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سایت آموزش مهندسی مکانیک

The Effectiveness-NTU Method

13-68C When the heat transfer surface area A of the heat exchanger is known, but the outlet temperatures are not, the effectiveness-NTU method is definitely preferred.

13-69C The effectiveness of a heat exchanger is defined as the ratio of the actual heat transfer rate to the maximum possible heat transfer rate and represents how closely the heat transfer in the heat exchanger approaches to maximum possible heat transfer. Since the actual heat transfer rate can not be greater than maximum possible heat transfer rate, the effectiveness can not be greater than one. The effectiveness of a heat exchanger depends on the geometry of the heat exchanger as well as the flow arrangement.

13-70C For a specified fluid pair, inlet temperatures and mass flow rates, the counter-flow heat exchanger will have the highest effectiveness.

13-71C Once the effectiveness ε is known, the rate of heat transfer and the outlet temperatures of cold and hot fluids in a heat exchanger are determined from

$$\dot{Q} = \varepsilon \dot{Q}_{\max} = \varepsilon C_{\min}(T_{h,in} - T_{c,in})$$
$$\dot{Q} = \dot{m}_c C_{p,c}(T_{c,out} - T_{c,in})$$
$$\dot{Q} = \dot{m}_h C_{p,h}(T_{h,in} - T_{h,out})$$

13-72C The heat transfer in a heat exchanger will reach its maximum value when the hot fluid is cooled to the inlet temperature of the cold fluid. Therefore, the temperature of the hot fluid cannot drop below the inlet temperature of the cold fluid at any location in a heat exchanger.

13-73C The heat transfer in a heat exchanger will reach its maximum value when the cold fluid is heated to the inlet temperature of the hot fluid. Therefore, the temperature of the cold fluid cannot rise above the inlet temperature of the hot fluid at any location in a heat exchanger.

13-74C The fluid with the lower mass flow rate will experience a larger temperature change. This is clear from the relation

$$\dot{Q} = \dot{m}_c C_p \Delta T_{cold} = \dot{m}_h C_p \Delta T_{hot}$$

13-75C The maximum possible heat transfer rate is in a heat exchanger is determined from

$$\dot{Q}_{\max} = C_{\min}(T_{h,in} - T_{c,in})$$

where $C_{\min}$ is the smaller heat capacity rate. The value of $\dot{Q}_{\max}$ does not depend on the type of heat exchanger.

13-76C The longer heat exchanger is more likely to have a higher effectiveness.

13-77C The increase of effectiveness with NTU is not linear. The effectiveness increases rapidly with NTU for small values (up to abo ut NTU = 1.5), but rather slowly for larger values. Therefore, the effectiveness will not double when the length of heat exchanger is doubled.

13-78C A heat exchanger has the smallest effectiveness value when the heat capacity rates of two fluids are identical. Therefore, reducing the mass flow rate of cold fluid by half will increase its effectiveness.

13-79C When the capacity ratio is equal to zero and the number of transfer units value is greater than 5, a counter-flow heat exchanger has an effectiveness of one. In this case the exit temperature of the fluid with smaller capacity rate will equal to inlet temperature of the other fluid. For a parallel-flow heat exchanger the answer would be the same.

13-80C The NTU of a heat exchanger is defined as $NTU = \frac{UA_s}{C_{\min}} = \frac{UA_s}{(\dot{m}C_p)_{\min}}$ where U is the overall heat transfer coefficient and A_s is the heat transfer surface area of the heat exchanger. For specified values of U and $C_{\min}$, the value of NTU is a measure of the heat exchanger surface area A_s. Because the effectiveness increases slowly for larger values of NTU, a large heat exchanger cannot be justified economically. Therefore, a heat exchanger with a very large NTU is not necessarily a good one to buy.

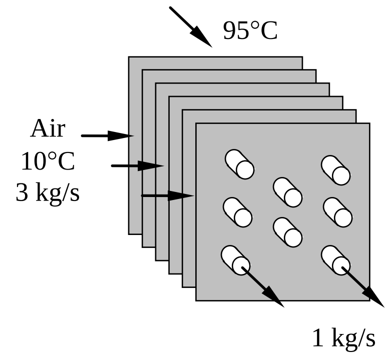
13-81C The value of effectiveness increases slowly with a large values of NTU (usually larger than 3). Therefore, doubling the size of the heat exchanger will not save much energy in this case since the increase in the effectiveness will be very small.

13-82C The value of effectiveness increases rapidly with a small values of NTU (up to about 1.5). Therefore, tripling the NTU will cause a rapid increase in the effectiveness of the heat exchanger, and thus saves energy. I would support this proposal.

13-83 Air is heated by a hot water stream in a cross-flow heat exchanger. The maximum heat transfer rate and the outlet temperatures of the cold and hot fluid streams 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 specific heats of water and air are given to be 4.19 and 1.005 kJ/kg.°C.



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

$$C_h = \dot{m}_h C_{ph} = (1 \text{ kg/s})(4190 \text{ J/kg.°C}) = 4190 \text{ W/°C}$$

$$C_c = \dot{m}_c C_{pc} = (3 \text{ kg/s})(1005 \text{ J/kg.°C}) = 3015 \text{ W/°C}$$

Therefore

$$C_{\min} = C_c = 3015 \text{ W/°C}$$

which is the smaller of the two heat capacity rates. Then the maximum heat transfer rate becomes

$$\dot{Q}_{\max} = C_{\min}(T_{h,in} - T_{c,in}) = (3015 \text{ W/°C})(95°\text{C} - 10°\text{C}) = 256{,}275 \text{ W} = \mathbf{256.3\ kW}$$

The outlet temperatures of the cold and the hot streams in this limiting case are determined to be

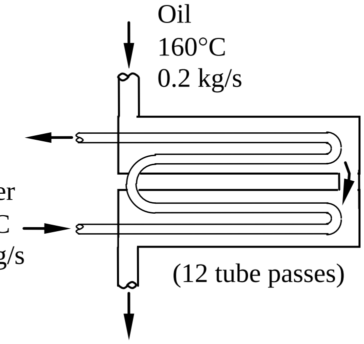
$$\dot{Q} = C_c(T_{c,out} - T_{c,in}) \longrightarrow T_{c,out} = T_{c,in} + \frac{\dot{Q}}{C_c} = 10°\text{C} + \frac{256.275 \text{kW}}{3.015 \text{ kW/°C}} = \mathbf{95°C}$$

$$\dot{Q} = C_h(T_{h,in} - T_{h,out}) \longrightarrow T_{h,out} = T_{h,in} - \frac{\dot{Q}}{C_h} = 95°\text{C} - \frac{256.275 \text{kW}}{4.19 \text{ kW/°C}} = \mathbf{33.8°C}$$

13-84 Hot oil is to be cooled by water in a heat exchanger. The mass flow rates and the 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 thickness of the tube is negligible since it is thin-walled. **5** 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 The heat capacity rates of the hot and cold fluids are

$$C_h = \dot{m}_h C_{ph} = (0.2\text{ kg/s})(2200\text{ J/kg.°C}) = 440\text{ W/°C}$$
$$C_c = \dot{m}_c C_{pc} = (0.1\text{ kg/s})(4180\text{ J/kg.°C}) = 418\text{ W/°C}$$

Therefore, $C_{\min} = C_c = 418\text{ W/°C}$

and $C = \dfrac{C_{\min}}{C_{\max}} = \dfrac{418}{440} = 0.95$

Then the maximum heat transfer rate becomes

$$\dot{Q}_{\max} = C_{\min}(T_{h,in} - T_{c,in}) = (418\text{ W/°C})(160\text{°C} - 18\text{°C}) = 59.36\text{ kW}$$

The heat transfer surface area is

$$A_s = n(\pi DL) = (12)(\pi)(0.018\text{m})(3\text{m}) = 2.04\text{ m}^2$$

The NTU of this heat exchanger is

$$NTU = \frac{UA_s}{C_{\min}} = \frac{(340\text{ W/m}^2.\text{°C})\,(2.04\text{ m}^2)}{418\text{ W/°C}} = 1.659$$

Then the effectiveness of this heat exchanger corresponding to C = 0.95 and NTU = 1.659 is determined from Fig. 13-26d to be

$\varepsilon = 0.61$

Then the actual rate of heat transfer becomes

$$\dot{Q} = \varepsilon\dot{Q}_{\max} = (0.61)(5936\text{ kW}) = \mathbf{36.2\ kW}$$

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

$$\dot{Q} = C_c(T_{c,out} - T_{c,in}) \longrightarrow T_{c,out} = T_{c,in} + \frac{\dot{Q}}{C_c} = 18\text{°C} + \frac{36.2\text{ kW}}{0.418\text{ kW/°C}} = \mathbf{104.6\text{°C}}$$
$$\dot{Q} = C_h(T_{h,in} - T_{h,out}) \longrightarrow T_{h,out} = T_{h,in} - \frac{\dot{Q}}{C_h} = 160\text{°C} - \frac{36.2\text{ kW}}{0.44\text{ kW/°C}} = \mathbf{77.7\text{°C}}$$

13-85 Inlet and outlet temperatures of the hot and cold 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 and the effectiveness of it.

Analysis This is a counter-flow heat exchanger because in the parallel-flow heat exchangers the outlet temperature of the cold fluid (55°C in this case) cannot exceed the outlet temperature of the hot fluid, which is (45°C in this case). Noting that the mass flow rates of both hot and cold oil streams are the same, we have $C_{\min} = C_{\max} = C$. Then the effectiveness of this heat exchanger is determined from

$$\varepsilon = \frac{\dot{Q}}{\dot{Q}_{\max}} = \frac{C_h(T_{h,in} - T_{h,out})}{C_{\min}(T_{h,in} - T_{c,in})} = \frac{C_h(T_{h,in} - T_{h,out})}{C_h(T_{h,in} - T_{c,in})} = \frac{80°\text{C} - 45°\text{C}}{80°\text{C} - 20°\text{C}} = \mathbf{0.583}$$

13-86E Inlet and outlet temperatures of the hot and cold fluids in a double-pipe heat exchanger are given. It is to be determined the fluid, which has the smaller heat capacity rate and the effectiveness of the heat exchanger.

Analysis Hot water has the smaller heat capacity rate since it experiences a greater temperature change. The effectiveness of this heat exchanger is determined from

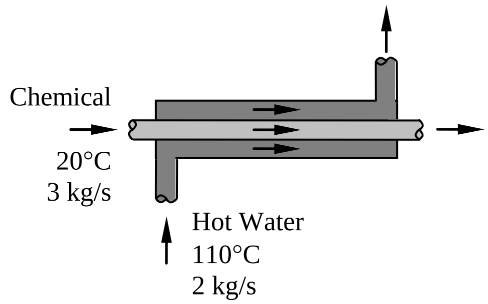
$$\varepsilon = \frac{\dot{Q}}{\dot{Q}_{\max}} = \frac{C_h(T_{h,in} - T_{h,out})}{C_{\min}(T_{h,in} - T_{c,in})} = \frac{C_h(T_{h,in} - T_{h,out})}{C_h(T_{h,in} - T_{c,in})} = \frac{220°\text{F} - 100°\text{F}}{220°\text{F} - 70°\text{F}} = \mathbf{0.8}$$

13-87 A chemical is heated by water in a heat exchanger. The mass flow rates and the inlet temperatures are given. 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 thickness of the tube is negligible since tube is thin-walled. **5** The overall heat transfer coefficient is constant and uniform.

Properties The specific heats of the water and chemical are given to be 4.18 and 1.8 kJ/kg.°C, respectively.

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



$$C_h = \dot{m}_h C_{ph} = (2 \text{ kg/s})(4.18 \text{ kJ/kg.°C}) = 8.36 \text{ kW/°C}$$

$$C_c = \dot{m}_c C_{pc} = (3 \text{ kg/s})(1.8 \text{ kJ/kg.°C}) = 5.40 \text{ kW/°C}$$

Therefore, $C_{\min} = C_c = 5.4 \text{ kW/°C}$

and $C = \dfrac{C_{\min}}{C_{\max}} = \dfrac{5.40}{8.36} = 0.646$

Then the maximum heat transfer rate becomes

$$\dot{Q}_{\max} = C_{\min}(T_{h,in} - T_{c,in}) = (5.4 \text{ kW/°C})(110\text{°C} - 20\text{°C}) = 486 \text{ kW}$$

The NTU of this heat exchanger is

$$NTU = \frac{UA_s}{C_{\min}} = \frac{(1.2 \text{ kW/m}^2.\text{°C})\,(7 \text{ m}^2)}{5.4 \text{ kW/°C}} = 1.556$$

Then the effectiveness of this parallel-flow heat exchanger corresponding to C = 0.646 and NTU=1.556 is determined from

$$\varepsilon = \frac{1 - \exp[-NTU(1+C)]}{1+C} = \frac{1 - \exp[-1.556(1+0.646)]}{1+0.646} = 0.56$$

Then the actual rate of heat transfer rate becomes

$$\dot{Q} = \varepsilon \dot{Q}_{\max} = (0.56)(486 \text{ kW}) = 272.2 \text{ kW}$$

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

$$\dot{Q} = C_c(T_{c,out} - T_{c,in}) \longrightarrow T_{c,out} = T_{c,in} + \frac{\dot{Q}}{C_c} = 20\text{°C} + \frac{272.2 \text{ kW}}{5.4 \text{ kW/°C}} = \mathbf{70.4\text{°C}}$$

$$\dot{Q} = C_h(T_{h,in} - T_{h,out}) \longrightarrow T_{h,out} = T_{h,in} - \frac{\dot{Q}}{C_h} = 110\text{°C} - \frac{272.2 \text{ kW}}{8.36 \text{ kW/°C}} = \mathbf{77.4\text{°C}}$$

13-88 "!PROBLEM 13-88"

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"GIVEN"
T_chemical_in=20 "[C], parameter to be varied"
C_p_chemical=1.8 "[kJ/kg-C]"
m_dot_chemical=3 "[kg/s]"
"T_w_in=110 [C], parameter to be varied"
m_dot_w=2 "[kg/s]"
C_p_w=4.18 "[kJ/kg-C]"
A=7 "[m^2]"
U=1.2 "[kW/m^2-C]"

"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_w_in-T_chemical_in
DELTAT_2=T_w_out-T_chemical_out
DELTAT_lm=(DELTAT_1-DELTAT_2)/ln(DELTAT_1/DELTAT_2)
Q_dot=U*A*DELTAT_lm
Q_dot=m_dot_chemical*C_p_chemical*(T_chemical_out-T_chemical_in)
Q_dot=m_dot_w*C_p_w*(T_w_in-T_w_out)
```

$T_{chemical, in}$ [C]	$T_{chemical, out}$ [C]
10	66.06
12	66.94
14	67.82
16	68.7
18	69.58
20	70.45
22	71.33
24	72.21
26	73.09
28	73.97
30	74.85
32	75.73
34	76.61
36	77.48
38	78.36
40	79.24
42	80.12
44	81
46	81.88
48	82.76
50	83.64

$T_{w, in}$ [C]	$T_{w, out}$ [C]
80	58.27
85	61.46
90	64.65
95	67.84
100	71.03
105	74.22
110	77.41
115	80.6
120	83.79
125	86.98
130	90.17
135	93.36
140	96.55
145	99.74
150	102.9

13-89 Water is heated by hot air in a heat exchanger. The mass flow rates and the inlet temperatures are given. The heat transfer surface area of the heat exchanger on the water side is to be determined.

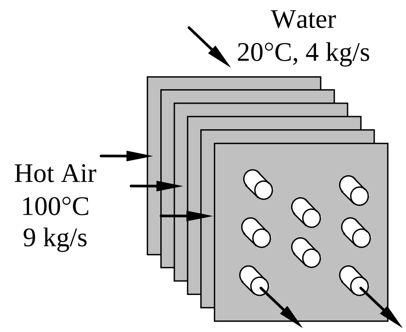
Assumptions **1** Steady operating conditions exist. **2** The heat exchanger is well-insulated so that heat loss to the surroundings is negligible and thus heat transfer from the hot fluid is equal to the heat transfer to the cold fluid. **3** Changes in the kinetic and potential energies of fluid streams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

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

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

$$C_h = \dot{m}_h C_{ph} = (4\text{ kg/s})(4.18\text{ kJ/kg.°C}) = 16.72\text{ kW/°C}$$

$$C_c = \dot{m}_c C_{pc} = (9\text{ kg/s})(1.01\text{ kJ/kg.°C}) = 9.09\text{ kW/°C}$$



Therefore, $C_{\min} = C_c = 9.09\text{ kW/°C}$

and $C = \dfrac{C_{\min}}{C_{\max}} = \dfrac{9.09}{16.72} = 0.544$

Then the NTU of this heat exchanger corresponding to C = 0.544 and ε = 0.65 is determined from Fig. 13-26 to be

NTU = 1.5

Then the surface area of this heat exchanger becomes

$$\text{NTU} = \frac{UA_s}{C_{\min}} \longrightarrow A_s = \frac{\text{NTU}\,C_{\min}}{U} = \frac{(1.5)(9.09\text{ kW/°C})}{0.260\text{ kW/m}^2\text{.°C}} = \mathbf{52.4\ m^2}$$

13-90 Water is heated by steam condensing in a condenser. The required length of the tube is to be determined.

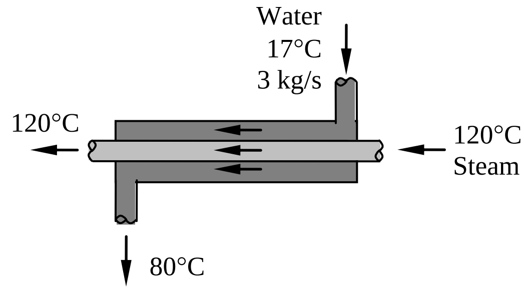
Assumptions **1** Steady operating conditions exist. **2** The heat exchanger is well-insulated so that heat loss to the surroundings is negligible and thus heat transfer from the hot fluid is equal to the heat transfer to the cold fluid. **3** Changes in the kinetic and potential energies of fluid streams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

Properties The specific heat of the water is given to be 4.18 kJ/kg.°C. The heat of vaporization of water at 120°C is given to be 2203 kJ/kg.

Analysis (*a*) The temperature differences between the steam and the water at the two ends of the condenser are

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

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



The logarithmic mean temperature difference is

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

The rate of heat transfer is determined from

$$\dot{Q} = \dot{m}_c C_{pc}(T_{c,out} - T_{c,in}) = (3\text{ kg/s})(4.18\text{ kJ/kg.°C})(80°\text{C} - 17°\text{C}) = 790.02\text{ kW}$$

The surface area of heat transfer is

$$\dot{Q} = UA_s\Delta T_{lm} \longrightarrow A_s = \frac{\dot{Q}}{U\Delta T_{lm}} = \frac{790.02\text{kW}}{0.9\text{ kW/m}^2\text{.°C})(66.6°\text{C})} = 13.18\text{m}^2$$

The length of tube required then becomes

$$A_s = \pi DL \longrightarrow L = \frac{A_s}{\pi D} = \frac{13.18\text{ m}^2}{\pi(0.025\text{m})} = \mathbf{167.8\text{ m}}$$

(*b*) The rate of heat transfer is

$$\dot{Q} = \dot{m}_c C_{pc}(T_{c,out} - T_{c,in}) = (3\text{ kg/s})(4.18\text{ kJ/kg.°C})(80°\text{C} - 17°\text{C}) = 790.02\text{ kW}$$

and the maximum rate of heat transfer rate is

$$\dot{Q}_{\max} = C_{\min}(T_{h,in} - T_{c,in}) = (12.54\text{ W/°C})(120°\text{C - }17°\text{C}) = 1291.62\text{ kW}$$

Then the effectiveness of this heat exchanger becomes

$$\varepsilon = \frac{Q}{Q_{\max}} = \frac{790.02\text{ kW}}{1291.62\text{ kW}} = 0.61$$

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

$$\text{NTU} = -\ln(1-\varepsilon) = -\ln(1-0.61) = 0.942$$

The surface area is

$$NTU = \frac{UA_s}{C_{\min}} \longrightarrow A_s = \frac{NTU\ C_{\min}}{U} = \frac{(0.942)(12.54\text{ kW/°C})}{0.9\text{ kW/m}^2\text{.°C}} = 13.12\text{ m}^2$$

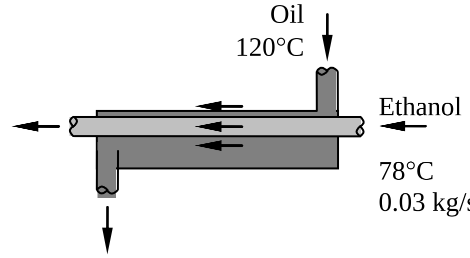
Finally, the length of tube required is

$$A_s = \pi DL \longrightarrow L = \frac{A_s}{\pi D} = \frac{13.12\text{ m}^2}{\pi(0.025\text{m})} = \mathbf{167\text{ m}}$$

13-91 Ethanol is vaporized by hot oil in a double-pipe parallel-flow heat exchanger. The outlet temperature and the mass flow rate of oil are to be determined using 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 heat of oil is given to be 2.2 kJ/kg.°C. The heat of vaporization of ethanol at 78°C is given to be 846 kJ/kg.



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

$$\dot{Q} = \dot{m}h_{fg} = (0.03 \text{ kg/s})(846 \text{ kJ/kg}) = 25.38 \text{ kW}$$

The log mean temperature difference is

$$\dot{Q} = UA_s\Delta T_{lm} \longrightarrow \Delta T_{lm} = \frac{\dot{Q}}{UA_s} = \frac{25{,}380 \text{ W}}{(320 \text{ W/m}^2.°\text{C})(6.2 \text{ m}^2)} = 12.8°\text{C}$$

The outlet temperature of the hot fluid can be determined as follows

$$\Delta T_1 = T_{h,in} - T_{c,in} = 120°\text{C} - 78°\text{C} = 42°\text{C}$$
$$\Delta T_2 = T_{h,out} - T_{c,out} = T_{h,out} - 78°\text{C}$$

and
$$\Delta T_{lm} = \frac{\Delta T_1 - \Delta T_2}{\ln(\Delta T_1/\Delta T_2)} = \frac{42 - (T_{h,out} - 78)}{\ln[42/(T_{h,out} - 78)]} = 12.8°\text{C}$$

whose solution is $T_{h,out} = \mathbf{79.8°C}$

Then the mass flow rate of the hot oil becomes

$$\dot{Q} = \dot{m}C_p(T_{h,in} - T_{h,out}) \longrightarrow \dot{m} = \frac{\dot{Q}}{C_p(T_{h,in} - T_{h,out})} = \frac{25{,}380 \text{ W}}{(2200 \text{ J/kg.°C})(120°\text{C} - 79.8°\text{C})} = \mathbf{0.287 \text{ kg/s}}$$

(*b*) The heat capacity rate $C = \dot{m}C_p$ of a fluid condensing or evaporating in a heat exchanger is infinity, and thus $C = C_{\min}/C_{\max} = 0$.

The efficiency in this case is determined from $\varepsilon = 1 - e^{-NTU}$

where $NTU = \dfrac{UA_s}{C_{\min}} = \dfrac{(320 \text{ W/m}^2.°\text{C})(6.2 \text{ m}^2)}{(\dot{m}, \text{kg/s})(2200 \text{ J/kg.°C})}$

and $\dot{Q}_{\max} = C_{\min}(T_{h,in} - T_{c,in})$

$$\varepsilon = \frac{Q}{Q_{\max}} = \frac{C_{\min}(T_{h,in} - T_{c,in})}{C_{\min}(T_{h,in} - T_{c,in})} = \frac{120 - T_{h,out}}{120 - 78}$$

$$\dot{Q} = C_h(T_{h,in} - T_{h,out}) = 25{,}380 \text{ W}$$
$$\dot{Q} = \dot{m} \times 2200(120 - T_{h,out}) = 25{,}380 \text{ W} \quad (1)$$

Also
$$\frac{120 - T_{h,out}}{120 - 78} = 1 - e^{-\frac{6.2 \times 320}{\dot{m} \times 2200}} \quad (2)$$

Solving (1) and (2) simultaneously gives

$\dot{m}_h = \mathbf{0.287 \text{ kg/s}}$ and $T_{h,out} = \mathbf{79.8°C}$

13-92 Water is heated by solar-heated hot air in a heat exchanger. The mass flow rates and the inlet temperatures are given. The outlet temperatures of the water and 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** The overall heat transfer coefficient is constant and uniform.

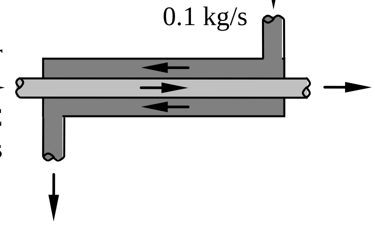
Properties The specific heats of the water and air are given to be 4.18 and 1.01 kJ/kg.°C, respectively.

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

$$C_h = \dot{m}_h C_{ph} = (0.3\text{kg/s})(1010\text{ J/kg.°C}) = 303\text{ W/°C}$$
$$C_c = \dot{m}_c C_{pc} = (0.1\text{ kg/s})(4180\text{ J/kg.°C}) = 418\text{ W/°C}$$

Therefore, $C_{\min} = C_c = 303\text{ W/°C}$ and $C = \frac{C_{\min}}{C_{\max}} = \frac{303}{418} = 0.725$

Then the maximum heat transfer rate becomes



$$\dot{Q}_{\max} = C_{\min}(T_{h,in} - T_{c,in})$$
$$= (303\text{W/°C})(90\text{°C} - 22\text{°C}) = 20{,}604\text{ kW}$$

The heat transfer surface area is

$$A_s = \pi DL = (\pi)(0.012\text{m})(12\text{m}) = 0.45\text{ m}^2$$

Then the NTU of this heat exchanger becomes

$$NTU = \frac{UA_s}{C_{\min}} = \frac{(80\text{ W/m}^2.\text{°C})\,(0.45\text{ m}^2)}{303\text{W/°C}} = 0.119$$

The effectiveness of this counter-flow heat exchanger corresponding to C = 0.725 and NTU = 0.119 is determined using the relation in Table 13-5 to be

$$\varepsilon = \frac{1-\exp[-NTU(1-C)]}{1-C\exp[-NTU(1-C)]} = \frac{1-\exp[-0.119(1-0.725)]}{1-0.725\exp[-0.119(1-0.725)]} = 0.108$$

Then the actual rate of heat transfer becomes

$$\dot{Q} = \varepsilon\dot{Q}_{\max} = (0.108)(20{,}604\text{ W}) = 2225.2\text{ W}$$

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

$$\dot{Q} = C_c(T_{c,out} - T_{c,in}) \longrightarrow T_{c,out} = T_{c,in} + \frac{\dot{Q}}{C_c} = 22\text{°C} + \frac{2225.2\text{ W}}{418\text{ W/°C}} = \mathbf{27.3\text{°C}}$$

$$\dot{Q} = C_h(T_{h,in} - T_{h,out}) \longrightarrow T_{h,out} = T_{h,in} - \frac{\dot{Q}}{C_h} = 90\text{°C} - \frac{2225.2\text{ W}}{303\text{W/°C}} = \mathbf{82.7\text{°C}}$$

13-93 "!PROBLEM 13-93"

```
"GIVEN"
T_air_in=90 "[C]"
m_dot_air=0.3 "[kg/s]"
C_p_air=1.01 "[kJ/kg-C]"
T_w_in=22 "[C]"
m_dot_w=0.1 "[kg/s], parameter to be varied"
C_p_w=4.18 "[kJ/kg-C]"
U=0.080 "[kW/m^2-C]"
"L=12 [m], parameter to be varied"
D=0.012 "[m]"

"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_air_in-T_w_out
DELTAT_2=T_air_out-T_w_in
DELTAT_lm=(DELTAT_1-DELTAT_2)/ln(DELTAT_1/DELTAT_2)
A=pi*D*L
Q_dot=U*A*DELTAT_lm
Q_dot=m_dot_air*C_p_air*(T_air_in-T_air_out)
Q_dot=m_dot_w*C_p_w*(T_w_out-T_w_in)
```

m_w [kg/s]	$T_{w, out}$ [C]	$T_{air, out}$ [C]
0.05	32.27	82.92
0.1	27.34	82.64
0.15	25.6	82.54
0.2	24.72	82.49
0.25	24.19	82.46
0.3	23.83	82.44
0.35	23.57	82.43
0.4	23.37	82.42
0.45	23.22	82.41
0.5	23.1	82.4
0.55	23	82.4
0.6	22.92	82.39
0.65	22.85	82.39
0.7	22.79	82.39
0.75	22.74	82.38
0.8	22.69	82.38
0.85	22.65	82.38
0.9	22.61	82.38
0.95	22.58	82.38
1	22.55	82.37

L [m]	**$T_{w, out}$ [C]**	**$T_{air, out}$ [C]**
5	24.35	86.76
6	24.8	86.14
7	25.24	85.53
8	25.67	84.93
9	26.1	84.35
10	26.52	83.77
11	26.93	83.2
12	27.34	82.64
13	27.74	82.09
14	28.13	81.54
15	28.52	81.01
16	28.9	80.48
17	29.28	79.96
18	29.65	79.45
19	30.01	78.95
20	30.37	78.45
21	30.73	77.96
22	31.08	77.48
23	31.42	77
24	31.76	76.53
25	32.1	76.07

13-94E Oil is cooled by water in a double-pipe heat exchanger. The overall heat transfer coefficient of this 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 thickness of the tube is negligible since it is thin-walled.

Properties The specific heats of the water and oil are given to be 1.0 and 0.525 Btu/lbm.°F, respectively.

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

$$\dot{Q} = \dot{m}_h C_{ph}(T_{h,in} - T_{h,out}) = (5\,\text{lbm/s})(0.525\,\text{Btu/lbm.°F})(300-105\text{°F}) = 511.9\,\text{Btu/s}$$

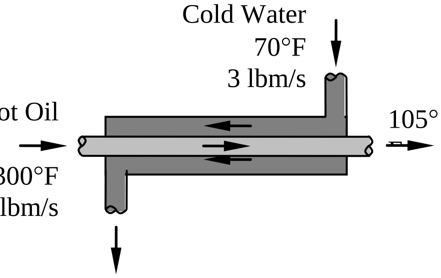
The outlet temperature of the cold fluid is

$$\dot{Q} = \dot{m}_c C_{pc}(T_{c,out} - T_{c,in}) \longrightarrow T_{c,out} = T_{c,in} + \frac{\dot{Q}}{\dot{m}_c C_{pc}} = 70\text{°F} + \frac{511.9\,\text{Btu/s}}{(3\,\text{lbm/s})(1.0\,\text{Btu/lbm.°F})} = 240.6\text{°F}$$

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

$$\Delta T_1 = T_{h,in} - T_{c,out} = 300\text{° F} - 240.6\text{° F} = 59.4\text{° F}$$

$$\Delta T_2 = T_{h,out} - T_{c,in} = 105\text{° F} - 70\text{° F} = 35\text{° F}$$



The logarithmic mean temperature difference is

$$\Delta T_{lm} = \frac{\Delta T_1 - \Delta T_2}{\ln(\Delta T_1 / \Delta T_2)} = \frac{59.4 - 35}{\ln(59.4/35)} = 46.1\text{°F}$$

Then the overall heat transfer coefficient becomes

$$\dot{Q} = UA_s \Delta T_{lm} \longrightarrow U = \frac{\dot{Q}}{A_s \Delta T_{lm}} = \frac{511.9\,\text{Btu/s}}{\pi(1/12\,\text{m})(20\,\text{ft})(46.1\text{°F})} = \mathbf{2.12\ Btu/s.ft^2.°F}$$

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

$$C_h = \dot{m}_h C_{ph} = (5\text{ lbm/s})(0.525\text{ Btu/lbm.° F}) = 2.625\text{ Btu/s.° F}$$

$$C_c = \dot{m}_c C_{pc} = (3\text{ lbm/s})(1.0\text{ Btu/lbm.° F}) = 3.0\text{ Btu/s.° F}$$

Therefore, $C_{\min} = C_h = 2.625\text{ Btu/s.° F}$ and $C = \dfrac{C_{\min}}{C_{\max}} = \dfrac{2.625}{3.0} = 0.875$

Then the maximum heat transfer rate becomes

$$\dot{Q}_{\max} = C_{\min}(T_{h,in} - T_{c,in}) = (2.625\text{ Btu/s.° F})(300\text{° F - }70\text{° F}) = 603.75\text{ Btu/s}$$

The actual rate of heat transfer and the effectiveness are

$$\dot{Q} = C_h(T_{h,in} - T_{h,out}) = (2.625\text{ Btu/s.° F})(300\text{° F - }105\text{° F}) = 511.9\text{ Btu/s}$$

$$\varepsilon = \frac{\dot{Q}}{\dot{Q}_{\max}} = \frac{511.9}{603.75} = 0.85$$

The NTU of this heat exchanger is determined using the relation in Table 13-3 to be

$$NTU = \frac{1}{C-1}\ln\left(\frac{\varepsilon - 1}{\varepsilon C - 1}\right) = \frac{1}{0.875-1}\ln\left(\frac{0.85-1}{0.85\times 0.875 - 1}\right) = 4.28$$

The heat transfer surface area of the heat exchanger is

$$A_s = \pi DL = \pi(1/12\,\text{ft})(20\,\text{ft}) = 5.24\,\text{ft}^2$$

and $$NTU = \frac{UA_s}{C_{\min}} \longrightarrow U = \frac{NTU\ C_{\min}}{A_s} = \frac{(4.28)(2.625\,\text{Btu/s.°F})}{5.24\,\text{ft}^2} = \mathbf{2.14\ Btu/s.ft^2.°F}$$