ESD Homework 2

March 7, 2022

[1]:
```
import sympy as sp
from msu_esd import cross_flow_unmixed, log_mean_temp_difference,␣
↪parallel_single_pass, counter_single_pass
```

Contents

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1 Problem 1

1.1 Given

Water enters a counterflow, double-pipe heat exchanger at a rate of 70 $\frac{kg}{min}$ and is heated from $15°C$ to $60°C$ by an oil with a specific heat of 1.9 $\frac{kJ}{kg\,K}$. The oil enters at $116°C$ and leaves at $27°C$. The overall heat transfer coefficient is 300 $\frac{W}{m^2\,K}$

1.2 Find

a. What heat transfer area is required?
b. What area is required if all conditions remain the same except that a shell and tube heat exchanger is used, with the water making one shell pass and the oil making two tube passes?
c. What exit water temperature would result if, for the exchanger of part (a), the water flow rate were decreased to 50 $\frac{kg}{min}$

1.3 Solution

The specific heat of water will be taken at the average temperature of the water entrance and exit ($C_p = 4.18\,\frac{kJ}{kg\,K}$)

1.3.1 Part A

The oil is the hot fluid and the water is the cold fluid. The condition is unmixed because the fluids never meet.

[2]:
```
# Declare constants as given
mc_ = 70
Cp_c_, Cp_h_ = 4.18, 1.9
Tc_in_, Tc_out_ = 15, 60
Th_in_, Th_out_ = 116, 27
U_ = 300

Cc, Ch, Th_out, Th_in, Tc_out, Tc_in = sp.symbols(r'C_c C_h T_{h\,out}␣
↪T_{h\,in} T_{c\,out} T_{c\,in}')

# Solving for Ch
eq = sp.Eq(Cc*(Tc_out - Tc_in), Ch*(Th_in - Th_out))
eq
```

[2]:
$$C_c\left(-T_{c,in} + T_{c,out}\right) = C_h\left(T_{h,in} - T_{h,out}\right)$$

[3]:
```
Ch_solved = sp.solve(eq, Ch)[0]
Ch_solved
```

[3]:
$$\frac{C_c\left(-T_{c,in} + T_{c,out}\right)}{T_{h,in} - T_{h,out}}$$

[4]:
```python
# Solving for Cc
Cc_ = mc_*Cp_c_
Cc_  # kJ per (min deg C)
```

[4]: 292.59999999999997

[5]:
```python
Ch_ = Cc_*(Tc_out_ - Tc_in_)/(Th_in_ - Th_out_)
Ch_  # kJ per (min deg C)
```

[5]: 147.94382022471908

[6]:
```python
C_min_ = min([Ch_, Cc_])
C_min_  # kJ per (min deg C)
```

[6]: 147.94382022471908

[7]:
```python
# Get actual q
q_act_ = Cc_*(Tc_out_ - Tc_in_)
q_act_  # kJ per min
```

[7]: 13166.999999999998

[8]:
```python
# Get q max
q_max_ = C_min_*(Th_in_ - Tc_in_)
q_max_  # kJ per min
```

[8]: 14942.325842696626

[9]:
```python
# Effectiveness
epsilon_ = q_act_/q_max_
epsilon_
```

[9]: 0.8811881188118813

[10]:
```python
# C
C_ = C_min_/Cc_
C_
```

[10]: 0.5056179775280899

[11]:
```python
# Find the ntu value
ntu_ = cross_flow_unmixed(epsilon_, C_)
ntu_
```

[11]: 4.180545804015178

The NTU relationship is,

$NTU = \frac{UA}{C_{min}} \rightarrow A = NTU\frac{C_{min}}{U}$

[12]:
```python
# Finding the area (unit manipulation added)
A_ = ntu_*C_min_/U_*1000/60
A_  # m^2
```

[12]: 34.36032871502362

1.3.2 LMTD Method

[13]:
```python
T_ = log_mean_temp_difference(Th_in_, Th_out_, Tc_in_, Tc_out_)
q_act_/(U_*T_)*1000/60
```

[13]: 25.60989880574635

2 Problem 2

2.1 Given

The attributes of the inlet streams to a heat exchanger are,

Stream	Inlet Temperature ($^\circ F$)	Capacity ($\frac{Btu}{hr\,^\circ F}$)
Hot	600	50,000
Cold	500	25,000

The UA product in $\frac{Btu}{hr\,^\circ F}$ for the heat exchanger is given by,

$UA = \frac{1}{\frac{0.12}{C_h^{0.8}} + \frac{0.06}{C_c^{0.8}} + 2\times 10^{-7}}$

where C_h and C_c are the capacities in $\frac{Btu}{hr\,^\circ F}$.

2.2 Find

Using only the NTU method,

a. Find the outlet temperatures and rating for a parallel flow arrangement
b. Find the outlet temperatures and rating for a counter flow arrangement
c. Find the outlet temperatures and rating if two of these heat exchangers are placed in series and are operated in a parallel flow arrangement. What are the interface temperatures?
d. Find the outlet temperatures and rating if two of these heat exchangers are placed in series and operated in a counterflow arrangement. What are the interface temperatures?
e. Based ont he results of the above, discuss the utility of placing parallel and counterflow heat exchangers in series.

2.3 Solution

[14]:
```
# Define known constants with units mentioned in the given statement
Cc_ = 25_000
Ch_ = 50_000
Tc_in_ = 500
Th_in_ = 600

# Find the value for UA
# First a symbolic definition
UA = 1/(0.12/Ch**0.8 + 0.06/Cc**0.8 + 2e-7)
UA
```

[14]:

$$\frac{1}{\frac{0.06}{C_c^{0.8}} + \frac{0.12}{C_h^{0.8}} + 2.0 \cdot 10^{-7}}$$

[15]:
```
UA_ = float(UA.subs([(Cc, Cc_), (Ch, Ch_)]))
UA_  # In Btu per (hr*deg F)
```

[15]: 25457.073923275435

[16]:
```
# Find NTU
C_min_ = min([Cc_, Ch_])
NTU_ = UA_/C_min_
NTU_
```

[16]: 1.0182829569310174

[17]:
```
# Get the C_value
C_ = C_min_/max([Cc_, Ch_])
C_
```

[17]: 0.5

2.3.1 Part A

We know the NTU value and C, which is enough to solve for the effectiveness.

[18]:
```
# Get the effectiveness/rating
# Assuming a one pass parallel
parallel_effectiveness = parallel_single_pass(NTU_, C_, find='e')
parallel_effectiveness
```

[18]: 0.5219372748457521

[19]:
```
# Find q max
q_max_ = C_min_*(Th_in_ - Tc_in_)
q_max_  # Btu per hr
```

[19]: 2500000

[20]:
```
# Find the actual q
q_act_ = q_max_*parallel_effectiveness
q_act_  # In btu per hour
```

[20]: 1304843.1871143803

[21]:
```
# Find cold outlet temperature
Tc_out_A = q_act_/Cc_ + Tc_in_
Tc_out_A  # deg F
```

[21]: 552.1937274845752

[22]:
```
# Find the hot outlet temperature
Th_out_A = Th_in_ - q_act_/Ch_
Th_out_A  # deg F
```

[22]: 573.9031362577124

2.3.2 Part B

Everything is the same except the effectiveness correlation is different.

[23]:
```
# Solving for the effectiveness/rating
counter_effectiveness = counter_single_pass(NTU_, C_, find='e')
counter_effectiveness
```

[23]: 0.5703958472801851

[24]:
```
q_act_ = q_max_*counter_effectiveness
q_act_  # Btu per hr
```

[24]: 1425989.6182004628

[25]:
```
# Find cold outlet temperature
Tc_out_B = q_act_/Cc_ + Tc_in_
Tc_out_B  # deg F
```

[25]: 557.0395847280186

[26]:
```
# Find the hot outlet temperature
Th_out_B = Th_in_ - q_act_/Ch_
Th_out_B  # deg F
```

[26]: 571.4802076359907

2.3.3 Part C

In order to solve this, take the outlet temperatures solved in the previous problems and apply that to the next heat exchanger in the series. The values of NTU, C, ξ, and UA are all the same because the capacity and conductance does not change.

[27]:
```
# From the part A in deg F
Tc_in_ = Tc_out_A
Th_in_ = Th_out_A

q_max_ = C_min_*(Th_in_ - Tc_in_)
q_max_  # Btu per hr
```

[27]: 542735.2193284292

[28]:
```
q_act_ = parallel_effectiveness*q_max_
q_act_  # Btu per hr
```

[28]: 283273.7413390919

[29]:
```
Tc_out_ = q_act_/Cc_ + Tc_in_
Tc_out_  # deg F
```

[29]: 563.5246771381389

[30]:
```
Th_out_ = Th_in_ - q_act_/Ch_
Th_out_  # deg F
```

[30]: 568.2376614309305

2.4 Answer

a. $\xi = 0.522$, $T_{c,out} = 552.19°F$, $T_{h,out} = 573.90°F$
b. $\xi = 0.570$, $T_{c,out} = 557.04°F$, $T_{h,out} = 571.48°F$
c. Effectiveness and temperatures at the interface is the same as Part A. Coming out of the second heat exchanger is: $T_{c,out} = 563.52°F$, $T_{h,out} = 568.2°F$
d.