pi*D*L*Convert(cm, m)
NTU=(U*A)/C_min
epsilon=1-exp(-NTU) "from Table 13-4 of the text with C=0"
Q_dot=epsilon*Q_dot_max
"(b)"
Q_dot=m_dot_cond*h_fg_steam

T_{steam} [C]	Q [kW]	m_{cond} [kg/s]
20	10.45	0.0043
22.5	15.68	0.006451
25	20.9	0.008601
27.5	26.12	0.01075
30	31.35	0.0129
32.5	36.58	0.01505
35	41.8	0.0172
37.5	47.03	0.01935
40	52.25	0.0215
42.5	57.47	0.02365
45	62.7	0.0258
47.5	67.93	0.02795
50	73.15	0.0301
52.5	78.38	0.03225
55	83.6	0.0344
57.5	88.82	0.03655
60	94.05	0.0387
62.5	99.27	0.04085
65	104.5	0.043
67.5	109.7	0.04515
70	114.9	0.0473

D [cm]	**Q [kW]**	**m_{cond} [kg/s]**
1	31.35	0.0129
1.05	31.35	0.0129
1.1	31.35	0.0129
1.15	31.35	0.0129
1.2	31.35	0.0129
1.25	31.35	0.0129
1.3	31.35	0.0129
1.35	31.35	0.0129
1.4	31.35	0.0129
1.45	31.35	0.0129
1.5	31.35	0.0129
1.55	31.35	0.0129
1.6	31.35	0.0129
1.65	31.35	0.0129
1.7	31.35	0.0129
1.75	31.35	0.0129
1.8	31.35	0.0129
1.85	31.35	0.0129
1.9	31.35	0.0129
1.95	31.35	0.0129
2	31.35	0.0129

13-102 Cold water is heated by hot oil in a shell-and-tube heat exchanger. The rate of heat transfer is to be determined using both the LMTD and NTU methods.

Assumptions **1** Steady operating conditions exist. **2** The heat exchanger is well-insulated so that heat loss to the surroundings is negligible and thus heat transfer from the hot fluid is equal to the heat transfer to the cold fluid. **3** Changes in the kinetic and potential energies of fluid streams are negligible. **4** The overall heat transfer coefficient is constant and uniform.

Properties The specific heats of the water and oil are given to be 4.18 and 2.2 kJ/kg.°C, respectively.

Analysis (*a*) The LMTD method in this case involves iterations, which involves the following steps:

1) Choose $T_{h,out}$

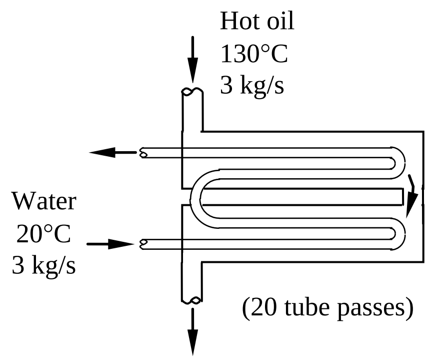
2) Calculate $\dot{Q}$ from $\dot{Q} = \dot{m}_h C_p (T_{h,out} - T_{h,in})$

3) Calculate $T_{h,out}$ from $\dot{Q} = \dot{m}_h C_p (T_{h,out} - T_{h,in})$

4) Calculate $\Delta T_{\ln,CF}$

5) Calculate $\dot{Q}$ from $\dot{Q} = UA_s F \Delta T_{\ln,CF}$

6) Compare to the $\dot{Q}$ calculated at step 2, and repeat until reaching the same result



Result: **385 kW**

(*b*) The heat capacity rates of the hot and the cold fluids are

$$C_h = \dot{m}_h C_{ph} = (3 \text{ kg/s})(2.2 \text{ kJ/kg.°C}) = 6.6 \text{ kW/°C}$$
$$C_c = \dot{m}_c C_{pc} = (3 \text{ kg/s})(4.18 \text{ kJ/kg.°C}) = 12.54 \text{ kW/°C}$$

Therefore, $C_{\min} = C_h = 6.6 \text{ kW/°C}$ and $C = \dfrac{C_{\min}}{C_{\max}} = \dfrac{6.6}{12.54} = 0.53$

Then the maximum heat transfer rate becomes

$$\dot{Q}_{\max} = C_{\min}(T_{h,in} - T_{c,in}) = (6.6 \text{ kW/°C})(130\text{°C} - 20\text{°C}) = 726 \text{ kW}$$

The NTU of this heat exchanger is

$$NTU = \frac{UA_s}{C_{\min}} = \frac{(0.3 \text{ kW/m}^2.\text{°C})(20 \text{ m}^2)}{6.6 \text{ kW/°C}} = 0.91$$

Then the effectiveness of this heat exchanger corresponding to C = 0.53 and NTU = 0.91 is determined from Fig. 13-26d to be

$$\varepsilon = 0.53$$

The actual rate of heat transfer then becomes

$$\dot{Q} = \varepsilon \dot{Q}_{\max} = (0.53)(726 \text{kW}) = \textbf{385 kW}$$

Selection of The Heat Exchangers

13-103C 1) Calculate heat transfer rate, 2) select a suitable type of heat exchanger, 3) select a suitable type of cooling fluid, and its temperature range, 4) calculate or select U, and 5) calculate the size (surface area) of heat exchanger

13-104C The first thing we need to do is determine the life expectancy of the system. Then we need to evaluate how much the larger will save in pumping cost, and compare it to the initial cost difference of the two units. If the larger system saves more than the cost difference in its lifetime, it should be preferred.

13-105C In the case of automotive and aerospace industry, where weight and size considerations are important, and in situations where the space availability is limited, we choose the smaller heat exchanger.

13-106 Oil is to be cooled by water in a heat exchanger. The heat transfer rating of the heat exchanger is to be determined and a suitable type is to be proposed.

Assumptions **1** Steady operating conditions exist. **2** The heat exchanger is well-insulated so that heat loss to the surroundings is negligible and thus heat transfer from the hot fluid is equal to the heat transfer to the cold fluid. **3** Changes in the kinetic and potential energies of fluid streams are negligible.

Properties The specific heat of the oil is given to be 2.2 kJ/kg.°C.

Analysis The heat transfer rate of this heat exchanger is

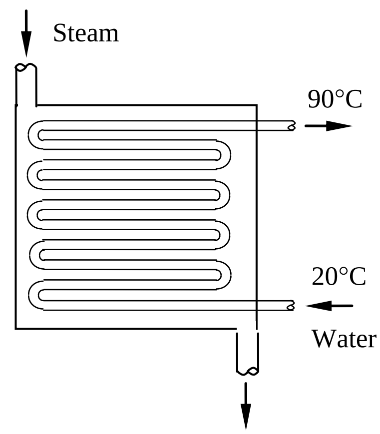
$$\dot{Q} = \dot{m}_c C_{pc}(T_{c,out} - T_{c,in}) = (13\,\text{kg/s})(2.2\,\text{kJ/kg.°C})(120°\text{C} - 50°\text{C}) = \mathbf{2002\ kW}$$

We propose a compact heat exchanger (like the car radiator) if air cooling is to be used., or a tube-and-shell or plate heat exchanger if water cooling is to be used.

3-107 Water is to be heated by steam in a shell-and-tube process heater. The number of tube passes need to be used is to be determined.

Assumptions **1** Steady operating conditions exist. **2** The heat exchanger is well-insulated so that heat loss to the surroundings is negligible and thus heat transfer from the hot fluid is equal to the heat transfer to the cold fluid. **3** Changes in the kinetic and potential energies of fluid streams are negligible.

Properties The specific heat of the water is given to be 4.19 kJ/kg.°C.



Analysis The mass flow rate of the water is

$$\dot{Q} = \dot{m}_c C_{pc}(T_{c,out} - T_{c,in})$$

$$\dot{m} = \frac{\dot{Q}}{C_{pc}(T_{c,out} - T_{c,in})} = \frac{600\,\text{kW}}{(4.19\,\text{kJ/kg.°C})(90°\text{C} - 20°\text{C})} = 2.046\,\text{kg/s}$$

The total cross-section area of the tubes corresponding to this mass flow rate is

$$\dot{m} = \rho V A_c \rightarrow A_c = \frac{\dot{m}}{\rho V} = \frac{2.046\text{ kg/s}}{(1000\text{ kg/m}^3)(3\text{ m/s})} = 6.82\times10^{-4}\text{ m}^2$$

Then the number of tubes that need to be used becomes

$$A_s = n\frac{\pi D^2}{4} \longrightarrow n = \frac{4A_s}{\pi D^2} = \frac{4(6.82\times10^{-4}\text{ m}^2)}{\pi(0.01\,\text{m})^2} = 8.68 \cong \mathbf{9}$$

Therefore, we need to use at least 9 tubes entering the heat exchanger.

13-108 "!PROBLEM 13-108"

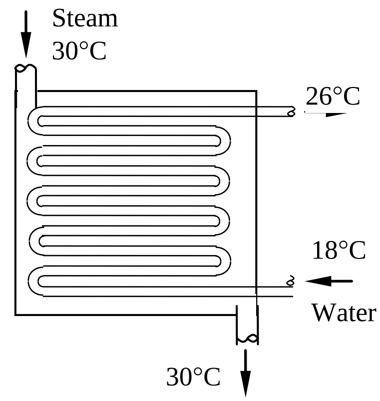
```
"GIVEN"
C_p_w=4.19 "[kJ/kg-C]"
T_w_in=20 "[C]"
T_w_out=90 "[C]"
Q_dot=600 "[kW]"
D=0.01 "[m]"
"Vel=3 [m/s], parameter to be varied"

"PROPERTIES"
rho=density(water, T=T_ave, P=100)
T_ave=1/2*(T_w_in+T_w_out)

"ANALYSIS"
Q_dot=m_dot_w*C_p_w*(T_w_out-T_w_in)
m_dot_w=rho*A_c*Vel
A_c=N_pass*pi*D^2/4
```

Vel [m/s]	N_{pass}
1	26.42
1.5	17.62
2	13.21
2.5	10.57
3	8.808
3.5	7.55
4	6.606
4.5	5.872
5	5.285
5.5	4.804
6	4.404
6.5	4.065
7	3.775
7.5	3.523
8	3.303

13-109 Cooling water is used to condense the steam in a power plant. The total length of the tubes required in the condenser is to be determined and a suitable HX type is to be proposed.

Assumptions **1** Steady operating conditions exist. **2** The heat exchanger is well-insulated so that heat loss to the surroundings is negligible and thus heat transfer from the hot fluid is equal to the heat transfer to the cold fluid. **3** Changes in the kinetic and potential energies of fluid streams are negligible. **4** The overall heat transfer coefficient is constant and uniform.

Properties The specific heat of the water is given to be 4.18 kJ/kg.°C. The heat of condensation of steam at 30°C is given to be 2430 kJ/kg.



Analysis The temperature differences between the steam and the water at the two ends of condenser are

$$\Delta T_1 = T_{h,in} - T_{c,out} = 30°\text{C} - 26°\text{C} = 4°\text{C}$$
$$\Delta T_2 = T_{h,out} - T_{c,in} = 30°\text{C} - 18°\text{C} = 12°\text{C}$$

and the logarithmic mean temperature difference is

$$\Delta T_{lm} = \frac{\Delta T_1 - \Delta T_2}{\ln(\Delta T_1 / \Delta T_2)} = \frac{4-12}{\ln(4/12)} = 7.28°\text{C}$$

The heat transfer surface area is

$$\dot{Q} = UA_s \Delta T_{lm} \longrightarrow A_s = \frac{\dot{Q}}{U\Delta T_{lm}} = \frac{500\times10^6\ \text{W}}{(3500\,\text{W/m}^2.°\text{C})(7.28°\text{C})} = 1.96\times10^4\ \text{m}^2$$

The total length of the tubes required in this condenser then becomes

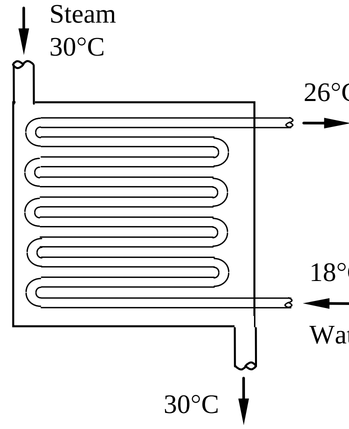
$$A_s = \pi DL \longrightarrow L = \frac{A_s}{\pi D} = \frac{1.96\times10^4\ \text{m}^2}{\pi(0.02\,\text{m})} = 3.123\times10^5\ \text{m} = \mathbf{312.3\ km}$$

A multi-pass shell-and-tube heat exchanger is suitable in this case.

13-110 Cold water is heated by hot water in a heat exchanger. The net rate of heat transfer and the heat transfer surface area of the heat exchanger are to be determined.

Assumptions **1** Steady operating conditions exist. **2** The heat exchanger is well-insulated so that heat loss to the surroundings is negligible and thus heat transfer from the hot fluid is equal to the heat transfer to the cold fluid. **3** Changes in the kinetic and potential energies of fluid streams are negligible. **4** The overall heat transfer coefficient is constant and uniform.

Properties The specific heats of the cold and hot water are given to be 4.18 and 4.19 kJ/kg.°C, respectively.



Analysis The temperature differences between the steam and the water at the two ends of condenser are

$$\Delta T_1 = T_{h,in} - T_{c,out} = 30°\text{C} - 26°\text{C} = 4°\text{C}$$
$$\Delta T_2 = T_{h,out} - T_{c,in} = 30°\text{C} - 18°\text{C} = 12°\text{C}$$

and the logarithmic mean temperature difference is

$$\Delta T_{lm} = \frac{\Delta T_1 - \Delta T_2}{\ln(\Delta T_1 / \Delta T_2)} = \frac{4-12}{\ln(4/12)} = 7.28°\text{C}$$

The heat transfer surface area is

$$\dot{Q} = UA_s \Delta T_{lm} \longrightarrow A_s = \frac{\dot{Q}}{U\Delta T_{lm}} = \frac{300\times10^6 \text{ W}}{(3500 \text{ W/m}^2.°\text{C})(7.28°\text{C})} = 1.177\times10^4 \text{ m}^2$$

The total length of the tubes required in this condenser then becomes

$$A_s = \pi DL \longrightarrow L = \frac{A_s}{\pi D} = \frac{1.177\times10^4 \text{ m}^2}{\pi(0.02 \text{ m})} = 1.874\times10^5 \text{ m} = \mathbf{187.4\ km}$$

A multi-pass shell-and-tube heat exchanger is suitable in this case.