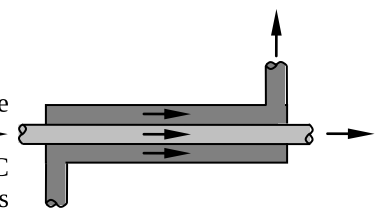
13-54 Glycerin is heated by ethylene glycol in a thin-walled double-pipe parallel-flow heat exchanger. The rate of heat transfer, the outlet temperature of the glycerin, and the mass flow rate of the ethylene glycol are to be determined.

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** There is no fouling. **5** Fluid properties are constant. **6** The thermal resistance of the inner tube is negligible since the tube is thin-walled and highly conductive.

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



Analysis (*a*) The temperature differences at the two ends are

$$\Delta T_1 = T_{h,in} - T_{c,in} = 60°\text{C} - 20°\text{C} = 40°\text{C}$$

$$\Delta T_2 = T_{h,out} - T_{c,out} = T_{h,out} - (T_{h,out} - 15°\text{C}) = 15°\text{C}$$

and $$\Delta T_{lm} = \frac{\Delta T_1 - \Delta T_2}{\ln(\Delta T_1 / \Delta T_2)} = \frac{40-15}{\ln(40/15)} = 25.5°\text{C}$$

Then the rate of heat transfer becomes

$$\dot{Q} = UA_s \Delta T_{lm} = (240\,\text{W/m}^2.°\text{C})(3.2\,\text{m}^2)(25.5°\text{C}) = 19{,}584\,\text{W} = \mathbf{19.58\ kW}$$

(*b*) The outlet temperature of the glycerin is determined from

$$\dot{Q} = [\dot{m}C_p(T_{out} - T_{in})]_{\text{glycerin}} \longrightarrow T_{out} = T_{in} + \frac{\dot{Q}}{\dot{m}C_p} = 20°\text{C} + \frac{19.584\,\text{kW}}{(0.3\,\text{kg/s})(2.4\,\text{kJ/kg.°C})} = \mathbf{47.2°C}$$

(*c*) Then the mass flow rate of ethylene glycol becomes

$$\dot{Q} = [\dot{m}C_p(T_{in} - T_{out})]_{\text{ethylene glycol}}$$

$$\dot{m}_{\text{ethylene glycol}} = \frac{\dot{Q}}{C_p(T_{in} - T_{out})} = \frac{19.584\,\text{kJ/s}}{(2.5\,\text{kJ/kg.°C})[(47.2+15)°\text{C} - 60°\text{C}]} = \mathbf{3.56\ kg/s}$$

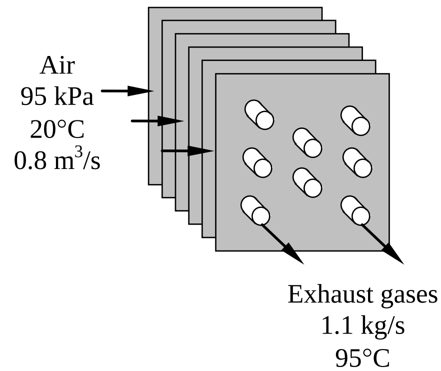
13-55 Air is preheated by hot exhaust gases in a cross-flow heat exchanger. The rate of heat transfer and the outlet temperature of the air are to be determined.

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** There is no fouling. **5** Fluid properties are constant.

Properties The specific heats of air and combustion gases are given to be 1005 and 1100 J/kg.°C, respectively.

Analysis The rate of heat transfer is

$$\dot{Q} = [\dot{m}C_p(T_{in} - T_{out})]_{\text{gas.}}$$
$$= (1.1\,\text{kg/s})(1.1\,\text{kJ/kg.°C})(180°\text{C} - 95°\text{C})$$
$$= \mathbf{103\ kW}$$



The mass flow rate of air is

$$\dot{m} = \frac{P\dot{V}}{RT} = \frac{(95\ \text{kPa})(0.8\ \text{m}^3/\text{s})}{(0.287\ \text{kPa.m}^3/\text{kg.K}) \times 293\ \text{K}} = 0.904\ \text{kg/s}$$

Then the outlet temperature of the air becomes

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

$$T_{c,out} = T_{c,in} + \frac{\dot{Q}}{\dot{m}C_p} = 20°\text{C} + \frac{103 \times 10^3\ \text{W}}{(0.904\,\text{kg/s})(1005\,\text{J/kg.°C})} = \mathbf{133°C}$$

13-56 Water is heated by hot oil in a 2-shell passes and 12-tube passes heat exchanger. The heat transfer surface area on the tube 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** There is no fouling. **5** Fluid properties are constant.

Properties The specific heats of water and oil are given to be 4.18 and 2.3 kJ/kg.°C, respectively.

Analysis The rate of heat transfer in this heat exchanger is

$$\dot{Q} = [\dot{m}C_p(T_{out} - T_{in})]_{\text{water}} = (4.5 \text{ kg/s})(4.18 \text{ kJ/kg.°C})(70°\text{C} - 20°\text{C}) = 940.5 \text{ kW}$$

The outlet temperature of the hot water is determined from

$$\dot{Q} = [\dot{m}C_p(T_{in} - T_{out})]_{\text{oil}} \longrightarrow T_{out} = T_{in} - \frac{\dot{Q}}{\dot{m}C_p} = 170°\text{C} - \frac{940.5 \text{ kW}}{(10 \text{ kg/s})(2.3 \text{ kJ/kg.°C})} = 129°\text{C}$$

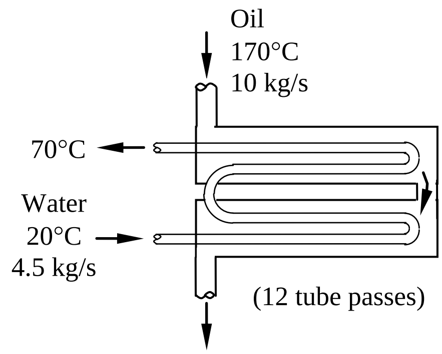
The logarithmic mean temperature difference for counter-flow arrangement and the correction factor F are

$$\Delta T_1 = T_{h,in} - T_{c,out} = 170°\text{C} - 70°\text{C} = 100°\text{C}$$

$$\Delta T_2 = T_{h,out} - T_{c,in} = 129°\text{C} - 20°\text{C} = 109°\text{C}$$

$$\Delta T_{lm,CF} = \frac{\Delta T_1 - \Delta T_2}{\ln(\Delta T_1/\Delta T_2)} = \frac{100-109}{\ln(100/109)} = 105°\text{C}$$

$$\left.\begin{aligned} P &= \frac{t_2 - t_1}{T_1 - t_1} = \frac{129-170}{20-170} = 0.27 \\ R &= \frac{T_1 - T_2}{t_2 - t_1} = \frac{20-70}{129-170} = 1.2 \end{aligned}\right\} F = 1.0$$



Then the heat transfer surface area on the tube side becomes

$$\dot{Q} = UA_s F\Delta T_{lm,CF} \longrightarrow A_s = \frac{\dot{Q}}{UF\Delta T_{lm,CF}} = \frac{940.5 \text{ kW}}{(0.6 \text{ kW/m}^2.°\text{C})(1.0)(105°\text{C})} = \mathbf{15\ m^2}$$

13-57 Water is heated by hot oil in a 2-shell passes and 12-tube passes heat exchanger. The heat transfer surface area on the tube 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** There is no fouling. **5** Fluid properties are constant.

Properties The specific heats of water and oil are given to be 4.18 and 2.3 kJ/kg.°C, respectively.

Analysis The rate of heat transfer in this heat exchanger is

$$\dot{Q} = [\dot{m}C_p(T_{out} - T_{in})]_{\text{water}} = (2\text{ kg/s})(4.18\text{ kJ/kg.°C})(70\text{°C} - 20\text{°C}) = 418\text{ kW}$$

The outlet temperature of the oil is determined from

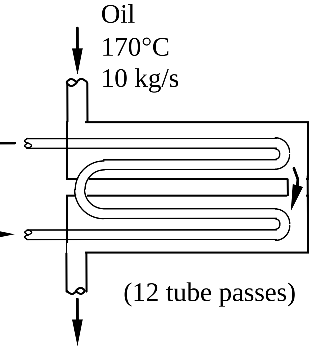
$$\dot{Q} = [\dot{m}C_p(T_{in} - T_{out})]_{\text{oil}} \longrightarrow T_{out} = T_{in} - \frac{\dot{Q}}{\dot{m}C_p} = 170\text{°C} - \frac{418\text{ kW}}{(10\text{ kg/s})(2.3\text{ kJ/kg.°C})} = 151.8\text{°C}$$

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

$$\Delta T_1 = T_{h,in} - T_{c,out} = 170\text{°C} - 70\text{°C} = 100\text{°C}$$

$$\Delta T_2 = T_{h,out} - T_{c,in} = 151.8\text{°C} - 20\text{°C} = 131.8\text{°C}$$

$$\Delta T_{lm,CF} = \frac{\Delta T_1 - \Delta T_2}{\ln(\Delta T_1/\Delta T_2)} = \frac{100 - 131.8}{\ln(100/131.8)} = 115.2\text{°C}$$



$$\left.\begin{aligned} P &= \frac{t_2 - t_1}{T_1 - t_1} = \frac{151.8 - 170}{20 - 170} = 0.12 \\ R &= \frac{T_1 - T_2}{t_2 - t_1} = \frac{20 - 70}{151.8 - 170} = 2.7 \end{aligned}\right\} F = 1.0$$

Then the heat transfer surface area on the tube side becomes

$$\dot{Q} = U_i A_i F \Delta T_{lm,CF} \longrightarrow A_i = \frac{\dot{Q}}{U_i F \Delta T_{lm,CF}} = \frac{418\text{ kW}}{(0.6\text{ kW/m}^2.\text{°C})(1.0)(115.2\text{°C})} = \mathbf{6.05\ m^2}$$

13-58 Ethyl alcohol is heated by water in a 2-shell passes and 8-tube passes heat exchanger. The heat transfer surface area of the heat exchanger is to be determined.

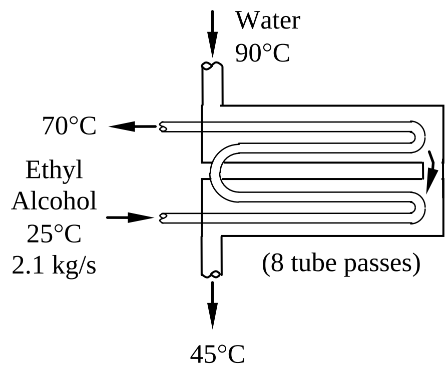
Assumptions **1** Steady operating conditions exist. **2** The heat exchanger is well-insulated so that heat loss to the surroundings is negligible and thus heat transfer from the hot fluid is equal to the heat transfer to the cold fluid. **3** Changes in the kinetic and potential energies of fluid streams are negligible. **4** There is no fouling. **5** Fluid properties are constant.

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

Analysis The rate of heat transfer in this heat exchanger is

$$\dot{Q} = [\dot{m}C_p(T_{out} - T_{in})]_{\text{ethyl alcohol}} = (2.1\text{ kg/s})(2.67\text{ kJ/kg.°C})(70°\text{C} - 25°\text{C}) = 252.3\text{ kW}$$

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



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

$$\Delta T_2 = T_{h,out} - T_{c,in} = 45°\text{C} - 25°\text{C} = 20°\text{C}$$

$$\Delta T_{lm,CF} = \frac{\Delta T_1 - \Delta T_2}{\ln(\Delta T_1 / \Delta T_2)} = \frac{25 - 20}{\ln(25/20)} = 22.4°\text{C}$$

$$\left.\begin{aligned} P &= \frac{t_2 - t_1}{T_1 - t_1} = \frac{45 - 95}{25 - 95} = 0.7 \\ R &= \frac{T_1 - T_2}{t_2 - t_1} = \frac{25 - 70}{45 - 95} = 0.9 \end{aligned}\right\} F = 0.77$$

Then the heat transfer surface area on the tube side becomes

$$\dot{Q} = U_i A_i F \Delta T_{lm,CF} \longrightarrow A_i = \frac{\dot{Q}}{U_i F \Delta T_{lm,CF}} = \frac{252.3\text{ kW}}{(0.950\text{ kW/m}^2.°\text{C})(0.77)(22.4°\text{C})} = \mathbf{15.4\ m^2}$$

13-59 Water is heated by ethylene glycol in a 2-shell passes and 12-tube passes heat exchanger. The rate of heat transfer and the heat transfer surface area on the tube side 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** There is no fouling. **5** Fluid properties are constant.

Properties The specific heats of water and ethylene glycol are given to be 4.18 and 2.68 kJ/kg.°C, respectively.

Analysis The rate of heat transfer in this heat exchanger is :

$$\dot{Q} = [\dot{m}C_p(T_{out} - T_{in})]_{\text{water}} = (0.8\text{ kg/s})(4.18\text{ kJ/kg.°C})(70°\text{C} - 22°\text{C}) = \mathbf{160.5\ kW}$$

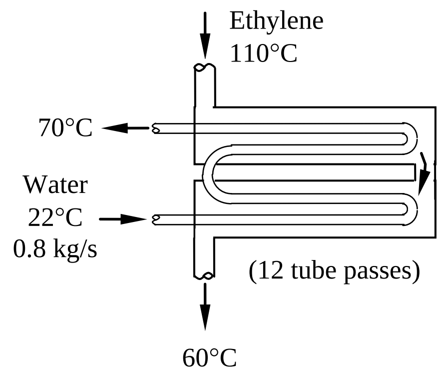
The logarithmic mean temperature difference for counter-flow arrangement and the correction factor F are

$$\Delta T_1 = T_{h,in} - T_{c,out} = 110°\text{C} - 70°\text{C} = 40°\text{C}$$

$$\Delta T_2 = T_{h,out} - T_{c,in} = 60°\text{C} - 22°\text{C} = 38°\text{C}$$

$$\Delta T_{lm,CF} = \frac{\Delta T_1 - \Delta T_2}{\ln(\Delta T_1 / \Delta T_2)} = \frac{40 - 38}{\ln(40/38)} = 39°\text{C}$$

$$\left.\begin{array}{l} P = \dfrac{t_2 - t_1}{T_1 - t_1} = \dfrac{60 - 110}{22 - 110} = 0.57 \\ R = \dfrac{T_1 - T_2}{t_2 - t_1} = \dfrac{22 - 70}{60 - 110} = 0.96 \end{array}\right\} F = 0.94$$



Then the heat transfer surface area on the tube side becomes

$$\dot{Q} = U_i A_i F \Delta T_{lm,CF} \longrightarrow A_i = \frac{\dot{Q}}{U_i F \Delta T_{lm,CF}} = \frac{160.5\text{ kW}}{(0.28\text{ kW/m}^2.°\text{C})(0.94)(39°\text{C})} = \mathbf{15.6\ m^2}$$

13-60 "!PROBLEM 13-60"

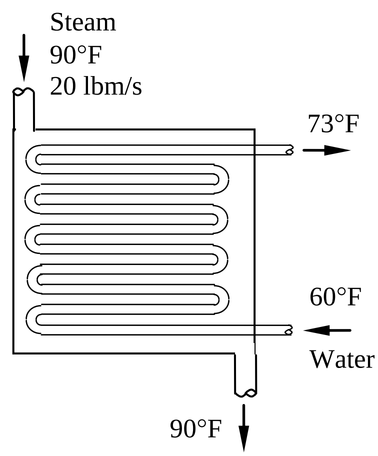
```
"GIVEN"
T_w_in=22 "[C]"
T_w_out=70 "[C]"
"m_dot_w=0.8 [kg/s], parameter to be varied"
C_p_w=4.18 "[kJ/kg-C]"
T_glycol_in=110 "[C]"
T_glycol_out=60 "[C]"
C_p_glycol=2.68 "[kJ/kg-C]"
U=0.28 "[kW/m^2-C]"

"ANALYSIS"
Q_dot=m_dot_w*C_p_w*(T_w_out-T_w_in)
Q_dot=m_dot_glycol*C_p_glycol*(T_glycol_in-T_glycol_out)
DELTAT_1=T_glycol_in-T_w_out
DELTAT_2=T_glycol_out-T_w_in
DELTAT_lm_CF=(DELTAT_1-DELTAT_2)/ln(DELTAT_1/DELTAT_2)
P=(T_glycol_out-T_glycol_in)/(T_w_in-T_glycol_in)
R=(T_w_in-T_w_out)/(T_glycol_out-T_glycol_in)
F=0.94 "from Fig. 13-18b of the text at the calculated P and R"
Q_dot=U*A*F*DELTAT_lm_CF
```

m_w [kg/s]	Q [kW]	A [m^2]
0.4	80.26	7.82
0.5	100.3	9.775
0.6	120.4	11.73
0.7	140.4	13.69
0.8	160.5	15.64
0.9	180.6	17.6
1	200.6	19.55
1.1	220.7	21.51
1.2	240.8	23.46
1.3	260.8	25.42
1.4	280.9	27.37
1.5	301	29.33
1.6	321	31.28
1.7	341.1	33.24
1.8	361.2	35.19
1.9	381.2	37.15
2	401.3	39.1
2.1	421.3	41.06
2.2	441.4	43.01

13-61E Steam is condensed by cooling water in a condenser. The rate of heat transfer, the rate of condensation of steam, and the mass flow rate of cold water 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** There is no fouling. **5** Fluid properties are constant. **6** The thermal resistance of the inner tube is negligible since the tube is thin-walled and highly conductive.

Properties We take specific heat of water are given to be 1.0 Btu/lbm.°F. The heat of condensation of steam at 90°F is 1043 Btu/lbm.



Analysis (*a*) The log mean temperature difference is determined from

$$\Delta T_1 = T_{h,in} - T_{c,out} = 90°\text{F} - 73°\text{F} = 17°\text{F}$$

$$\Delta T_2 = T_{h,out} - T_{c,in} = 90°\text{F} - 60°\text{F} = 30°\text{F}$$

$$\Delta T_{lm,CF} = \frac{\Delta T_1 - \Delta T_2}{\ln(\Delta T_1 / \Delta T_2)} = \frac{17-30}{\ln(17/30)} = 22.9°\text{F}$$

The heat transfer surface area is

$$A_s = 8n\pi DL = 8\times 50\times \pi(3/48\,\text{ft})(5\text{ft}) = 392.7\,\text{ft}^2$$

and

$$\dot{Q} = UA_s\Delta T_{lm} = (600\,\text{Btu/h.ft}^2.°\text{F})(392.7\text{ft}^2)(22.9°\text{F}) = \mathbf{5.396\times 10^6\ Btu/h}$$

(*b*) The rate of condensation of the steam is

$$\dot{Q} = (\dot{m}h_{fg})_{steam} \longrightarrow \dot{m}_{steam} = \frac{\dot{Q}}{h_{fg}} = \frac{5.396\times 10^6\ \text{Btu/h}}{1043\,\text{Btu/lbm}} = \mathbf{5173\ lbm/h = 1.44\ lbm/s}$$

(*c*) Then the mass flow rate of cold water becomes

$$\dot{Q} = [\dot{m}C_p(T_{out} - T_{in})]_{\text{cold water}}$$

$$\dot{m}_{\text{cold water}} = \frac{\dot{Q}}{C_p(T_{out} - T_{in})} = \frac{5.396\times 10^6\ \text{Btu/h}}{(1.0\,\text{Btu/lbm.°F})(73°\text{F} - 60°\text{F}]} = \mathbf{4.15\times 10^5\ lbm/h = 115\ lbm/s}$$

13-62 "!PROBLEM 13-62E"

```
"GIVEN"
N_pass=8
N_tube=50
"T_steam=90 [F], parameter to be varied"
h_fg_steam=1043 "[Btu/lbm]"
T_w_in=60 "[F]"
T_w_out=73 "[F]"
C_p_w=1.0 "[Btu/lbm-F]"
D=3/4*1/12 "[ft]"
L=5 "[ft]"
U=600 "[Btu/h-ft^2-F]"

"ANALYSIS"
"(a)"
DELTAT_1=T_steam-T_w_out
DELTAT_2=T_steam-T_w_in
DELTAT_lm=(DELTAT_1-DELTAT_2)/ln(DELTAT_1/DELTAT_2)
A=N_pass*N_tube*pi*D*L
Q_dot=U*A*DELTAT_lm*Convert(Btu/h, Btu/s)
"(b)"
Q_dot=m_dot_steam*h_fg_steam
"(c)"
Q_dot=m_dot_w*C_p_w*(T_w_out-T_w_in)
```

T_{steam} [F]	Q [Btu/s]	m_{steam}[lbm/s]	m_w [lbm/s]
80	810.5	0.7771	62.34
82	951.9	0.9127	73.23
84	1091	1.046	83.89
86	1228	1.177	94.42
88	1363	1.307	104.9
90	1498	1.436	115.2
92	1632	1.565	125.6
94	1766	1.693	135.8
96	1899	1.821	146.1
98	2032	1.948	156.3
100	2165	2.076	166.5
102	2297	2.203	176.7
104	2430	2.329	186.9
106	2562	2.456	197.1
108	2694	2.583	207.2
110	2826	2.709	217.4
112	2958	2.836	227.5
114	3089	2.962	237.6
116	3221	3.088	247.8
118	3353	3.214	257.9
120	3484	3.341	268

13-63 Glycerin is heated by hot water in a 1-shell pass and 13-tube passes heat exchanger. The mass flow rate of glycerin and the overall heat transfer coefficient 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** There is no fouling. **5** Fluid properties are constant.

Properties The specific heats of water and glycerin are given to be 4.18 and 2.48 kJ/kg.°C, respectively.

Analysis The rate of heat transfer in this heat exchanger is

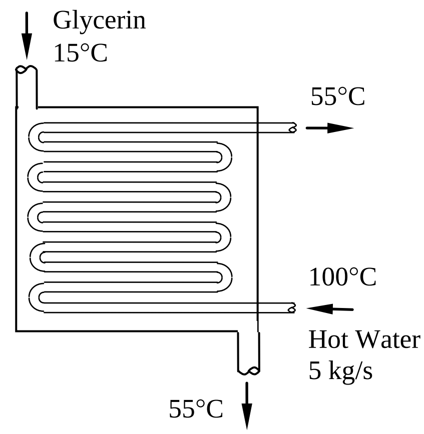
$$\dot{Q} = [\dot{m}C_p(T_{in} - T_{out})]_{\text{water}} = (5\text{ kg/s})(4.18\text{ kJ/kg.°C})(100\text{°C} - 55\text{°C}) = 940.5\text{ kW}$$

The mass flow rate of the glycerin is determined from

$$\dot{Q} = [\dot{m}C_p(T_{out} - T_{in})]_{\text{glycerin}}$$

$$\dot{m}_{\text{glycerin}} = \frac{\dot{Q}}{C_p(T_{out} - T_{in})} = \frac{940.5\text{ kJ/s}}{(2.48\text{ kJ/kg.°C})[(55\text{°C} - 15\text{°C}]} = \mathbf{9.5\ kg/s}$$

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



$$\Delta T_1 = T_{h,in} - T_{c,out} = 100\text{°C} - 55\text{°C} = 45\text{°C}$$

$$\Delta T_2 = T_{h,out} - T_{c,in} = 55\text{°C} - 15\text{°C} = 40\text{°C}$$

$$\Delta T_{lm,CF} = \frac{\Delta T_1 - \Delta T_2}{\ln(\Delta T_1/\Delta T_2)} = \frac{45 - 40}{\ln(45/40)} = 42.5\text{°C}$$

$$\left.\begin{aligned} P &= \frac{t_2 - t_1}{T_1 - t_1} = \frac{55 - 100}{15 - 100} = 0.53 \\ R &= \frac{T_1 - T_2}{t_2 - t_1} = \frac{15 - 55}{55 - 100} = 0.89 \end{aligned}\right\} F = 0.77$$

The heat transfer surface area is

$$A_s = n\pi DL = 10\pi(0.015\text{ m})(2\text{ m}) = 0.94\text{ m}^2$$

Then the overall heat transfer coefficient of the heat exchanger is determined to be

$$\dot{Q} = UA_sF\Delta T_{lm,CF} \longrightarrow U = \frac{\dot{Q}}{A_sF\Delta T_{lm,CF}} = \frac{940.5\text{ kW}}{(0.94\text{ m}^2)(0.77)(42.5\text{°C})} = \mathbf{30.6\ kW/m^2.°C}$$

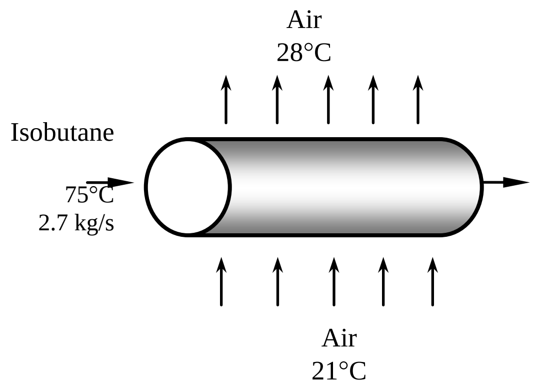
13-64 Isobutane is condensed by cooling air in the condenser of a power plant. The mass flow rate of air and the overall heat transfer coefficient are to be determined.

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** There is no fouling. **5** Fluid properties are constant.

Properties The heat of vaporization of isobutane at 75°C is given to be h_{fg} = 255.7 kJ/kg and specific heat of air is given to be C_p = 1005 J/kg.°C.

Analysis First, the rate of heat transfer is determined from

$$\dot{Q} = (\dot{m}h_{fg})_{\text{isobutane}} = (2.7\ \text{kg/s})(255.7\ \text{kJ/kg}) = 690.39\ \text{kW}$$



The mass flow rate of air is determined from

$$\dot{Q} = [\dot{m}C_p(T_{\text{out}} - T_{\text{in}})]_{\text{air}}$$

$$\dot{m}_{\text{air}} = \frac{\dot{Q}}{C_p(T_{\text{out}} - T_{\text{in}})} = \frac{690.39\ \text{kJ/s}}{(1.005\ \text{kJ/kg.°C})(28°\text{C} - 21°\text{C})} = \mathbf{98.14\ kg/s}$$

The temperature differences between the isobutane and the air at the two ends of the condenser are

$$\Delta T_1 = T_{\text{h,in}} - T_{\text{c,out}} = 75°\text{C} - 21°\text{C} = 54°\text{C}$$

$$\Delta T_2 = T_{\text{h,out}} - T_{\text{c,in}} = 75°\text{C} - 28°\text{C} = 47°\text{C}$$

and

$$\Delta T_{\text{lm}} = \frac{\Delta T_1 - \Delta T_2}{\ln(\Delta T_1/\Delta T_2)} = \frac{54 - 47}{\ln(54/47)} = 50.4°\text{C}$$

Then the overall heat transfer coefficient is determined from

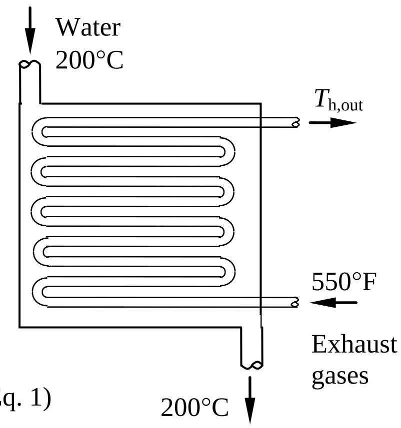
$$\dot{Q} = UA_s\Delta T_{\text{lm}} \longrightarrow 690{,}390\ \text{W} = U(24\ \text{m}^2)(50.4°\text{C}) \longrightarrow U = \mathbf{571\ W/m^2.°C}$$

13-65 Water is evaporated by hot exhaust gases in an evaporator. The rate of heat transfer, the exit temperature of the exhaust gases, and the rate of evaporation of water 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** There is no fouling. **5** Fluid properties are constant.

Properties The heat of vaporization of water at 200°C is given to be h_{fg} = 1941 kJ/kg and specific heat of exhaust gases is given to be C_p = 1051 J/kg.°C.

Analysis The temperature differences between the water and the exhaust gases at the two ends of the evaporator are



$$\Delta T_1 = T_{h,in} - T_{c,out} = 550°C - 200°C = 350°C$$
$$\Delta T_2 = T_{h,out} - T_{c,in} = (T_{h,out} - 200)°C$$

and

$$\Delta T_{lm} = \frac{\Delta T_1 - \Delta T_2}{\ln(\Delta T_1 / \Delta T_2)} = \frac{350 - (T_{h,out} - 200)}{\ln[350/(T_{h,out} - 200)]}$$

Then the rate of heat transfer can be expressed as

$$\dot{Q} = UA_s \Delta T_{lm} = (1.780\,\text{kW/m}^2.°\text{C})(0.5\,\text{m}^2)\frac{350 - (T_{h,out} - 200)}{\ln[350/(T_{h,out} - 200)]} \quad \text{(Eq. 1)}$$

The rate of heat transfer can also be expressed as in the following forms

$$\dot{Q} = [\dot{m}C_p(T_{h,in} - T_{h,out})]_{\substack{\text{exhaust}\\ \text{gases}}} = (0.25\,\text{kg/s})(1.051\,\text{kJ/kg.°C})(550°\text{C} - T_{h,out}) \quad \text{(Eq. 2)}$$

$$\dot{Q} = (\dot{m}h_{fg})_{\text{water}} = \dot{m}_{\text{water}}(1941\,\text{kJ/kg}) \quad \text{(Eq. 3)}$$

We have three equations with three unknowns. Using an equation solver such as EES, the unknowns are determined to be

$$\dot{Q} = \mathbf{88.85\ kW}$$
$$T_{h,out} = \mathbf{211.8°C}$$
$$\dot{m}_{\text{water}} = \mathbf{0.0458\ kg/s}$$

13-66 "!PROBLEM 13-66"

```
"GIVEN"
"T_exhaust_in=550 [C], parameter to be varied"
C_p_exhaust=1.051 "[kJ/kg-C]"
m_dot_exhaust=0.25 "[kg/s]"
T_w=200 "[C]"
h_fg_w=1941 "[kJ/kg]"
A=0.5 "[m^2]"
U=1.780 "[kW/m^2-C]"

"ANALYSIS"
DELTAT_1=T_exhaust_in-T_w
DELTAT_2=T_exhaust_out-T_w
DELTAT_lm=(DELTAT_1-DELTAT_2)/ln(DELTAT_1/DELTAT_2)
Q_dot=U*A*DELTAT_lm
Q_dot=m_dot_exhaust*C_p_exhaust*(T_exhaust_in-T_exhaust_out)
Q_dot=m_dot_w*h_fg_w
```

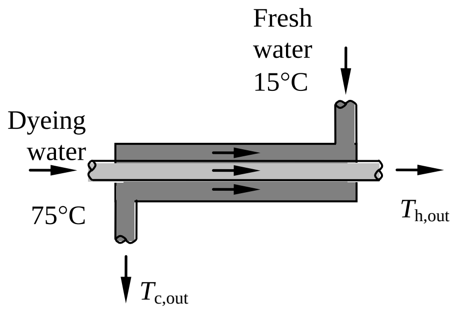
$T_{exhaust,in}$ [C]	Q [kW]	$T_{exhaust,out}$ [C]	m_w [kg/s]
300	25.39	203.4	0.01308
320	30.46	204.1	0.0157
340	35.54	204.7	0.01831
360	40.62	205.4	0.02093
380	45.7	206.1	0.02354
400	50.77	206.8	0.02616
420	55.85	207.4	0.02877
440	60.93	208.1	0.03139
460	66.01	208.8	0.03401
480	71.08	209.5	0.03662
500	76.16	210.1	0.03924
520	81.24	210.8	0.04185
540	86.32	211.5	0.04447
560	91.39	212.2	0.04709
580	96.47	212.8	0.0497
600	101.5	213.5	0.05232

13-67 The waste dyeing water is to be used to preheat fresh water. The outlet temperatures of each fluid and the mass flow 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** There is no fouling. **5** Fluid properties are constant.

Properties The specific heats of waste dyeing water and the fresh water are given to be C_p = 4295 J/kg.°C and C_p = 4180 J/kg.°C, respectively.

Analysis The temperature differences between the dyeing water and the fresh water at the two ends of the heat exchanger are



$$\Delta T_1 = T_{h,in} - T_{c,out} = 75 - T_{c,out}$$
$$\Delta T_2 = T_{h,out} - T_{c,in} = T_{h,out} - 15$$

and

$$\Delta T_{lm} = \frac{\Delta T_1 - \Delta T_2}{\ln(\Delta T_1 / \Delta T_2)} = \frac{(75 - T_{c,out}) - (T_{h,out} - 15)}{\ln\left[(75 - T_{c,out})/(T_{h,out} - 15)\right]}$$

Then the rate of heat transfer can be expressed as

$$\dot{Q} = UA_s \Delta T_{lm}$$
$$35\text{ kW} = (0.625\text{ kW/m}^2.°\text{C})(1.65\text{ m}^2)\frac{(75 - T_{c,out}) - (T_{h,out} - 15)}{\ln\left[(75 - T_{c,out})/(T_{h,out} - 15)\right]} \quad \text{(Eq. 1)}$$

The rate of heat transfer can also be expressed as

$$\dot{Q} = [\dot{m}C_p(T_{h,in} - T_{h,out})]_{\substack{\text{dyeing}\\ \text{water}}} \longrightarrow 35\text{ kW} = \dot{m}(4.295\text{ kJ/kg.°C})(75°\text{C} - T_{h,out}) \quad \text{(Eq. 2)}$$

$$\dot{Q} = [\dot{m}C_p(T_{h,in} - T_{h,out})]_{\substack{\text{dyeing}\\ \text{water}}} \longrightarrow 35\text{ kW} = \dot{m}(4.18\text{ kJ/kg.°C})(T_{c,out} - 15°\text{C}) \quad \text{(Eq. 3)}$$

We have three equations with three unknowns. Using an equation solver such as EES, the unknowns are determined to be

$$T_{c,out} = \mathbf{41.4°C}$$
$$T_{h,out} = \mathbf{49.3°C}$$
$$\dot{m} = \mathbf{0.317\ kg/s}$$