Department of Chemical Engineering Thapar Institute of Engineering & Technology, Patiala

Course: Material and Energy Balances UCH301

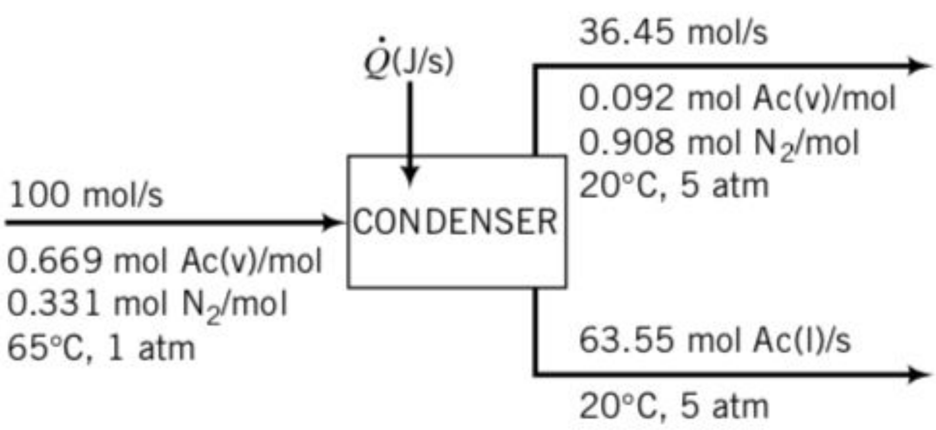
Course Instructor:

Dr. R. K. Gupta, Professor, Chemical Engineering

Exercise

(Based on the procedure discussed for applying energy balance)

- Acetone (denoted as Ac) is partially condensed out of a gas stream containing 66.9 mole% acetone vapor and the balance nitrogen. Process specifications and material balance calculations lead to the flowchart shown below.



SOLUTION

1. Perform required material balance calculations: In this case not, required as the flow and compositions of all streams are given.

2. Simplify the Energy Balance:

$$Q+W = (\Delta H+\Delta K+\Delta P)$$

Here, W =0, Q=?, ΔK =0, ΔP =0

Therefore, E.B. in this case reduces to:

$$Q= \Delta H$$

$$\Rightarrow \quad Q = \Delta H = \sum_{out} n_i H_i - \sum_{in} n_i H_i$$

3. Choose reference states for acetone and nitrogen.

4. Obtain data for H_i at in and out conditions

References: Ac(l, 20°C, 5 atm), N_2(g, 25°C, 1 atm)

Substance	$\dot{n}_{in}$ (mol/s)	$\hat{H}_{in}$ (kJ/mol)	$\dot{n}_{out}$ (mol/s)	$\hat{H}_{out}$ (kJ/mol)
Ac(v)	66.9	$\hat{H}_1$	3.35	$\hat{H}_3$
Ac(l)	—	—	63.55	0
N_2	33.1	$\hat{H}_2$	33.1	$\hat{H}_4$

References: Ac(l, 20°C, 5 atm), N_2(g, 25°C, 1 atm)

Substance	$\dot{n}_{in}$ (mol/s)	$\hat{H}_{in}$ (kJ/mol)	$\dot{n}_{out}$ (mol/s)	$\hat{H}_{out}$ (kJ/mol)
Ac(v)	66.9	35.7	3.35	32.0
Ac(l)	—	—	63.55	0
N_2	33.1	1.16	33.1	−0.10

5. Calculate ΔH from the relation:

$$Q = \Delta H = \sum_{out} n_i H_i - \sum_{in} n_i H_i$$

$Ac(v)_{out}$ = 0.092*36.45 = 3.35 mol/s; $Ac(v)_{in}$ = 0.669*100= 66.9 mol/s

$N_{2,out}$ = 0.908*36.45 = 33.1 mol/s; $N_{2,out}$ = 33.1 mol

$Ac(l)_{out}$= 63.55 mol/s

Q = ΔH = {3.35*32+33.1*(1.16)+63.55*0}

- {66.9*35.7+33.1*(-1.0)} = 2320 kJ/s

Therefore, Q = -2320 kJ/mol

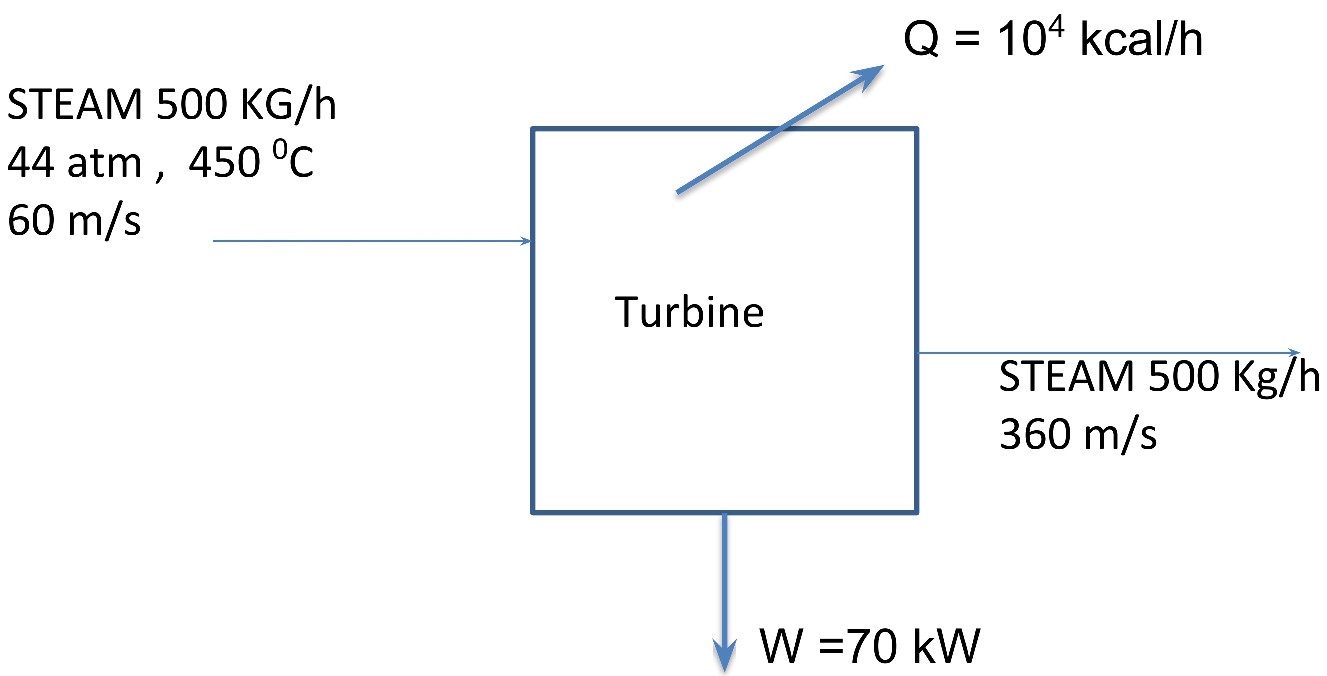
Heat removed in the condenser (-ve for process)

PROBLEMS RELATED TO ENERGY BALANCE WITHOUT REACTIONS

Problem

- Steam at a mass flow rate of 500 kg/hour is being used to drive a turbine. Steam enters the turbine at 44 atm and 450 ^{0}C at a velocity of 60 m/s, and leaves at a point 5 m below the inlet point at atmospheric pressure and a velocity of 360 m/s. The turbine delivers shaft work at a rate of 70 kW, and heat loss from the turbine is 10^4 kcal/hour. Calculate the specific enthalpy change for this process.

Sketch



Q = 10^4 kcal/h
STEAM 500 KG/h
44 atm , 450 ^{0}C
60 m/s
Turbine
STEAM 500 Kg/h
360 m/s
W =70 kW

Solution

- From the steady state e. b. equation, we may write for this process

  $Q+W = \Delta H + \Delta K + \Delta P$

  (for this process W is being done by the process, so W is negative. Also process is loosing heat, therefore Q is also negative)

$\Rightarrow$ $\mathbf{\Delta H = Q+W - \Delta K - \Delta P}$

m= 500 kg/h= 500/3600 = 0.139 kg/s (for units consistency)

Evaluating change in kinetic, and potential energy

$\Delta K = m(v_2^{\,2}-v_1^{\,2})/2 = (0.139)(360^2-60^2)/2$

$= 8.75$ kW

$\Delta P = mg(z_2-z_1) = 0.139(kg/s)*9.81\ m/s^2*(-5-0)$

$= -\ 0.00681$ kW

W = -70 kW

Q = 10^4 kcal/h= -11.6 kW (1 J = 0.239 cal)

Therefore, $\Delta H = -11.6-70-8.75+0.00681$

$= -90.3$ kW

Change in enthalpy per unit mass of steam

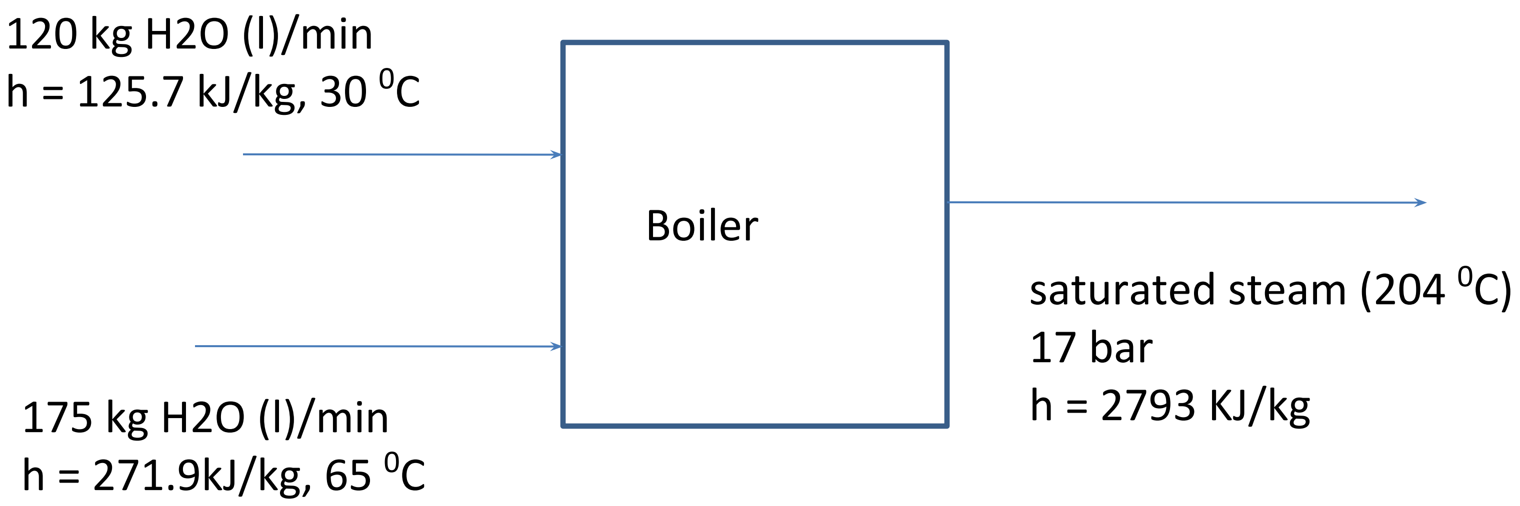
$H_2-H_1 = -\ 90.3\ (kJ/s)/0.139(kg/s) = -650\ kJ/kg$

Negative sign indicates that steam will lose enthalpy

Problem

- Two streams of water are fed to a boiler (as shown in figure). The boiler pressure is 17 bar absolute. The steam comes out of the boiler through a 6 cm ID pipe. Calculate the heat required to be supplied to the boiler in KJ/min, if the emerging steam is saturated at the boiler pressure. Neglect the kinetic energies of the liquid inlet streams. Specific volume of the steam is $0.1166 m^3/kg$. Assume potential energy changes as negligible.

Sketch


120 kg H2O (l)/min
h = 125.7 kJ/kg, 30 ⁰C
Boiler
saturated steam (204 ⁰C)
17 bar
h = 2793 KJ/kg
175 kg H2O (l)/min
h = 271.9kJ/kg, 65 ⁰C

Energy balance equation

$\Delta E = Q+W- (\Delta H+\Delta K+\Delta P)$ (at steady state $\Delta E=0$)

Using steady state E.B. for this process

$$Q+W = \Delta H + \Delta K + \Delta P$$

For the given process: $W= 0$; $\Delta P = 0$

Therefore, $\mathbf{Q = \Delta H + \Delta K}$

Material balance: $m_{out} = 120+175 = 295$ kg/min

Evaluating ΔH

$$\Delta H = \sum m_i(h_i)_{outlet} - \sum m_i(h_i)_{inlet}$$

$= 295$ kg/min * 2793 kJ/kg – (120 kg/min* 125.7 kJ/kg) – (175kg/min*271.9 kJ/kg)

$$\mathbf{\Delta H = 7.61\times10^5\ kJ/min}$$

- Evaluating ΔK

$\Delta K = k_{outlet} - K_{inlet}$ ($K_{inlet} = 0$, given)

- Steam velocity at the outlet=

volumetric flow rate/area for flow

Vol flow(m^3/s)=(295 kg/min*(1/60)*0.1166m^3/kg)

Area for flow, A = (3.1416*(6/100)*(6/100))/4

$= 2.8\times10^{-3}\ m^2$

Therefore, u (m/s) = Vol. flow./Area = 202 m/s

$K_{outlet} = mu^2/2$

$= 295\text{kg/min}*(202^2 m^2/s^2)/2$ ($1N = 1\text{kg.m/s}^2$)

$= 6018\times10^3 \text{J/min} = 6018\ \text{kJ/min}$

Heat required to be supplied to the boiler

- $Q = \Delta H + \Delta K$

$= 7.61\times10^5$ kJ/min + 0.06×10^5 kJ/min

$= 7.67\times10^5$ kJ/min