

```
%% Problem 1
```

```
%define all the known values given in the problem
```

```
stream_1_temp = 50; %degrees Celsius
```

```
stream_1_m_dot = 200; %kg/min
```

```
stream_1_spec_enth = 209.3; %kJ/kg
```

```
Q_dot = 1.26*10^5; %kJ/min
```

```
stream_2_temp = 100; %degrees Celsius
```

```
stream_2_spec_enth = 419.1; %kJ/kg
```

```
stream_3_temp = 100; %degrees Celsius
```

```
stream_3_spec_enth = 2676; %kJ/kg
```

```
%create symbolic variables and equations to solve
```

```
syms Q_dot_equation M_dot_equation stream_2_m_dot stream_3_m_dot
```

```
%the general balance equation in this case becomes to  $Q_{dot} = \Delta H_{dot}$ 
```

```
% $\Delta H_{dot}$  is the rate of change in enthalpy between the input and output streams
```

```
%given that rate of enthalpy change is equal to mass flow rate times specific enthalpy
```

```
% $H_{dot out}$  is equal to the stream 2's mass flow rate times its specific
```

```
%enthalpy plus stream 3's mass flow rate times its specific enthalpy
```

```
% $H_{dot in}$  is equal to stream's mass flow rate times its specific enthalpy
```

```
Q_dot_equation = (stream_2_m_dot*stream_2_spec_enth + stream_3_m_dot*stream_3_spec_enth) -  
- (stream_1_m_dot*stream_1_spec_enth) == Q_dot;
```

```
%the second equation accounts for the conservation of mass flow
```

```
%the total flow rate out needs to be the same as the total flow rate in
```

```
M_dot_equation = stream_2_m_dot + stream_3_m_dot == stream_1_m_dot;
```

```
%solve the equation
```

```
solution = solve([Q_dot_equation, M_dot_equation], [stream_2_m_dot, stream_3_m_dot]);
```

```
%display results
```

```
fprintf("1.a) Stream 2 Mass Flow Rate: %.3f g/s \n", solution.stream_2_m_dot)
```

```
fprintf("1.a) Stream 3 Mass Flow Rate: %.3f g/s \n", solution.stream_3_m_dot)
```

```
%create symbolic variable to solve for
```

```
syms Q_dot_max
```

```
%set stream_3 m dot equal to stream_1 m dot
```

```
%since if 100% of water is boiled, the mass flow rate of steam out will be the same
```

```
%as the mass flow of water in
```

```
stream_3_m_dot_max = stream_1_m_dot;
```

```
%rearrange the equation solving for the value of  $Q_{dot}$  when 100% of water
```

```
%is boiled by solving for  $Q_{dot}$  plus the product of stream 1's mass flow
```

```
%rate and its specific enthalpy when it is equal to the product of stream
```

```
%3's mass flow rate and its specific enthalpy
```

```
Q_dot_max_eqn = Q_dot_max + stream_1_m_dot*stream_1_spec_enth ==
```

```
stream_3_m_dot_max*stream_3_spec_enth;
```

```
%solve equation for  $Q_{dot}$ 
```

```

Q_dot = solve(Q_dot_max_eqn, Q_dot_max);
%divide Q dot by .06 to convert from kJ/min to Watts
Q_dot = Q_dot / .06; % 1W = .06 kJ/min
%display results
fprintf("1.b) Energy Needed to Boil 100%% of Incoming Water: %.3e W\n", Q_dot);

%% Problem 2

m_dot_NH3 = 175*10^6; %175m tonnes/yr
%365 days per year, 24 hours per day, 60 mins per hour, 60 seconds per min,
% 1000 kg per tonne, 1000 g per kg
conversion_factor = 365*24*60*60/(1000*1000);
%conversion to g/s
m_dot_NH3 = m_dot_NH3/conversion_factor;
%conversion to mol/s
N_dot_NH3 = m_dot_NH3 / 17.031; % divide 17.031 g/mol (molar mass of NH3)
N_dot_H2 = N_dot_NH3 * (3/2); %multiply by molar ratio of H2 to NH3 in Haber-Bosch reaction ✓

%gray H2 accounts for 90 percent of total H2 usage
N_dot_grayH2 = N_dot_H2 * .9; %mol/s
%multiply by molar mass of H2
M_dot_grayH2 = N_dot_grayH2*2.016; %g/s

fprintf("2.a) Required mass flow rate of gray H2: %.3e g/s \n", M_dot_grayH2);

%divide by stoichometric coefficient of 4 to get rate of reaction
r4 = N_dot_grayH2/4; %mol/s

fprintf("2.b) Net rate of reaction r4: %.3e mol/s \n", r4);

%Molar flow rate of CO2 will be equal to the rate of reaction because the
%stoichometric coefficient of CO2 is 1
N_dot_CO2 = r4;
%multiply molar flow rate of CO2 by molar mass of CO2 to get mass flow rate
M_dot_CO2 = N_dot_CO2 * 44.01; %g/s

fprintf("2.c) Mass flow rate of CO2 from reaction r4: %.3e g/s \n", M_dot_CO2);

delta_H_r4 = 165; %kJ/mol
Q_dot_gray = r4*delta_H_r4; %kJ/s
% 1 kJ/s = 1000 W
fprintf("2.d) required heating rate gray: %.3e W \n", Q_dot_gray * 1000);

syms r5

%gray hydrogen reactor system is endothermic, so the combustor is
%exothermic
Q_dot_gray_combustor = -Q_dot_gray;
efficiency = .85;

```

```

delta_H_combustion = -803;
%product of efficiency, rate of reaction and delta H gives Q dot
Q_dot_combustor_eqn = efficiency * r5 * delta_H_combustion == Q_dot_gray_combustor;

r5 = solve(Q_dot_combustor_eqn, r5);

%total CO2 production
M_dot_CO2_combustion = r5;
%multiply molar flow rate of CO2 by molar mass of CO2 to get mass flow rate
M_dot_CO2_combustion = M_dot_CO2_combustion*44.01;

fprintf("2.e) mass flow rate of CO2 produced by r5: %.3e \n", M_dot_CO2_combustion);

%total CO2 production
M_dot_CO2_total = M_dot_CO2_combustion + M_dot_CO2; %g/s
%convert from g/s to kg/yr
%60 sec per min, 60 min per hour, 24 hour per day, 365 day per year, and
%1000 kg/g
M_dot_CO2_total = M_dot_CO2_total * 60*60*24*365/1000;

fprintf("2.f) Total CO2 production rate: %.3e kg/yr \n", M_dot_CO2_total);

%% Problem 3

%10% of H2 production is turquoise
N_dot_turqH2 = .1*N_dot_H2; %mol/s
%multiply by molar mass of H2 to get mass flow rate
M_dot_turqH2 = N_dot_turqH2*2.016; %g/s

fprintf("3.a) Required mass flow rate of turquoise H2: %.3e g/s \n", M_dot_turqH2);

%stoichiometric coefficient of hydrogen in methane pyrolysis (Turquoise H2 proudction) is 2
r3 = N_dot_turqH2/2;

fprintf("3.b) net rate of reaction r3: %.3e mol/s \n", r3)

%stoichiometric coefficient of solid Carbon product is 1, so molar flow rate of solid Carbon is equal to rate of reaction
N_dot_Cs = r3;
%multiply by molar mass of Carbon to get mass flow rate
M_dot_Cs = N_dot_Cs * 12.011; %g/s

fprintf("3.c) mass flow rate of C(s) that is produced as part of r: %.3e g/s \n", M_dot_Cs);

delta_H_r3 = 75; %kJ/mol
Q_dot_r3 = r3 * delta_H_r3; %kJ/s

%multiply by 1000 as 1 kJ/s = 1000 W

```

```
fprintf("3.d) required heating rate Turquoise: %.3e W \n", Q_dot_r3*1000);

%turquoise hydrogen reactor system is endothermic, so the combustor is
%exothermic, equal to the opposite of the thermal requirements
Q_dot_turq_combustor = -Q_dot_r3;
syms r5_turquoise

%product of efficiency, rate of reaction and delta H gives Q dot
Q_dot_turq_combustor_eqn = .85 * r5_turquoise * delta_H_combustion ==
Q_dot_turq_combustor;

%solve equation for rate of combustion reaction required for turquoise H2
%production
r5_turquoise = solve(Q_dot_turq_combustor_eqn, r5_turquoise);

%stoichiometric coefficient of CO2 in combustion reaction is one so molar flow rate is
equal to rate of reaction
n_dot_CO2_turq_combustion = r5_turquoise;

%multiply by molar mass of CO2 to get mass flow rate
M_dot_CO2_turq_combustion = n_dot_CO2_turq_combustion * 44.01;

fprintf("3.e) mass flow rate of CO2 produced by r5 for turquoise H2: %.3e g/s \n",
M_dot_CO2_combustion);

%combustion releases CO2, pyrolysis only produces solid carbon
%multiply by 60 seconds/min, 60 mins/hr, 24 hrs/day, 365 days/yr, divide by
%1000 g/kg to get total in kg/yr
M_dot_CO2_turq_total = M_dot_CO2_turq_combustion * 60*60*24*365/1000; %kg/yr

fprintf("3.f) Total CO2 production rate Turquoise: %.3e kg/yr \n", M_dot_CO2_turq_total);
```

```
>> hw4
1.a) Stream 2 Mass Flow Rate: 162.763 g/s
1.a) Stream 3 Mass Flow Rate: 37.237 g/s
1.b) Energy Needed to Boil 100% of Incoming Water: 8.222e+06 W
2.a) Required mass flow rate of gray H2: 8.868e+05 g/s
2.b) Net rate of reaction r4: 1.100e+05 mol/s
2.c) Mass flow rate of CO2 from reaction r4: 4.840e+06 g/s
2.d) required heating rate gray: 1.814e+10 W
2.e) mass flow rate of CO2 produced by r5: 1.170e+06
2.f) Total CO2 production rate: 1.895e+11 kg/yr
3.a) Required mass flow rate of turquoise H2: 9.853e+04 g/s
3.b) net rate of reaction r3: 2.444e+04 mol/s
3.c) mass flow rate of C(s) that is produced as part of r: 2.935e+05 g/s
3.d) required heating rate Turquoise: 1.833e+09 W
3.e) mass flow rate of CO2 produced by r5 for turquoise H2: 1.170e+06 g/s
3.f) Total CO2 production rate Turquoise: 3.727e+09 kg/yr
>>
```

energy balance equation for a boiler with water in and water and steam out



The energy balance for a boiler involves accounting for the energy added to the system (in the form of heat) and the energy associated with the inlet and outlet streams. In this case, you have water entering and both water and steam exiting the boiler.

Assumptions:

- Steady-state operation (no accumulation of energy within the boiler).
- Negligible changes in kinetic and potential energy.
- Only sensible and latent heat contributions considered.

Energy Balance Equation:

Using the first law of thermodynamics for an open system at steady-state:

$$\dot{Q} = \dot{m}_{out}h_{out} - \dot{m}_{in}h_{in}$$

Where:

- \dot{Q} = rate of heat energy added to the boiler (kW or kJ/s),
- \dot{m}_{in} = mass flow rate of water entering the boiler (kg/s),
- h_{in} = specific enthalpy of water entering the boiler (kJ/kg),
- \dot{m}_{out} = total mass flow rate of water and steam exiting the boiler (kg/s),
- h_{out} = average specific enthalpy of the water and steam exiting (kJ/kg).

Since you have both liquid water and steam exiting, we can break down the mass and enthalpy of the outlet streams.

Let:

- \dot{m}_{water} = mass flow rate of water exiting (kg/s),
- \dot{m}_{steam} = mass flow rate of steam exiting (kg/s),
- $h_{water,out}$ = specific enthalpy of the water exiting (kJ/kg),
- $h_{steam,out}$ = specific enthalpy of the steam exiting (kJ/kg).

Thus, the total energy leaving the boiler is a combination of the energy in both the water and steam streams. The energy balance becomes:

$$\dot{Q} = \dot{m}_{steam}h_{steam,o} \downarrow + \dot{m}_{water}h_{water,out} - \dot{m}_{in}h_{in}$$

Additional Relationships:

- The mass flow rate of the outlet streams should equal the mass flow rate of the inlet stream:

$$\dot{m}_{in} = \dot{m}_{water} + \dot{m}_{steam}$$

Steps to Use the Equation:

1. Determine the inlet conditions:

- Obtain \dot{m}_{in} (mass flow rate of the water entering the boiler).
- Get the specific enthalpy h_{in} of the water entering the boiler from steam tables, using the inlet temperature and pressure.

2. Determine the outlet conditions:

- Use steam tables or a Mollier diagram to find the specific enthalpy $h_{steam,out}$ of the steam and $h_{water,out}$ of the saturated water (or subcooled liquid) at the exit conditions (pressure and temperature).

3. Calculate the heat added:

- Using the mass flow rates \dot{m}_{steam} and \dot{m}_{water} (which may need to be solved from a mass balance), calculate the total enthalpy of the outlet streams.
- Substitute values into the energy balance equation to find \dot{Q} .

Example:

Let's consider a boiler where:

- Water enters at 25°C and exits as a mixture of saturated liquid and saturated vapor at 100°C.
- The mass flow rate of water entering the boiler is $\dot{m}_{in} = 2 \text{ kg/s}$.

From steam tables:

- The specific enthalpy of water entering at 25°C, h_{in} , is approximately 104.8 kJ/kg.
- At 100°C, the specific enthalpy of saturated water $h_{water,out} = 419.0 \text{ kJ/kg}$.
- The specific enthalpy of saturated steam at 100°C $h_{steam,out} = 2676.0 \text{ kJ/kg}$.

If 1 kg/s of water exits as steam and 1 kg/s exits as liquid water, the heat added to the boiler is:

$$\dot{Q} = (1 \text{ kg/s}) \cdot (2676.0 \text{ kJ/kg}) + (1 \text{ kg/s}) \cdot (419.0 \text{ kJ/kg}) - (2 \text{ kg/s}) \cdot (104.8 \text{ kJ/kg})$$

Simplifying:

$$\dot{Q} = 2676 + 419 - 209.6 = 2885.4 \text{ kJ/s} = 2885.4 \text{ kW}$$

Thus, the rate of heat added to the boiler is **2885.4 kW**.

This is a basic example, and depending on the system, you might need to account for different pressures or non-saturated conditions.



AI and ChatGPT used to explain the equation and terms used in the steady state energy balance equation for an open system (boiler)