The Log Mean Temperature Difference Method

13-32C ΔT_{lm} is called the log mean temperature difference, and is expressed as

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

where

$\Delta T_1 = T_{h,in} - T_{c,in}$ $\Delta T_2 = T_{h,out} - T_{c,out}$ for parallel-flow heat exchangers and

$\Delta T = T_{h,in} - T_{c,out}$ $\Delta T_2 = T_{h,out} - T_{c,in}$ for counter-flow heat exchangers

13-33C The temperature difference between the two fluids decreases from ΔT_1 at the inlet to ΔT_2 at the outlet, and arithmetic mean temperature difference is defined as $\Delta T_m = \frac{\Delta T_1 + \Delta T_2}{2}$. The logarithmic mean temperature difference ΔT_{lm} is obtained by tracing the actual temperature profile of the fluids along the heat exchanger, and is an exact representation of the average temperature difference between the hot and cold fluids. It truly reflects the exponential decay of the local temperature difference. The logarithmic mean temperature difference is always less than the arithmetic mean temperature.

13-34C ΔT_{lm} cannot be greater than both ΔT_1 and ΔT_2 because ΔT_{ln} is always less than or equal to ΔT_{m} (arithmetic mean) which can not be greater than both ΔT_1 and ΔT_2.

13-35C No, it cannot. When ΔT_1 is less than ΔT_2 the ratio of them must be less than one and the natural logarithms of the numbers which are less than 1 are negative. But the numerator is also negative in this case. When ΔT_1 is greater than ΔT_2, we obtain positive numbers at the both numerator and denominator.

13-36C In the parallel-flow heat exchangers the hot and cold fluids enter the heat exchanger at the same end, and the temperature of the hot fluid decreases and the temperature of the cold fluid increases along the heat exchanger. But the temperature of the cold fluid can never exceed that of the hot fluid. In case of the counter-flow heat exchangers the hot and cold fluids enter the heat exchanger from the opposite ends and the outlet temperature of the cold fluid may exceed the outlet temperature of the hot fluid.

13-37C The ΔT_{lm} will be greatest for double-pipe counter-flow heat exchangers.

13-38C The factor F is called as correction factor which depends on the geometry of the heat exchanger and the inlet and the outlet temperatures of the hot and cold fluid streams. It represents how closely a heat exchanger approximates a counter-flow heat exchanger in terms of its logarithmic mean temperature difference. F cannot be greater than unity.

13-39C In this case it is not practical to use the LMTD method because it requires tedious iterations. Instead, the effectiveness-NTU method should be used.

13-40C First heat transfer rate is determined from $\dot{Q} = \dot{m}C_p[T_{in} - T_{out}]$, $\Delta T_{\ln}$ from $\Delta T_{lm} = \dfrac{\Delta T_1 - \Delta T_2}{\ln(\Delta T_1 / \Delta T_2)}$, correction factor from the figures, and finally the surface area of the heat exchanger from $\dot{Q} = UAFDT_{lm,cf}$

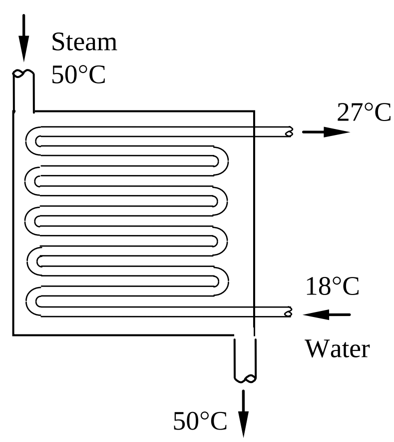
13-41 Steam is condensed by cooling water in the condenser of a power plant. The mass flow rate of the cooling water and the rate of condensation are to be determined.

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 50°C is given to be h_{fg} = 2305 kJ/kg and specific heat of cold water at the average temperature of 22.5°C is given to be C_p = 4180 J/kg.°C.

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

$$\Delta T_1 = T_{h,in} - T_{c,out} = 50°\text{C} - 27°\text{C} = 23°\text{C}$$
$$\Delta T_2 = T_{h,out} - T_{c,in} = 50°\text{C} - 18°\text{C} = 32°\text{C}$$



and

$$\Delta T_{lm} = \frac{\Delta T_1 - \Delta T_2}{\ln(\Delta T_1 / \Delta T_2)} = \frac{23-32}{\ln(23/32)} = 27.3°\text{C}$$

Then the heat transfer rate in the condenser becomes

$$\dot{Q} = UA_s\Delta T_{lm} = (2400\,\text{W/m}^2.°\text{C})(58\,\text{m}^2)(27.3°\text{C}) = 3800\,\text{kW}$$

The mass flow rate of the cooling water and the rate of condensation of steam are determined from

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

$$\dot{m}_{\substack{\text{cooling}\\ \text{water}}} = \frac{\dot{Q}}{C_p(T_{out} - T_{in})} = \frac{3800\,\text{kJ/s}}{(4.18\,\text{kJ/kg.°C})(27°\text{C} - 18°\text{C})} = \mathbf{101\,kg/s}$$

$$\dot{Q} = (\dot{m}h_{fg})_{steam} \longrightarrow \dot{m}_{steam} = \frac{\dot{Q}}{h_{fg}} = \frac{3800\text{ kJ/s}}{2305\text{ kJ/kg}} = \mathbf{1.65\ kg/s}$$

13-42 Water is heated in a double-pipe parallel-flow heat exchanger by geothermal water. The required length of 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** There is no fouling. **5** Fluid properties are constant.

Properties The specific heats of water and geothermal fluid are given to be 4.18 and 4.31 kJ/kg.°C, respectively.

Analysis The rate of heat transfer in the heat exchanger is

$$\dot{Q} = [\dot{m}C_p(T_{out} - T_{in})]_{\text{water}} = (0.2 \text{ kg/s})(4.18 \text{ kJ/kg.°C})(60\text{°C} - 25\text{°C}) = 29.26 \text{ kW}$$

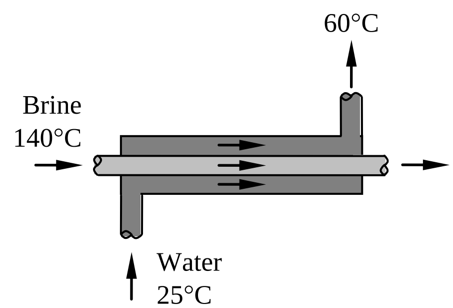
Then the outlet temperature of the geothermal water is determined from

$$\dot{Q} = [\dot{m}C_p(T_{in} - T_{out})]_{\text{geot.water}} \longrightarrow T_{out} = T_{in} - \frac{\dot{Q}}{\dot{m}C_p} = 140\text{°C} - \frac{29.26 \text{ kW}}{(0.3 \text{ kg/s})(4.31 \text{ kJ/kg.°C})} = 117.4\text{°C}$$

The logarithmic mean temperature difference is

$$\Delta T_1 = T_{h,in} - T_{c,in} = 140\text{°C} - 25\text{°C} = 115\text{°C}$$

$$\Delta T_2 = T_{h,out} - T_{c,out} = 117.4\text{°C} - 60\text{°C} = 57.4\text{°C}$$



and

$$\Delta T_{lm} = \frac{\Delta T_1 - \Delta T_2}{\ln(\Delta T_1 / \Delta T_2)} = \frac{115 - 57.4}{\ln(115/57.4)} = 82.9\text{°C}$$

The surface area of the heat exchanger is determined from

$$\dot{Q} = UA_s\Delta T_{lm} \longrightarrow A_s = \frac{\dot{Q}}{U\Delta T_{lm}} = \frac{29.26 \text{ kW}}{(0.55 \text{ kW/m}^2)(82.9\text{°C})} = 0.642 \text{ m}^2$$

Then the length of the tube required becomes

$$A_s = \pi DL \longrightarrow L = \frac{A_s}{\pi D} = \frac{0.642 \text{ m}^2}{\pi(0.008 \text{ m})} = \mathbf{25.5\ m}$$

13-43 "!PROBLEM 13-43"

```
"GIVEN"
T_w_in=25 "[C]"
T_w_out=60 "[C]"
m_dot_w=0.2 "[kg/s]"
C_p_w=4.18 "[kJ/kg-C]"
T_geo_in=140 "C], parameter to be varied"
m_dot_geo=0.3 "[kg/s], parameter to be varied"
C_p_geo=4.31 "[kJ/kg-C]"
D=0.008 "[m]"
U=0.55 "[kW/m^2-C]"

"ANALYSIS"
Q_dot=m_dot_w*C_p_w*(T_w_out-T_w_in)
Q_dot=m_dot_geo*C_p_geo*(T_geo_in-T_geo_out)
DELTAT_1=T_geo_in-T_w_in
DELTAT_2=T_geo_out-T_w_out
DELTAT_lm=(DELTAT_1-DELTAT_2)/ln(DELTAT_1/DELTAT_2)
Q_dot=U*A*DELTAT_lm
A=pi*D*L
```

$T_{geo,in}$ [C]	L [m]
100	53.73
105	46.81
110	41.62
115	37.56
120	34.27
125	31.54
130	29.24
135	27.26
140	25.54
145	24.04
150	22.7
155	21.51
160	20.45
165	19.48
170	18.61
175	17.81
180	17.08
185	16.4
190	15.78
195	15.21
200	14.67

m_{geo} [kg/s]	**L [m]**
0.1	46.31
0.125	35.52
0.15	31.57
0.175	29.44
0.2	28.1
0.225	27.16
0.25	26.48
0.275	25.96
0.3	25.54
0.325	25.21
0.35	24.93
0.375	24.69
0.4	24.49
0.425	24.32
0.45	24.17
0.475	24.04
0.5	23.92

13-44E Glycerin is heated by hot water in a 1-shell pass and 8-tube passes heat exchanger. The rate of heat transfer for the cases of fouling and no fouling 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** Heat transfer coefficients and fouling factors are constant and uniform. **5** The thermal resistance of the inner tube is negligible since the tube is thin-walled and highly conductive.

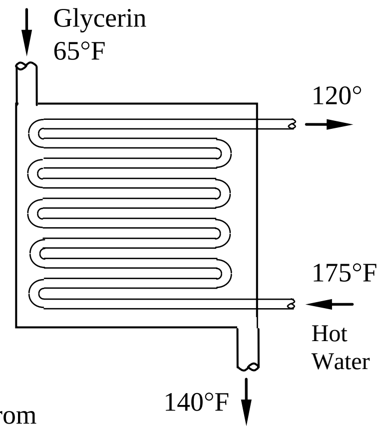
Properties The specific heats of glycerin and water are given to be 0.60 and 1.0 Btu/lbm.°F, respectively.

Analysis (*a*) The tubes are thin walled and thus we assume the inner surface area of the tube to be equal to the outer surface area. Then the heat transfer surface area of this heat exchanger becomes

$$A_s = n\pi DL = 8\pi(0.5/12\,\text{ft})(500\text{ft}) = 523.6\,\text{ft}^2$$

The temperature differences at the two ends of the heat exchanger are

$$\Delta T_1 = T_{h,in} - T_{c,out} = 175°\text{F} - 140°\text{F} = 35°\text{F}$$
$$\Delta T_2 = T_{h,out} - T_{c,in} = 120°\text{F} - 65°\text{F} = 55°\text{F}$$



and $$\Delta T_{lm,CF} = \frac{\Delta T_1 - \Delta T_2}{\ln(\Delta T_1/\Delta T_2)} = \frac{35-55}{\ln(35/55)} = 44.25°\text{F}$$

The correction factor is

$$\left.\begin{aligned} P &= \frac{t_2 - t_1}{T_1 - t_1} = \frac{120-175}{65-175} = 0.5 \\ R &= \frac{T_1 - T_2}{t_2 - t_1} = \frac{65-140}{120-175} = 1.36 \end{aligned}\right\} F = 0.70$$

In case of no fouling, the overall heat transfer coefficient is determined from

$$U = \frac{1}{\frac{1}{h_i} + \frac{1}{h_o}} = \frac{1}{\frac{1}{50\ \text{Btu/h.ft}^2.°\text{F}} + \frac{1}{4\ \text{Btu/h.ft}^2.°\text{F}}} = 3.7\ \text{Btu/h.ft}^2.°\text{F}$$

Then the rate of heat transfer becomes

$$\dot{Q} = UA_s F\Delta T_{lm,CF} = (3.7\ \text{Btu/h.ft}^2.°\text{F})(523.6\text{ft}^2)(0.70)(44.25°\text{F}) = \mathbf{60{,}000\ Btu/h}$$

(*b*) The thermal resistance of the heat exchanger with a fouling factor is

$$\begin{aligned} R &= \frac{1}{h_i A_i} + \frac{R_{fi}}{A_i} + \frac{1}{h_o A_o} \\ &= \frac{1}{(50\ \text{Btu/h.ft}^2.°\text{F})(523.6\ \text{ft}^2)} + \frac{0.002\ \text{h.ft}^2.°\text{F/Btu}}{523.6\ \text{ft}^2} + \frac{1}{(4\ \text{Btu/h.ft}^2.°\text{F})(523.6\ \text{ft}^2)} \\ &= 0.0005195\ \text{h.°F/Btu} \end{aligned}$$

The overall heat transfer coefficient in this case is

$$R = \frac{1}{UA_s} \longrightarrow U = \frac{1}{RA_s} = \frac{1}{(0.0005195\text{h.°F/Btu})(523.6\,\text{ft}^2)} = 3.68\,\text{Btu/h.ft}^2.°\text{F}$$

Then rate of heat transfer becomes

$$\dot{Q} = UA_s F\Delta T_{lm,CF} = (3.68\,\text{Btu/h.ft}^2.°\text{F})(523.6\text{ft}^2)(0.70)(44.25°\text{F}) = \mathbf{59{,}680\ Btu/h}$$

13-45 During an experiment, the inlet and exit temperatures of water and oil and the mass flow rate of water are measured. The overall heat transfer coefficient based on the inner surface area 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** Fluid properties are constant.

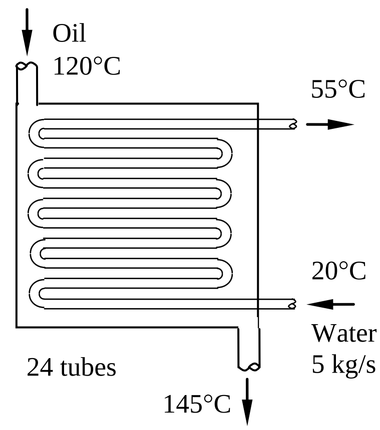
Properties The specific heats of water and oil are given to be 4180 and 2150 J/kg.°C, respectively.

Analysis The rate of heat transfer from the oil to the water is

$$\dot{Q} = [\dot{m}C_p(T_{out} - T_{in})]_{\text{water}} = (5\text{ kg/s})(4.18\text{ kJ/kg.°C})(55\text{°C} - 20\text{°C}) = 731.5\text{ kW}$$

The heat transfer area on the tube side is

$$A_i = n\pi D_i L = 24\pi(0.012\text{ m})(2\text{ m}) = 1.8\text{ m}^2$$



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

$$\Delta T_1 = T_{h,in} - T_{c,out} = 120\text{°C} - 55\text{°C} = 65\text{°C}$$

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

$$\Delta T_{lm,CF} = \frac{\Delta T_1 - \Delta T_2}{\ln(\Delta T_1 / \Delta T_2)} = \frac{65 - 25}{\ln(65/25)} = 41.9\text{°C}$$

$$\left.\begin{aligned} P &= \frac{t_2 - t_1}{T_1 - t_1} = \frac{55 - 20}{120 - 20} = 0.35 \\ R &= \frac{T_1 - T_2}{t_2 - t_1} = \frac{120 - 45}{55 - 20} = 2.14 \end{aligned}\right\} F = 0.70$$

Then the overall heat transfer coefficient becomes

$$\dot{Q} = U_i A_i F \Delta T_{lm,CF} \longrightarrow U_i = \frac{\dot{Q}}{A_i F \Delta T_{lm,CF}} = \frac{731.5\text{ kW}}{(1.8\text{ m}^2)(0.70)(41.9\text{°C})} = \mathbf{13.9\ kW/m^2.°C}$$

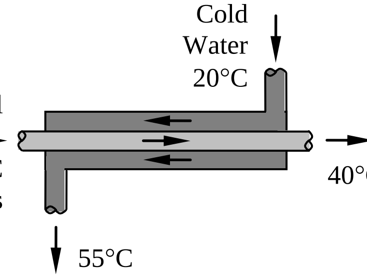
13-46 Ethylene glycol is cooled by water in a double-pipe counter-flow heat exchanger. The rate of heat transfer, the mass flow rate of water, and the heat transfer surface area on the inner side of the tubes are to be determined.

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 2.56 kJ/kg.°C, respectively.

Analysis (*a*) The rate of heat transfer is

$$\dot{Q} = [\dot{m}C_p(T_{in} - T_{out})]_{\text{glycol}}$$
$$= (3.5\text{ kg/s})(2.56\text{ kJ/kg.°C})(80°\text{C} - 40°\text{C})$$
$$= \mathbf{358.4\ kW}$$



(*b*) The rate of heat transfer from water must be equal to the rate of heat transfer to the glycol. Then,

$$\dot{Q} = [\dot{m}C_p(T_{out} - T_{in})]_{\text{water}} \longrightarrow \dot{m}_{\text{water}} = \frac{\dot{Q}}{C_p(T_{out} - T_{in})}$$
$$= \frac{358.4\text{ kJ/s}}{(4.18\text{ kJ/kg.°C})(55°\text{C} - 20°\text{C})} = \mathbf{2.45\ kg/s}$$

(*c*) The temperature differences at the two ends of the heat exchanger are

$$\Delta T_1 = T_{h,in} - T_{c,out} = 80°\text{C} - 55°\text{C} = 25°\text{C}$$
$$\Delta T_2 = T_{h,out} - T_{c,in} = 40°\text{C} - 20°\text{C} = 20°\text{C}$$

and

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

Then the heat transfer surface area becomes

$$\dot{Q} = U_i A_i \Delta T_{lm} \longrightarrow A_i = \frac{\dot{Q}}{U_i \Delta T_{lm}} = \frac{358.4\text{ kW}}{(0.25\text{ kW/m}^2.°\text{C})(22.4°\text{C})} = \mathbf{64.0\ m^2}$$

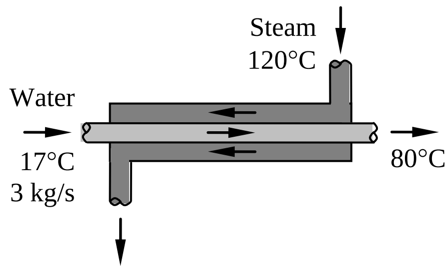
13-47 Water is heated by steam in a double-pipe counter-flow heat exchanger. The required length of the tubes is to be determined.

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 heat of water is given to be 4.18 kJ/kg.°C. The heat of condensation of steam at 120°C is given to be 2203 kJ/kg.

Analysis The rate of heat transfer is

$$\begin{aligned}\dot{Q} &= [\dot{m}C_p(T_{out} - T_{in})]_{\text{water}} \\ &= (3\text{ kg/s})(4.18\text{ kJ/kg.°C})(80°\text{C} - 17°\text{C}) \\ &= 790.02\text{ kW}\end{aligned}$$



The logarithmic mean temperature difference is

$$\Delta T_1 = T_{h,in} - T_{c,out} = 120°\text{C} - 80°\text{C} = 40°\text{C}$$

$$\Delta T_2 = T_{h,in} - T_{c,in} = 120°\text{C} - 17°\text{C} = 103°\text{C}$$

$$\Delta T_{lm} = \frac{\Delta T_1 - \Delta T_2}{\ln(\Delta T_1 / \Delta T_2)} = \frac{40 - 103}{\ln(40/103)} = 66.6°\text{C}$$

The heat transfer surface area is

$$\dot{Q} = U_i A_i \Delta T_{lm} \longrightarrow A_i = \frac{\dot{Q}}{U_i \Delta T_{lm}} = \frac{790.02\text{ kW}}{(1.5\text{ kW/m}^2.°\text{C})(66.6°\text{C})} = 7.9\text{ m}^2$$

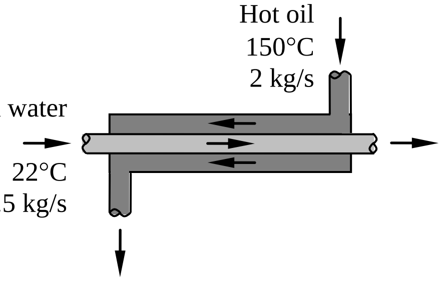
Then the length of tube required becomes

$$A_i = \pi D_i L \longrightarrow L = \frac{A_i}{\pi D_i} = \frac{7.9\text{ m}^2}{\pi(0.025\text{ m})} = \mathbf{100.6\text{ m}}$$

13-48 Oil is cooled by water in a thin-walled double-pipe counter-flow heat exchanger. The overall heat transfer coefficient 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. **6** The thermal resistance of the inner tube is negligible since the tube is thin-walled and highly conductive.

Properties The specific heats of water and oil are given to be 4.18 and 2.20 kJ/kg.°C, respectively.



Analysis The rate of heat transfer from the water to the oil is

$$\dot{Q} = [\dot{m}C_p(T_{in} - T_{out})]_{\text{oil}} = (2\text{ kg/s})(2.2\text{ kJ/kg.°C})(150°\text{C} - 40°\text{C}) = 484\text{ kW}$$

The outlet temperature of the water is determined from

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

$$= 22°\text{C} + \frac{484\text{ kW}}{(1.5\text{ kg/s})(4.18\text{ kJ/kg.°C})} = 99.2°\text{C}$$

The logarithmic mean temperature difference is

$$\Delta T_1 = T_{h,in} - T_{c,out} = 150°\text{C} - 99.2°\text{C} = 50.8°\text{C}$$

$$\Delta T_2 = T_{h,out} - T_{c,in} = 40°\text{C} - 22°\text{C} = 18°\text{C}$$

$$\Delta T_{lm} = \frac{\Delta T_1 - \Delta T_2}{\ln(\Delta T_1 / \Delta T_2)} = \frac{50.8 - 18}{\ln(50.8/18)} = 31.6°\text{C}$$

Then the overall heat transfer coefficient becomes

$$U = \frac{\dot{Q}}{A_s \Delta T_{lm}} = \frac{484\text{ kW}}{\pi(0.025\text{ m})(6\text{ m})(31.6°\text{C})} = \mathbf{32.5\ kW/m^2.°C}$$

13-49 "!PROBLEM 13-49"

```
"GIVEN"
T_oil_in=150 "[C]"
T_oil_out=40 "[C], parameter to be varied"
m_dot_oil=2 "[kg/s]"
C_p_oil=2.20 "[kJ/kg-C]"
"T_w_in=22 [C], parameter to be varied"
m_dot_w=1.5 "[kg/s]"
C_p_w=4.18 "[kJ/kg-C]"
D=0.025 "[m]"
L=6 "[m]"

"ANALYSIS"
Q_dot=m_dot_oil*C_p_oil*(T_oil_in-T_oil_out)
Q_dot=m_dot_w*C_p_w*(T_w_out-T_w_in)
DELTAT_1=T_oil_in-T_w_out
DELTAT_2=T_oil_out-T_w_in
DELTAT_lm=(DELTAT_1-DELTAT_2)/ln(DELTAT_1/DELTAT_2)
Q_dot=U*A*DELTAT_lm
A=pi*D*L
```

$T_{oil,out}$ [C]	U [kW/m^2-C]
30	53.22
32.5	45.94
35	40.43
37.5	36.07
40	32.49
42.5	29.48
45	26.9
47.5	24.67
50	22.7
52.5	20.96
55	19.4
57.5	18
60	16.73
62.5	15.57
65	14.51
67.5	13.53
70	12.63

$T_{w,in}$ [C]	U [kW/m^2-C]
5	20.7
6	21.15
7	21.61
8	22.09
9	22.6
10	23.13
11	23.69
12	24.28
13	24.9
14	25.55
15	26.24
16	26.97
17	27.75
18	28.58
19	29.46
20	30.4
21	31.4
22	32.49
23	33.65
24	34.92
25	36.29

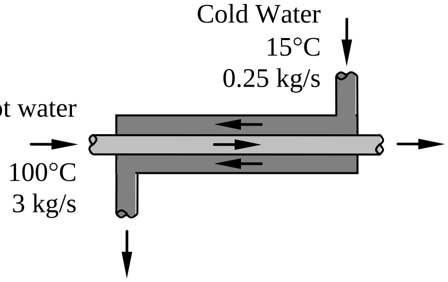
13-50 The inlet and outlet temperatures of the cold and hot fluids in a double-pipe heat exchanger are given. It is to be determined whether this is a parallel-flow or counter-flow heat exchanger.

Analysis In parallel-flow heat exchangers, the temperature of the cold water can never exceed that of the hot fluid. In this case $T_{\text{cold out}} = 50°\text{C}$ which is greater than $T_{\text{hot out}} = 45°\text{C}$. Therefore this must be a counter-flow heat exchanger.

13-51 Cold water is heated by hot water in a double-pipe counter-flow heat exchanger. The 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** 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 cold and hot water are given to be 4.18 and 4.19 kJ/kg.°C, respectively.



Analysis The rate of heat transfer in this heat exchanger is

$$\dot{Q} = [\dot{m}C_p(T_{out} - T_{in})]_{\text{cold water}}$$
$$= (0.25\text{ kg/s})(4.18\text{ kJ/kg.°C})(45°\text{C} - 15°\text{C})$$
$$= \mathbf{31.35\ kW}$$

The outlet temperature of the hot water is determined from

$$\dot{Q} = [\dot{m}C_p(T_{in} - T_{out})]_{\text{hot water}} \longrightarrow T_{out} = T_{in} - \frac{\dot{Q}}{\dot{m}C_p} = 100°\text{C} - \frac{31.35\text{ kW}}{(3\text{ kg/s})(4.19\text{ kJ/kg.°C})} = 97.5°\text{C}$$

The temperature differences at the two ends of the heat exchanger are

$$\Delta T_1 = T_{h,in} - T_{c,out} = 100°\text{C} - 45°\text{C} = 55°\text{C}$$
$$\Delta T_2 = T_{h,out} - T_{c,in} = 97.5°\text{C} - 15°\text{C} = 82.5°\text{C}$$

and

$$\Delta T_{lm} = \frac{\Delta T_1 - \Delta T_2}{\ln(\Delta T_1 / \Delta T_2)} = \frac{55 - 82.5}{\ln(55/82.5)} = 67.8°\text{C}$$

Then the surface area of this heat exchanger becomes

$$\dot{Q} = UA_s\Delta T_{lm} \longrightarrow A_s = \frac{\dot{Q}}{U\Delta T_{lm}} = \frac{31.35\text{ kW}}{(1.210\text{ kW/m}^2\text{.°C})(67.8°\text{C})} = \mathbf{0.382\ m^2}$$

13-52 Engine oil is heated by condensing steam in a condenser. The rate of heat transfer and the length of the tube required 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 heat of engine oil is given to be 2.1 kJ/kg.°C. The heat of condensation of steam at 130°C is given to be 2174 kJ/kg.

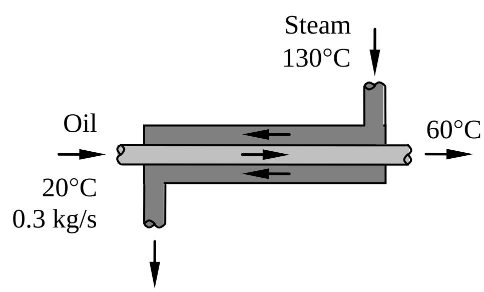
Analysis The rate of heat transfer in this heat exchanger is

$$\dot{Q} = [\dot{m}C_p(T_{out} - T_{in})]_{\text{oil}} = (0.3\,\text{kg/s})(2.1\,\text{kJ/kg.°C})(60°\text{C} - 20°\text{C}) = \mathbf{25.2\ kW}$$

The temperature differences at the two ends of the heat exchanger are

$$\Delta T_1 = T_{h,in} - T_{c,out} = 130°\text{C} - 60°\text{C} = 70°\text{C}$$

$$\Delta T_2 = T_{h,out} - T_{c,in} = 130°\text{C} - 20°\text{C} = 110°\text{C}$$



and

$$\Delta T_{lm} = \frac{\Delta T_1 - \Delta T_2}{\ln(\Delta T_1/\Delta T_2)} = \frac{70 - 110}{\ln(70/110)} = 88.5°\text{C}$$

The surface area is

$$A_s = \frac{\dot{Q}}{U\Delta T_{lm}} = \frac{25.2\,\text{kW}}{(0.65\,\text{kW/m}^2.°\text{C})(88.5°\text{C})} = 0.44\,\text{m}^2$$

Then the length of the tube required becomes

$$A_s = \pi DL \longrightarrow L = \frac{A_s}{\pi D} = \frac{0.44\,\text{m}^2}{\pi(0.02\,\text{m})} = \mathbf{7.0\ m}$$

13-53E Water is heated by geothermal water in a double-pipe counter-flow heat exchanger. The mass flow rate of each fluid and the total thermal resistance 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 geothermal fluid are given to be 1.0 and 1.03 Btu/lbm.°F, respectively.

Analysis The mass flow rate of each fluid are determined from

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

$$\dot{m}_{\text{water}} = \frac{\dot{Q}}{C_p(T_{out} - T_{in})} = \frac{30\ \text{Btu/s}}{(1.0\ \text{Btu/lbm.°F})(200°\text{F} - 140°\text{F})} = \mathbf{0.5\ lbm/s}$$

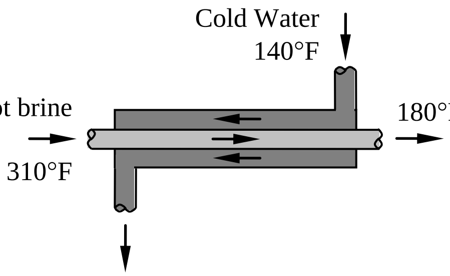
$$\dot{Q} = [\dot{m}C_p(T_{out} - T_{in})]_{\text{geo.water}}$$

$$\dot{m}_{\text{geo.water}} = \frac{\dot{Q}}{C_p(T_{out} - T_{in})} = \frac{30\ \text{Btu/s}}{(1.03\ \text{Btu/lbm.°F})(310°\text{F} - 180°\text{F})} = \mathbf{0.224\ lbm/s}$$

The temperature differences at the two ends of the heat exchanger are

$$\Delta T_1 = T_{h,in} - T_{c,out} = 310°\text{F} - 200°\text{F} = 110°\text{F}$$

$$\Delta T_2 = T_{h,out} - T_{c,in} = 180°\text{F} - 140°\text{F} = 40°\text{F}$$



and

$$\Delta T_{lm} = \frac{\Delta T_1 - \Delta T_2}{\ln(\Delta T_1 / \Delta T_2)} = \frac{110 - 40}{\ln(110/40)} = 69.20°\text{F}$$

Then

$$\dot{Q} = UA_s \Delta T_{lm} \longrightarrow UA_s = \frac{\dot{Q}}{\Delta T_{lm}} = \frac{30\ \text{Btu/s}}{69.20°\text{F}} = 0.4335\ \text{Btu/s.}^{\circ}\text{F}$$

$$U = \frac{1}{RA_s} \longrightarrow R = \frac{1}{UA_s} = \frac{1}{0.4336\ \text{Btu/s.°F}} = \mathbf{2.31\ s.°F/Btu}$$