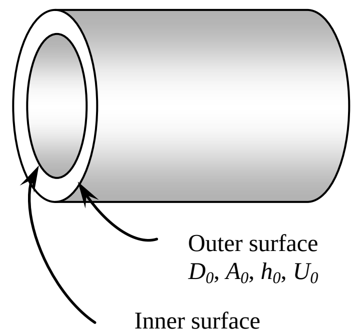
Review Problems

13-111 Hot oil is cooled by water in a multi-pass shell-and-tube heat exchanger. The overall heat transfer coefficient based on the inner surface is to be determined.

Assumptions **1** Water flow is fully developed. **2** Properties of the water are constant.

Properties The properties of water at 300 K ≈25°C are (Table A-9)

$$k = 0.607\ \text{W/m.°C}$$
$$\upsilon = \mu/\rho = 0.894\times10^{-6}\ \text{m}^2/\text{s}$$
$$\text{Pr} = 6.14$$



Analysis The Reynolds number is

$$\text{Re} = \frac{V_m D}{\upsilon} = \frac{(3\ \text{m/s})(0.013\ \text{m})}{0.894\times10^{-6}\ \text{m}^2/\text{s}} = 43{,}771$$

which is greater than 10,000. Therefore, we assume fully developed turbulent flow, and determine Nusselt number from

$$Nu = 0.023\text{Re}^{0.8}\,\text{Pr}^{0.4}\ 0.023(43{,}771)^{0.8}(6.14)^{0.4} = 245$$

and

$$h_i = \frac{k}{D}Nu = \frac{0.607\ \text{W/m.°C}}{0.013\ \text{m}}(245) = 11{,}440\ \text{W/m}^2.\text{°C}$$

The inner and the outer surface areas of the tube are

$$A_i = \pi D_i L = \pi(0.013\ \text{m})(1\ \text{m}) = 0.04084\ \text{m}^2$$
$$A_o = \pi D_o L = \pi(0.015\ \text{m})(1\ \text{m}) = 0.04712\ \text{m}^2$$

The total thermal resistance of this heat exchanger per unit length is

$$R = \frac{1}{h_i A_i} + \frac{\ln(D_o/D_i)}{2\pi kL} + \frac{1}{h_o A_o}$$
$$= \frac{1}{(11{,}440\ \text{W/m}^2.\text{°C})(0.04084\ \text{m}^2)} + \frac{\ln(1.5/1.3)}{2\pi(110\ \text{W/m.°C})(1\ \text{m})} + \frac{1}{(35\ \text{W/m}^2.\text{°C})(0.04712\ \text{m}^2)}$$
$$= 0.609\text{°C/W}$$

Then the overall heat transfer coefficient of this heat exchanger based on the inner surface becomes

$$R = \frac{1}{U_i A_i} \longrightarrow U_i = \frac{1}{RA_i} = \frac{1}{(0.609\text{°C/W})(0.04084\ \text{m}^2)} = \mathbf{40.2\ W/m^2.°C}$$

13-112 Hot oil is cooled by water in a multi-pass shell-and-tube heat exchanger. The overall heat transfer coefficient based on the inner surface is to be determined.

Assumptions **1** Water flow is fully developed. **2** Properties of the water are constant.

Properties The properties of water at 300 K ≈25°C are (Table A-9)

$$k = 0.607\ \text{W/m.°C}$$
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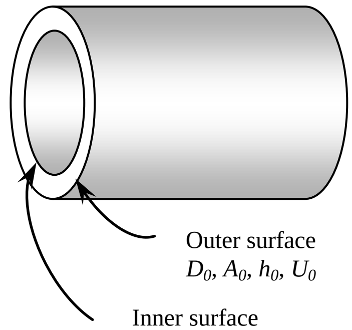

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$$\text{Re} = \frac{V_m D}{\upsilon} = \frac{(3\ \text{m/s})(0.013\ \text{m})}{0.894\times10^{-6}\ \text{m}^2/\text{s}} = 43{,}771$$

which is greater than 10,000. Therefore, we assume fully developed turbulent flow, and determine Nusselt number from

$$Nu = 0.023\text{Re}^{0.8}\ \text{Pr}^{0.4}\ 0.023(43{,}771)^{0.8}(6.14)^{0.4} = 245$$

and

$$h_i = \frac{k}{D}Nu = \frac{0.607\ \text{W/m.°C}}{0.013\ \text{m}}(245) = 11{,}440\ \text{W/m}^2.\text{°C}$$

The inner and the outer surface areas of the tube are

$$A_i = \pi D_i L = \pi(0.013\ \text{m})(1\ \text{m}) = 0.04084\ \text{m}^2$$
$$A_o = \pi D_o L = \pi(0.015\ \text{m})(1\ \text{m}) = 0.04712\ \text{m}^2$$

The total thermal resistance of this heat exchanger per unit length of it with a fouling factor is

$$R = \frac{1}{h_i A_i} + \frac{\ln(D_o/D_i)}{2\pi kL} + \frac{R_{f,o}}{A_o} + \frac{1}{h_o A_o}$$
$$= \frac{1}{(11{,}440\ \text{W/m}^2.\text{°C})(0.04084\ \text{m}^2)} + \frac{\ln(15/13)}{2\pi(110\ \text{W/m.°C})(1\ \text{m})}$$
$$+ \frac{0.0004\ \text{m}^2.\text{°C/W}}{0.04712\ \text{m}^2} + \frac{1}{(35\ \text{W/m}^2.\text{°C})(0.04712\ \text{m}^2)}$$
$$= 0.617\text{°C/W}$$

Then the overall heat transfer coefficient of this heat exchanger based on the inner surface becomes

$$R = \frac{1}{U_i A_i} \longrightarrow U_i = \frac{1}{RA_i} = \frac{1}{(0.617\text{°C/W})(0.04084\ \text{m}^2)} = \mathbf{39.7\ W/m^2.°C}$$

13-113 Water is heated by hot oil in a multi-pass shell-and-tube heat exchanger. The rate of heat transfer and the heat transfer surface area on the outer side of the tube 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 water and oil are given to be 4.18 and 2.2 kJ/kg.°C, respectively.

Analysis (*a*)The rate of heat transfer in this heat exchanger is

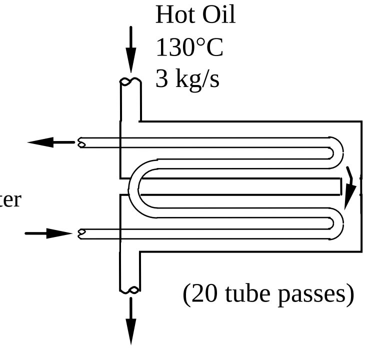
$$\dot{Q} = \dot{m}_h C_{ph}(T_{h,in} - T_{h,out}) = (3\text{ kg/s})(2.2\text{ kJ/kg.°C})(130°\text{C} - 60°\text{C}) = \mathbf{462\ kW}$$

(*b*) The outlet temperature of the cold water is

$$\dot{Q} = \dot{m}_c C_{pc}(T_{c,out} - T_{c,in}) \longrightarrow T_{c,out} = T_{c,in} + \frac{\dot{Q}}{\dot{m}_c C_{pc}} = 20°\text{C} + \frac{462\text{ kW}}{(3\text{ kg/s})(4.18\text{ kJ/kg.°C})} = 56.8°\text{C}$$

The temperature differences at the two ends are

$$\Delta T_1 = T_{h,in} - T_{c,out} = 130°\text{C} - 56.8°\text{C} = 73.2°\text{C}$$
$$\Delta T_2 = T_{h,out} - T_{c,in} = 60°\text{C} - 20°\text{C} = 40°\text{C}$$



The logarithmic mean temperature difference is

$$\Delta T_{lm,CF} = \frac{\Delta T_1 - \Delta T_2}{\ln(\Delta T_1/\Delta T_2)} = \frac{73.2 - 40}{\ln(73.2/40)} = 54.9°\text{C}$$

and

$$\left.\begin{array}{l} P = \dfrac{t_2 - t_1}{T_1 - t_1} = \dfrac{56.8 - 20}{130 - 20} = 0.335 \\ R = \dfrac{T_2 - T_1}{t_2 - t_1} = \dfrac{130 - 60}{56.8 - 20} = 1.90 \end{array}\right\} F = 0.96$$

The heat transfer surface area on the outer side of the tube is then determined from

$$\dot{Q} = UA_s F\Delta T_{lm} \longrightarrow A_s = \frac{\dot{Q}}{UF\Delta T_{lm}} = \frac{462\text{ kW}}{(0.3\text{ kW/m}^2.°\text{C})(0.96)(54.9°\text{C})} = \mathbf{29.2\ m^2}$$

13-114E Water is heated by solar-heated hot air in a double-pipe counter-flow heat exchanger. The required length of the tube 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. **4** The overall heat transfer coefficient is constant and uniform.

Properties The specific heats of the water and air are given to be 1.0 and 0.24 Btu/lbm.°F, respectively.

Analysis The rate of heat transfer in this heat exchanger is

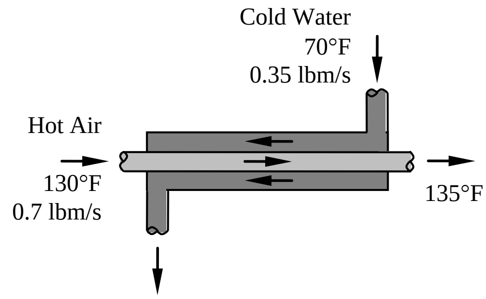
$$\dot{Q} = \dot{m}_h C_{ph}(T_{h,in} - T_{h,out}) = (0.7\text{ lbm/s})(0.24\text{ Btu/lbm.°F})(190°\text{F} - 135°\text{F}) = 9.24\text{ Btu/s}$$

The outlet temperature of the cold water is

$$\dot{Q} = \dot{m}_c C_{pc}(T_{c,out} - T_{c,in}) \longrightarrow T_{c,out} = T_{c,in} + \frac{\dot{Q}}{\dot{m}_c C_{pc}} = 70°\text{F} + \frac{9.24\text{ Btu/s}}{(0.35\text{ lbm/s})(1.0\text{ Btu/lbm.°F})} = 96.4°\text{F}$$

The temperature differences at the two ends are

$$\Delta T_1 = T_{h,in} - T_{c,out} = 190°\text{F} - 96.4°\text{F} = 93.6°\text{F}$$
$$\Delta T_2 = T_{h,out} - T_{c,in} = 135°\text{F} - 70°\text{F} = 65°\text{F}$$



The logarithmic mean temperature difference is

$$\Delta T_{lm} = \frac{\Delta T_1 - \Delta T_2}{\ln(\Delta T_1/\Delta T_2)} = \frac{93.6 - 65}{\ln(93.6/65)} = 78.43°\text{F}$$

The heat transfer surface area on the outer side of the tube is determined from

$$\dot{Q} = UA_s \Delta T_{lm} \longrightarrow A_s = \frac{\dot{Q}}{U\Delta T_{lm}} = \frac{9.24\text{ Btu/s}}{(20/3600\text{ Btu/s.ft}^2\text{.°F})(78.43°\text{F})} = 21.21\text{ ft}^2$$

Then the length of the tube required becomes

$$A_s = \pi DL \longrightarrow L = \frac{A_s}{\pi D} = \frac{21.21\text{ ft}^2}{\pi(0.5/12\text{ ft})} = \mathbf{162.0\ ft}$$

13-115 It is to be shown that when $\Delta T_1 = \Delta T_2$ for a heat exchanger, the ΔT_{lm} relation reduces to $\Delta T_{\text{lm}} = \Delta T_1 = \Delta T_2$.

Analysis When $\Delta T_1 = \Delta T_2$, we obtain

$$\Delta T_{lm} = \frac{\Delta T_1 - \Delta T_2}{\ln(\Delta T_1/\Delta T_2)} = \frac{0}{0}$$

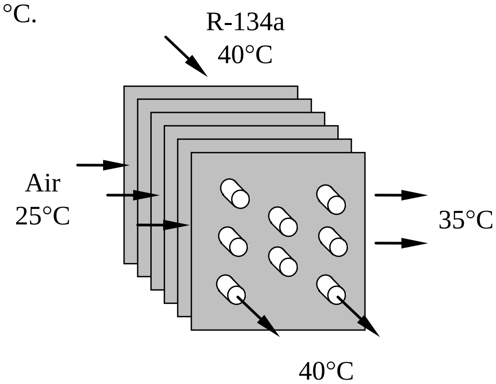
This case can be handled by applying L'Hospital's rule (taking derivatives of nominator and denominator separately with respect to ΔT_1 or ΔT_2). That is,

$$\Delta T_{lm} = \frac{d(\Delta T_1 - \Delta T_2)/d\Delta T_1}{d[\ln(\Delta T_1/\Delta T_2)]/d\Delta T_1} = \frac{1}{1/\Delta T_1} = \Delta T_1 = \Delta T_2$$

13-116 Refrigerant-134a is condensed by air in the condenser of a room air conditioner. The heat transfer area on the refrigerant side 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. **4** The overall heat transfer coefficient is constant and uniform.

Properties The specific heat of air is given to be 1.005 kJ/kg.°C.



Analysis The temperature differences at the two ends are

$$\Delta T_1 = T_{h,in} - T_{c,out} = 40°\text{C} - 35°\text{C} = 5°\text{C}$$

$$\Delta T_2 = T_{h,out} - T_{c,in} = 40°\text{C} - 25°\text{C} = 15°\text{C}$$

The logarithmic mean temperature difference is

$$\Delta T_{lm} = \frac{\Delta T_1 - \Delta T_2}{\ln(\Delta T_1 / \Delta T_2)} = \frac{5 - 15}{\ln(5/15)} = 9.1°\text{C}$$

The heat transfer surface area on the outer side of the tube is determined from

$$\dot{Q} = UA_s\Delta T_{lm} \longrightarrow A_s = \frac{\dot{Q}}{U\Delta T_{lm}} = \frac{(15{,}000/3600)\text{ kW}}{(0.150\text{ kW/m}^2.°\text{C})(9.1°\text{C})} = \mathbf{3.05\ m^2}$$

13-117 Air is preheated by hot exhaust gases in a cross-flow heat exchanger. The rate of heat transfer 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. **4** The overall heat transfer coefficient is constant and uniform.

Properties The specific heats of air and combustion gases are given to be 1.005 and 1.1 kJ/kg.°C, respectively.

Analysis The rate of heat transfer is simply

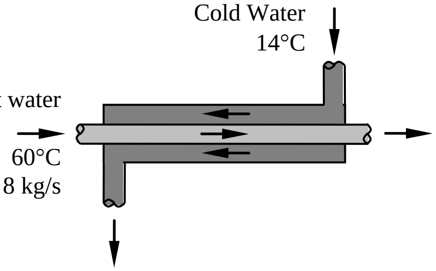
$$\dot{Q} = [\dot{m}C_p(T_{in} - T_{out})]_{\text{gas.}} = (1.1\text{ kg/s})(1.1\text{ kJ/kg.°C})(180°\text{C} - 95°\text{C}) = \mathbf{102.9\ kW}$$

13-118 A water-to-water heat exchanger is proposed to preheat the incoming cold water by the drained hot water in a plant to save energy. The heat transfer rating of the heat exchanger and the amount of money this heat exchanger will save 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.

Properties The specific heat of the hot water is given to be 4.18 kJ/kg.°C.

Analysis The maximum rate of heat transfer is



$$\begin{aligned}\dot{Q}_{\max} &= \dot{m}_h C_{ph}(T_{h,in} - T_{c,in}) \\ &= (8/60\text{ kg/s})(4.18\text{ kJ/kg.°C})(60°\text{C} - 14°\text{C}) \\ &= 25.6\text{ kW}\end{aligned}$$

Noting that the heat exchanger will recover 72% of it, the actual heat transfer rate becomes

$$\dot{Q} = \varepsilon\dot{Q}_{\max} = (0.72)(25.6\text{ kJ/s}) = 18.43\text{ kW}$$

which is the heat transfer rating. The operating hours per year are

The annual operating hours = (8 h/day)(5 days/week)(52 week/year) = 2080 h/year

The energy saved during the entire year will be

Energy saved = (heat transfer rate)(operating time)

= (18.43 kJ/s)(2080 h/year)(3600 s/h)

= $1.38\text{x}10^8$ kJ/year

Then amount of fuel and money saved will be

$$\text{Fuel saved} = \frac{\text{Energy saved}}{\text{Furnace efficiency}} = \frac{1.38\times10^8\text{ kJ/year}}{0.78}\left(\frac{1\text{ therm}}{105{,}500\text{ kJ}}\right) = 1677\text{ therms/year}$$

Money saved = (fuel saved)(the price of fuel)

= (1677 therms/year)($ 0.54/therm) = **$906/year**

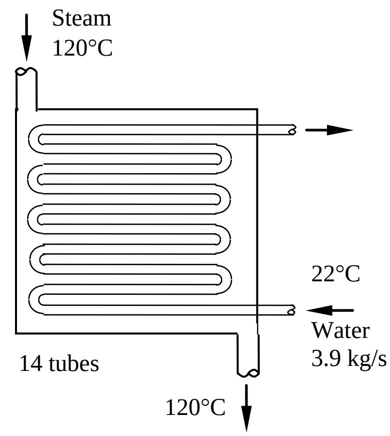
13-119 A shell-and-tube heat exchanger is used to heat water with geothermal steam condensing. The rate of heat transfer, the rate of condensation of steam, and the overall heat transfer coefficient are to be determined.

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** Fluid properties are constant.

Properties The heat of vaporization of geothermal water at 120°C is given to be h_{fg} = 2203 kJ/kg and specific heat of water is given to be C_p = 4180 J/kg.°C.

Analysis (*a*) The outlet temperature of the water is

$$T_{c,out} = T_{h,out} - 46 = 120°C - 46°C = 74°C$$



Then the rate of heat transfer becomes

$$\dot{Q} = [\dot{m}C_p(T_{out} - T_{in})]_{water}$$
$$= (3.9\text{ kg/s})(4.18\text{ kJ/kg.°C})(74°C - 22°C)$$
$$= \mathbf{847.7\ kW}$$

(*b*) The rate of condensation of steam is determined from

$$\dot{Q} = (\dot{m}h_{fg})_{\substack{\text{geothermal}\\ \text{steam}}}$$

$$847.7\text{ kW} = \dot{m}(2203\text{ kJ/kg}) \longrightarrow \dot{m} = \mathbf{0.385\ kg/s}$$

(*c*) The heat transfer area is

$$A_i = n\pi D_i L = 14\pi(0.024\text{ m})(3.2\text{ m}) = 3.378\text{ m}^2$$

The logarithmic mean temperature difference for counter-flow arrangement and the correction factor F are

$$\Delta T_1 = T_{h,in} - T_{c,out} = 120°C - 74°C = 46°C$$
$$\Delta T_2 = T_{h,out} - T_{c,in} = 120°C - 22°C = 98°C$$

$$\Delta T_{lm,CF} = \frac{\Delta T_1 - \Delta T_2}{\ln(\Delta T_1/\Delta T_2)} = \frac{46-98}{\ln(46/98)} = 68.8°C$$

$$\left.\begin{aligned} P &= \frac{t_2 - t_1}{T_1 - t_1} = \frac{74-22}{120-22} = 0.53 \\ R &= \frac{T_1 - T_2}{t_2 - t_1} = \frac{120-120}{74-22} = 0 \end{aligned}\right\} F = 1$$

Then the overall heat transfer coefficient is determined to be

$$\dot{Q} = U_i A_i F\Delta T_{lm,CF} \longrightarrow U_i = \frac{\dot{Q}}{A_i F\Delta T_{lm,CF}} = \frac{847{,}700\text{ W}}{(3.378\text{ m}^2)(1)(68.8°C)} = \mathbf{3648\ W/m^2.°C}$$

13-120 Water is heated by geothermal water in a double-pipe counter-flow heat exchanger. The mass flow rate of the geothermal water and the outlet temperatures of both fluids 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 geothermal water and the cold water are given to be 4.25 and 4.18 kJ/kg.°C, respectively.

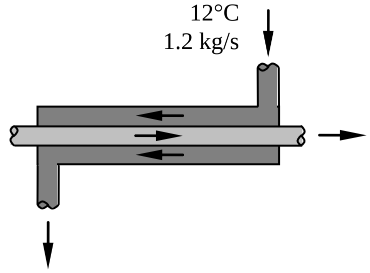
Analysis The heat capacity rates of the hot and cold fluids are

$$C_h = \dot{m}_h C_{ph} = \dot{m}_h (4.25\,\text{kJ/kg.°C}) = 4.25\dot{m}_h$$

$$C_c = \dot{m}_c C_{pc} = (1.2\,\text{kg/s})(4.18\,\text{kJ/kg.°C}) = 5.016\,\text{kW/°C}$$

$$C_{\min} = C_c = 5.016\,\text{kW/°C}$$

and $$C = \frac{C_{\min}}{C_{\max}} = \frac{5.016}{4.25\dot{m}_h} = \frac{1.1802}{\dot{m}_h}$$



The NTU of this heat exchanger is

$$NTU = \frac{UA_s}{C_{\min}} = \frac{(0.480\,\text{kW/m}^2.\text{°C})(25\,\text{m}^2)}{5.016\,\text{kW/°C}} = 2.392$$

Using the effectiveness relation, we find the capacity ratio

$$\varepsilon = \frac{1-\exp[-\text{NTU}(1-C)]}{1-C\exp[-\text{NTU}(1-C)]} \longrightarrow 0.823 = \frac{1-\exp[-2.392(1-C)]}{1-C\exp[-2.392(1-C)]} \longrightarrow C = 0.494$$

Then the mass flow rate of geothermal water is determined from

$$C = \frac{1.1802}{\dot{m}_h} \longrightarrow 0.494 = \frac{1.1802}{\dot{m}_h} \longrightarrow \dot{m}_h = \mathbf{2.39\ kg/s}$$

The maximum heat transfer rate is

$$\dot{Q}_{\max} = C_{\min}(T_{\text{h,in}} - T_{\text{c,in}}) = (5.016\,\text{kW/°C})(95\text{°C} - 12\text{°C}) = 416.328\,\text{kW}$$

Then the actual rate of heat transfer rate becomes

$$\dot{Q} = \varepsilon \dot{Q}_{\max} = (0.823)(416.328\,\text{kW}) = 342.64\,\text{kW}$$

The outlet temperatures of the geothermal and cold waters are determined to be

$$\dot{Q} = C_c(T_{\text{c,out}} - T_{\text{c,in}}) \longrightarrow 342.64\,\text{kW} = (5.016\,\text{kW/°C})(T_{\text{c,out}} - 12) \longrightarrow T_{\text{c,out}} = \mathbf{80.3°C}$$

$$\dot{Q} = \dot{m}_h C_{ph}(T_{\text{h,in}} - T_{\text{h,out}})$$

$$342.64\,\text{kW} = (2.39\,\text{kg/s})(4.25\,\text{kJ/kg.°C})(95 - T_{\text{h,out}}) \longrightarrow T_{\text{h,out}} = \mathbf{61.3°C}$$

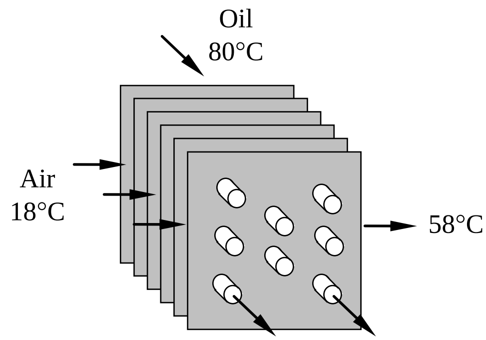
13-121 Air is to be heated by hot oil in a cross-flow heat exchanger with both fluids unmixed. The effectiveness of the heat exchanger, the mass flow rate of the cold fluid, and the rate of heat transfer are to be determined.

.***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 air and the oil are given to be 1.006 and 2.15 kJ/kg.°C, respectively.

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

$$C_h = \dot{m}_h C_{ph} = 0.5\dot{m}_c(2.15\,\text{kJ/kg.°C}) = 1.075\dot{m}_c$$
$$C_c = \dot{m}_c C_{pc} = \dot{m}_c(1.006\,\text{kJ/kg.°C}) = 1.006\dot{m}_c$$



Therefore, $C_{\min} = C_c = 1.006\dot{m}_c$

and $C = \dfrac{C_{\min}}{C_{\max}} = \dfrac{1.006\dot{m}_c}{1.075\dot{m}_c} = 0.936$

The effectiveness of the heat exchanger is determined from

$$\varepsilon = \frac{\dot{Q}}{\dot{Q}_{\max}} = \frac{C_c(T_{c,\text{out}} - T_{c,\text{in}})}{C_c(T_{h,\text{in}} - T_{c,\text{in}})} = \frac{58-18}{80-18} = \mathbf{0.645}$$

(*b*) The NTU of this heat exchanger is expressed as

$$NTU = \frac{UA_s}{C_{\min}} = \frac{(0.750\,\text{kW/°C})}{1.006\dot{m}_c} = \frac{0.7455}{\dot{m}_c}$$

The NTU of this heat exchanger can also be determined from

$$NTU = -\frac{\ln[C\ln(1-\varepsilon)+1]}{C} = -\frac{\ln[0.936\times\ln(1-0.645)+1]}{0.936} = 3.724$$

Then the mass flow rate of the air is determined to be

$$\text{NTU} = \frac{UA_s}{C_{\min}} \longrightarrow 3.724 = \frac{(0.750\,\text{kW/°C})}{1.006\dot{m}_c} \longrightarrow \dot{m}_c = \mathbf{0.20\ kg/s}$$

(*c*) The rate of heat transfer is determined from

$$\dot{Q} = \dot{m}_c C_{pc}(T_{c,\text{out}} - T_{c,\text{in}}) = (0.20\,\text{kg/s})(1.006\,\text{kJ/kg.°C})(58-18)\text{°C} = \mathbf{8.05\ kW}$$

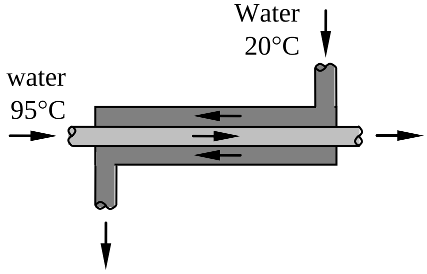
13-122 A water-to-water counter-flow heat exchanger is considered. The outlet temperature of the cold water, the effectiveness of the heat exchanger, the mass flow rate of the cold water, and the heat transfer rate are to be determined.

.***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 both the cold and the hot water are given to be 4.18 kJ/kg.°C.

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

$$C_h = \dot{m}_h C_{ph} = 1.5\dot{m}_c (4.18\,\text{kJ/kg.°C}) = 6.27\dot{m}_c$$
$$C_c = \dot{m}_c C_{pc} = \dot{m}_c (4.18\,\text{kJ/kg.°C}) = 4.18\dot{m}_c$$



Therefore, $C_{\min} = C_c = 4.18\dot{m}_c$

and $$C = \frac{C_{\min}}{C_{\max}} = \frac{4.18\dot{m}_c}{6.27\dot{m}_c} = 0.667$$

The rate of heat transfer can be expressed as

$$\dot{Q} = C_c (T_{\text{c,out}} - T_{\text{c,in}}) = (4.18\dot{m}_c)(T_{\text{c,out}} - 20)$$
$$\dot{Q} = C_h (T_{\text{h,in}} - T_{\text{h,out}}) = (6.27\dot{m}_c)\left[95 - (T_{\text{c,out}} + 15)\right] = (6.27\dot{m}_c)(80 - T_{\text{c,out}})$$

Setting the above two equations equal to each other we obtain the outlet temperature of the cold water

$$\dot{Q} = 4.18\dot{m}_c (T_{\text{c,out}} - 20) = 6.27\dot{m}_c (80 - T_{\text{c,out}}) \longrightarrow T_{\text{c,out}} = \mathbf{56°C}$$

(*b*) The effectiveness of the heat exchanger is determined from

$$\varepsilon = \frac{\dot{Q}}{\dot{Q}_{\max}} = \frac{C_c (T_{\text{c,out}} - T_{\text{c,in}})}{C_c (T_{\text{h,in}} - T_{\text{c,in}})} = \frac{4.18\dot{m}_c (56 - 20)}{4.18\dot{m}_c (95 - 20)} = \mathbf{0.48}$$

(*c*) The NTU of this heat exchanger is determined from

$$NTU = \frac{1}{C-1} \ln\left(\frac{\varepsilon - 1}{\varepsilon C - 1}\right) = \frac{1}{0.667 - 1} \ln\left(\frac{0.48 - 1}{0.48 \times 0.667 - 1}\right) = 0.805$$

Then, from the definition of NTU, we obtain the mass flow rate of the cold fluid:

$$NTU = \frac{UA_s}{C_{\min}} \longrightarrow 0.805 = \frac{1.400\,\text{kW/°C}}{4.18\dot{m}_c} \longrightarrow \dot{m}_c = \mathbf{0.416\ kg/s}$$

(*d*) The rate of heat transfer is determined from

$$\dot{Q} = \dot{m}_c C_{pc} (T_{\text{c,out}} - T_{\text{c,in}}) = (0.416\,\text{kg/s})(4.18\,\text{kJ/kg.°C})(56 - 20)\text{°C} = \mathbf{62.6\ kW}$$

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