HW3

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1 ME 591 HW 3

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ME 591

[1]:
```python
import os
import math
import pint
```

[2]:
```python
def bordered(text):
    lines = text.splitlines()
    width = max(len(s) for s in lines)
    res = [' ' + ' ' * width + ' ']
    for s in lines:
        res.append(' ' + (s + ' ' * width)[:width] + ' ')
    res.append(' ' + ' ' * width + ' ')
    return '\n'.join(res)
```

1.1 Problem 4-19

[3]:
```python
ureg = pint.UnitRegistry(autoconvert_offset_to_baseunit = True)
```

1.1.1 Defining the Inputs

[4]:
```python
P_solar = 8 * ureg.month
P_heater = 4 * ureg.month

T_water_hot = 60 * ureg.degC
T_water_cold = 20 * ureg.degC
M_water = 6e3 * ureg.kilogram / ureg.month    # is this imperial tons or metric␣
↪tons ? I am using metric tons bc everything else in the problem is metric
cost = 1.35 / (ureg.therm)
N_heater = 88 / 100
c_p = 4.18 * (ureg.kJ / (ureg.kilogram * ureg.delta_celsius))
```

1.1.2 Solving for Q

[5]:
```python
Q = M_water * c_p * (T_water_hot - T_water_cold)
Q
```

[5]: $1003200.0\ \frac{\text{kilojoule}}{\text{month}}$

1.1.3 Electricity Savings

[6]:
```python
e_savings = (Q / N_heater * P_solar).to('kJ')
e_savings
```

[6]: 9120000.0 kilojoule

1.1.4 Cost Savings

[7]:
```python
print(bordered(f"Savings = ${round(float((e_savings * cost)), 2)}"))
```

```
Savings = $116.7
```

1.2 Problem 4-34

[8]:
```python
ureg = pint.UnitRegistry(autoconvert_offset_to_baseunit = True)
```

[9]:
```python
CR = 7
N_ar = 0.88
T_collector = 145 * ureg.degC
T_air = 27 * ureg.degC

collectors = {
    'A': {
        'U': 2.5 * (ureg.watt / (ureg.meter ** 2 * ureg.delta_degC)),
        'G': 600 * (ureg.watt / (ureg.meter ** 2))
    },
    'B': {
        'U': 0.63 * (ureg.watt / (ureg.meter ** 2 * ureg.delta_degC))
    }
}
```

1.2.1 Collector Efficiency of A

[10]:
```python
collectors['A']['N_c'] = N_ar - collectors['A']['U'] * (T_collector - T_air) /␣
↪(CR * collectors['A']['G'])
collectors['A']['N_c']
```

[10]: 0.8097619047619048 *dimensionless*

1.2.2 Finding Solar Irradation Rate of B

[11]:
```
collectors['B']['N_c'] = collectors['A']['N_c']
collectors['B']['G'] = ((collectors['B']['N_c'] - N_ar) / (-1 *
↪collectors['B']['U']) / (T_collector - T_air)) ** (-1) / CR
print(bordered(f"G_B = {round(collectors['B']['G'], 2)}"))
```

```
G_B = 151.2 watt / meter ** 2
```

1.2.3 Collector Efficiency of A if Solar Irradiation Increases

[12]:
```
collectors['A']['G'] = 900 * (ureg.watt / (ureg.meter ** 2))
new_eff = N_ar - collectors['A']['U'] * (T_collector - T_air) / (CR *
↪collectors['A']['G'])
print(bordered(f"Efficiency Change = {round((new_eff.magnitude -
↪collectors['A']['N_c'].magnitude) * 100, 2)}%"))
```

```
Efficiency Change = 2.34%
```

1.3 Problem 4-45

A solar-power-tower plant is considered for Houston, Texas. Heliostats with a total area of 400,000 ft 2 are to be used to reflect solar radiation into a receiver. When the solar irradiation is 250 Btu/h ft 2 , steam is produced at 160 psia and 600°F at a rate of 15 lbm/s. This steam is expanded in a turbine to 2 psia pressure. The isentropic efficiency of the turbine is 88 percent. (a) Determine the power output, in kW and the thermal efficiency of the plant under these operating conditions. (b) How much electricity can be produced per year if the average thermal efficiency is 12 percent and the generator efficiency is 98 percent? Use the solar insolation value in Table 3-5 in Chap. 3. (c) The estimated cost of this plant is $17,000/kW and the plant is expected to operate 4500 h a year at the power output determined in part (a). If electricity generated is to be sold at a price of $0.11/kWh, how long will it take for this plant to pay for itself?

[13]:
```
ureg = pint.UnitRegistry(autoconvert_offset_to_baseunit = True)
```

[14]:
```
A = (400_000 * ureg.ft ** 2).to(ureg.meters **2)
G = (250 * (ureg.BTU / (ureg.hour * ureg.ft ** 2))).to(ureg.watt / (ureg.meter
↪** 2))
P_steam_in = (160 * ureg.psi).to('MPa')
T_steam = (600 * ureg.degF).to('degC')
m_dot_steam = (15 * ureg.pound / ureg.second).to('kg/s')
P_steam_out = (2 * ureg.psi).to('MPa')
N_isentropic = .88
```

[15]:
```
P_steam_in.to('kPa')
```

[15]:
1103.1611669069382 kilopascal

[16]:
```
P_steam_out.to('kPa')
```

[16]:
13.789514586336725 kilopascal

[17]:
```
T_steam
```

[17]:
315.55555555555566 degree_Celsius

1.3.1 Part A

[18]:
```
h1 = 3051.6 * ureg.kJ / ureg.kg   # (3051.6)
s1 = 7.1246 * ureg.kJ / (ureg.kg * ureg.degK) # (7.1246)

h2_s = 2590.7 * ureg.kJ / ureg.kg
```

[19]:
```
h2 = h1 - N_isentropic * (h1 - h2_s)
h2
```

[19]:
$2646.008 \ \frac{\text{kilojoule}}{\text{kilogram}}$

[20]:
```
W_out = m_dot_steam * (h1 - h2)
print(bordered(f"Power Output = {W_out.to('kW')}"))
```

```
Power Output = 2759.6015479956013 kilowatt
```

[21]:
```
N_th = W_out.to('watt') / (G * A)
print(bordered(f"Thermal Efficiency = {round(N_th.magnitude * 100, 2)}%"))
```

```
Thermal Efficiency = 9.42%
```

1.3.2 Part B

[22]:
```
N_th_average = 0.12
G = 15.90 * ureg.megajoules / (ureg.m**2 * ureg.day)
N_gen = 0.98
```

[23]:
```
W_out_B = N_th_average * A * G * (365 * ureg.day)
W_out_B.to('kWh')
```

[23]:
7188837.2352 kilowatt_hour

[24]:
```
W_elec = N_gen * W_out_B
W_elec.to('kWh')
print(bordered(f"Electric Energy = {round(W_elec.to('kWh'), 2)} kWh"))
```

```
Electric Energy = 7045060.49 kilowatt_hour kWh
```

1.3.3 Part C

[25]:
```
cost = W_out.to('kW') * (17_000 / (1 * ureg.kilowatt)).to('1/kW')
print(f"Cost = ${cost.magnitude}")
```

```
Cost = $46913226.315925226
```

[26]:
```
yearly_revenue = (W_out * (4500 * ureg.hour)).to('kWh') * (0.11 / (ureg.
↪kilowatt * ureg.hour)).to('1/kWh')
print(f"Revenue = ${yearly_revenue.magnitude} per year")
```

```
Revenue = $1366002.7662578227 per year
```

[27]:
```
print(bordered(f"Time to pay off = {round(cost.magnitude / yearly_revenue.
↪magnitude, 2)} years"))
```

```
Time to pay off = 34.34 years
```