Homework 11-1

Inputs

[1]:
```
from thermostate import Q_, State, units
from numpy import linspace, zeros_like
import matplotlib.pyplot as plt

import warnings
from pint.errors import UnitStrippedWarning
warnings.simplefilter(action='ignore', category=UnitStrippedWarning)
```

Definitions

[2]:
```
sub = 'water'

T_lo = Q_(20, 'degC')
```

Problem Statement

Lt. Cdr. Jordan Forge of the USS Enterskies is… trapped on a deserted planet. He's also unconscious. You, a junior engineer fresh out of Star Fleet Academy (yeah, sue me Gene Roddenberry, I couldn't think of an alternative name), are stuck on the planet with him. You're running low on water.

Fortunately, you know that water can be produced by combustion, and you happen to have a large butane torch with you. You can burn the butane (C_4H_{10}) completely with 150% of theoretical air.

1. If the combustion products are cooled at 1 atm to temperature T, plot the amount of water vapor condensed, in kmol water per kmol fuel, versus T ranging from 20 °C to the saturation temperature of the water in the combustion products. (Hint: calculate the saturation temperature first.)
2. You have 1 kmol of butane. You estimate you'll need 1.5 kmol of water to survive until the Enterskies can rescue you. You can capture all of the condensed water from the cooled combustion products. Based on your plot from Part 1, what is the maximum temperature you could cool the combustion products to while still capturing enough water to survive?

Solution

Part 1: Water Vapor Condensed vs Final Temperature

Combustion equations for butane

$$C_4H_{10} + a(O_2 + 3.76N_2) \to b \cdot CO_2 + c \cdot H_2O + d \cdot N_2$$

Reactants: 4 C atoms, 10 H atoms, 2a O atoms, 3.76(2a) N atoms

Products: b C atoms, 2c H atoms, 2b+c O atoms, 2d N atoms

System of equations:

$$4 = b$$

$$10 = 2c$$

$$2a = 2b + c$$

$$3.76(2a) = 2d$$

Solving this gives: a = 6.5, b = 4, c = 5, d = $3.76 \cdot 6.5$

For 150% theroretical air: we have $1.5 \cdot a$ is neeeded to combust C_4H_{10}

With a actually being 9.75, we will need to rebalence:

$$C_4H_{10} + 9.75(O_2 + 3.76N_2) \to 4CO_2 + 5H_2O + 36.66N_2 + 3.25O_2$$

CO_2 and H_2O don't change because out amount of carbon and hydrogen don't change.

Look at our equations, we from 5 kmol of H_2O for every kmol of butane.

Next we need to calculate the saturations temperature to see how much water liquid water is held in this reaction:

$$p_v = \frac{n_v}{n} \cdot p \qquad \frac{\Sigma n_i}{n} = 1 \qquad \Sigma p_i = p$$

Using the first equation mentioned above gives us $p_v = \frac{5}{4+5+36.66+3.25} \cdot 1$ atm

[3]:
```
st = State(sub, p=5/(4+5+36.66+3.25)*1*units.atm, x = 1.0*units.dimensionless)
T_dp = st.T.to("degC")
print(T_dp)
```

```
46.496616402402594 degC
```

This is the temperature at which our right side, products, will start to condense to liquid water.

For T below T_{dp}, total pressure will remain constant because we are inside the vapor dome. Using this, we will say the mols of water vapor per butane is:

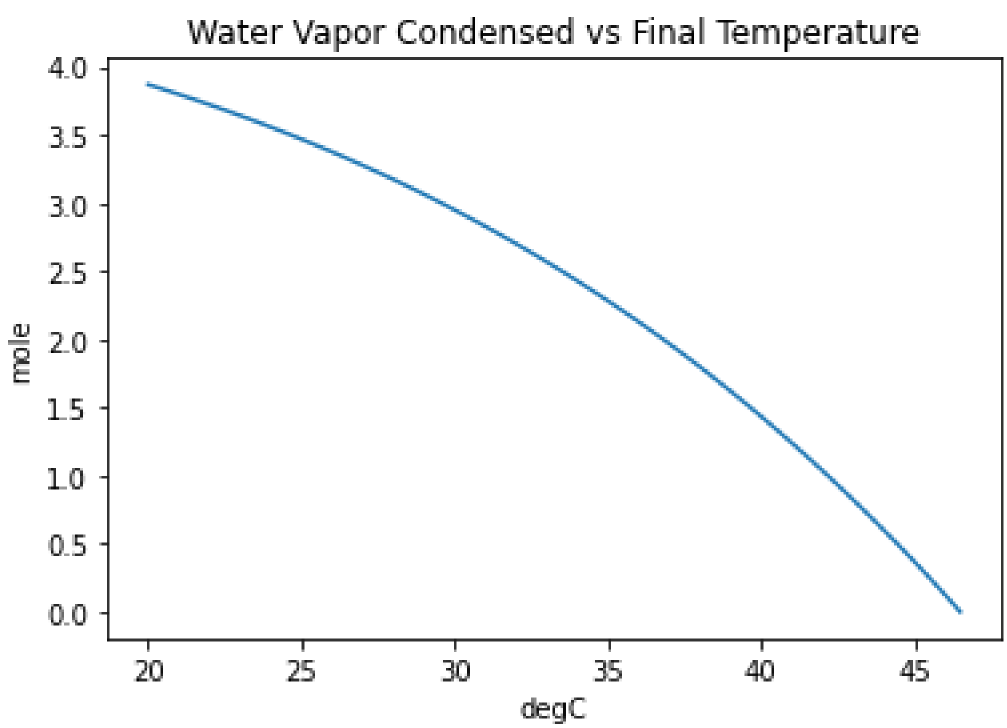
$$n_v = \frac{p_v n}{p}$$

Our mols of water liquid is our initial n, 5, minus n_v

[4]:

```
n_v_o = 5 * units.mole



T_range = linspace(T_lo.magnitude, T_dp.to("degC").magnitude)*units.degC
p_range = zeros_like(T_range)*units.atm
for i, T in enumerate(T_range):
    p_range[i] = State(sub, T=T, x = 1.0*units.dimensionless).p.to("atm")

n_v_range = p_range * (4+5+36.66+3.25)*units.mole/(1*units.atm)
n_liquid = n_v_o - n_v_range
print(n_liquid.round(2))

plt.plot(T_range,n_liquid)
plt.title("Water Vapor Condensed vs Final Temperature")
plt.show()
```

```
[3.87 3.83 3.79 3.75 3.71 3.67 3.62 3.58 3.53 3.48 3.43 3.38 3.33 3.27 3.22 3.16
3.1  3.04 2.98 2.92 2.85 2.78 2.72 2.65 2.57 2.5  2.42 2.34 2.26 2.18 2.09 2.01
1.92 1.83 1.73 1.63 1.54 1.43 1.33 1.22 1.11 1.  0.89 0.77 0.65 0.52 0.4  0.27
0.14 0.  ] mole
```



Part 2: Maximum Cooled Temperature to Yield Necessary Water

Our graph above shows how many mols of liquid water we get from 1 mol of butane at varyign temperatures. It is estimated that for 1 kmol of butane, the temperature required to get 1.5 kmols of water, is between:

[5]:
```
high = 0
low = 0
for i in range(len(n_liquid)):
    if n_liquid[i].round(2) == (1.54*units.mol):
        print(i)
        high = i
    elif n_liquid[i].round(2) == (1.43*units.mol):
        print(i)
        low = i

print(T_range[high],T_range[low])
```

```
36
37
39.466901846663134 degC 40.007649120181554 degC
```

Answer: $39.75 \pm 0.25\ ^o$C

Homework 11-2

Problem Statement

Enjoy your summer break!

Solution

Attach an image of your solution for this problem in this cell. Attach multiple images, one in each cell, if necessary. Please make sure the text is clear and legible.