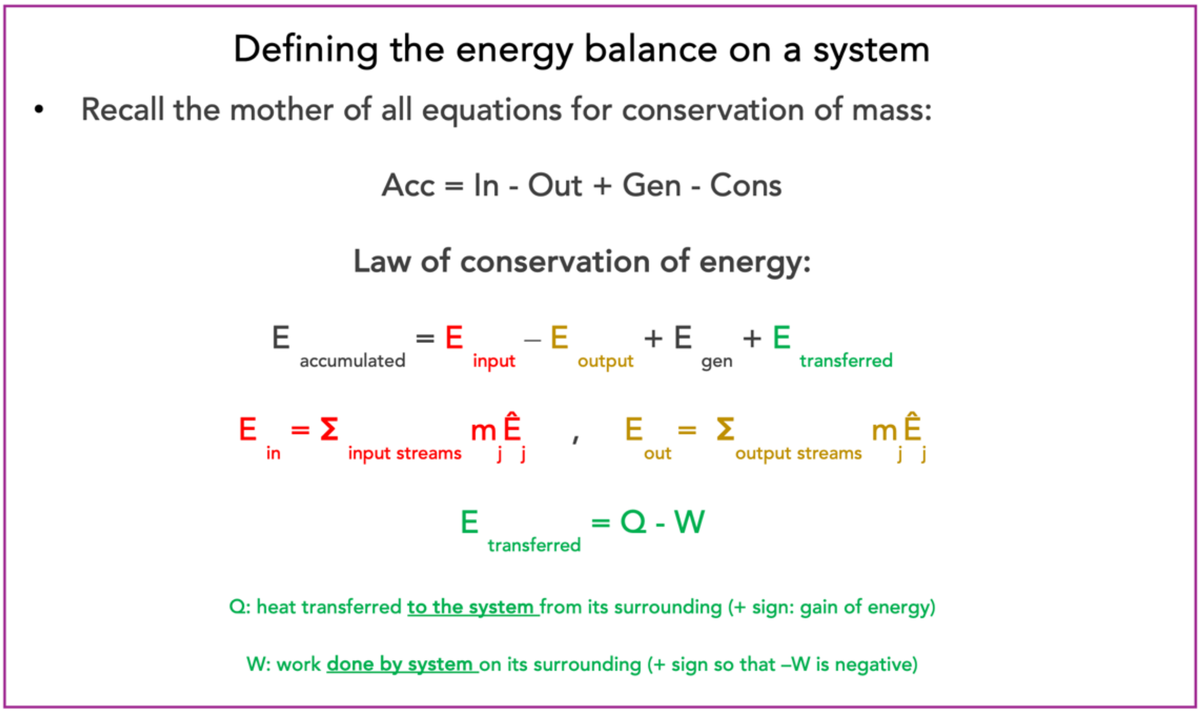
Introduction to Chemical Engineering

Problem Sheet 5 – Week 6 – October 17, 2025

<u>Goal</u>:

The aim of this session is to understand and formulate the energy balance equation for simple non-reactive processes, identify the different forms of energy involved, and learn how to represent energy flows in a process diagram.

<u>Recap</u>:



Defining the energy balance on a system

- Recall the mother of all equations for conservation of mass:

$$Acc = In - Out + Gen - Cons$$

Law of conservation of energy:

$$E_{accumulated} = E_{input} - E_{output} + E_{gen} + E_{transferred}$$

$$E_{in} = \Sigma_{input\ streams}\, m_j \hat{E}_j \quad , \quad E_{out} = \Sigma_{output\ streams}\, m_j \hat{E}_j$$

$$E_{transferred} = Q - W$$

Q: heat transferred <u>to the system</u> from its surrounding (+ sign: gain of energy)

W: work <u>done by system</u> on its surrounding (+ sign so that –W is negative)

Problem 1: Energy Balance, Non-reactive System

Values of the specific internal energy of bromine at three conditions are listed here:

State	T (K)	P (bar)	$\hat{V}$ (L/mol)	$\tilde{U}$ (kJ/mol)
Liquid	300	0.310	0.0516	0.000
Vapor	300	0.310	79.94	28.24
Vapor	340	1.33	20.92	29.62

(a) What reference state was used to generate the listed specific internal energies?

(b) Calculate $\Delta\tilde{U}$ (kJ/mol) for a process in which bromine vapor at 300 K is condensed at constant pressure. Then calculate $\Delta\hat{H}$ (kJ/mol) for the same process. Finally, calculate ΔH (kJ) for 5.00 mol of bromine undergoing the process.

(c) Bromine vapor in a 5.00-liter container at 300 K and 0.205 bar is to be heated to 340 K. Calculate the heat (kJ) that must be transferred to the gas to achieve the desired temperature increase, assuming that $\tilde{U}$ is independent of pressure.

(d) In reality, more heat than the amount calculated in part (c) would have to be transferred to the container to raise the gas temperature by 40 K, for several reasons. State two of them.

Problem 2: Energy Balance, Non-reactive Systems

Superheated steam at 40 bar absolute and 500°C flows at a rate of 250 kg/min to an adiabatic turbine, where it expands to 5 bar. The turbine develops 1500 kW. From the turbine, the steam flows to a heater, where it is reheated isobarically to its initial temperature. Neglect kinetic energy changes.

(a) Write an energy balance on the turbine and use it to determine the outlet stream temperature.

(b) Write an energy balance on the heater and use it to determine the required input (kW) to the steam.

(c) Verify that an overall energy balance on the two-unit process is satisfied.

(d) Suppose the turbine inlet and outlet pipes both have diameters of 0.5 meter. Show that it is reasonable to neglect the change in kinetic energy for this unit.

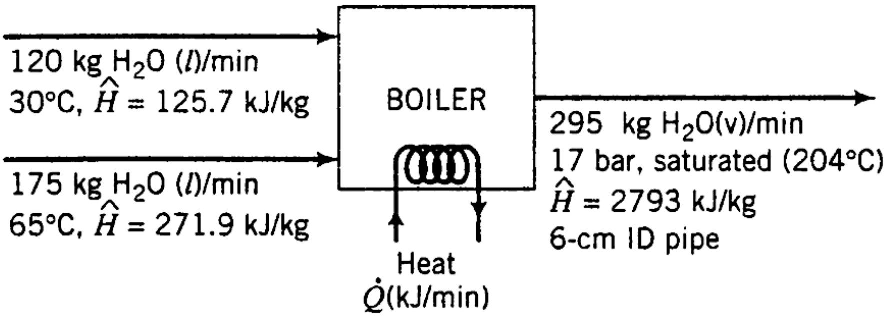
Problem 3: Energy Balance, Non-reactive Systems

Two streams of water are mixed to form the feed to a boiler. Process data are as follows:

Stream	Flowrate	Temperature
Feed stream 1	120 kg/min	30°C
Feed stream 2	175 kg/min	65°C
Boiler pressure	17 bar (absolute)	-

The exiting steam emerges from the boiler through a pipe that has an internal diameter of 6 cm. Calculate the required heat input to the boiler in kilojoules per minute if the emerging steam is saturated at the boiler pressure. Neglect the kinetic energies of the liquid inlet streams.

Given:



Problem 4: Energy Balance, Non-Reactive Systems (Midterm 2022-2023)

In the acetic anhydride process, 100mol/h of a process stream consisting of 4% moles ketene, 10% moles acetic acid and the remainder in equimolar proportions methane and carbon dioxide at 700°C is to be cooled to 400°C. To achieve such requirements, the input gas is quenched (mixed) with glacial acetic acid at 50°C.

(a) Given the data below, calculate the flow rate of quench acetic acid required and the composition of the cooled gas.
(b) Suppose now that the flow of cooling acetic acid is 40mol/h. Calculate the outlet gas temperature, assuming no phase change in the outlet stream.

Gas Heat Capacities ($\frac{cal}{mol*K}$)				
	a	$b*10^2$	$c*10^5$	$d*10^9$
CH_4	4.750	1.2	0.303	-2.63
CO_2	6.393	1.01	-0.3405	-
CH_3COOH	8.20	4.805	-3.056	8.31
CH_2O	4.11	2.966	-1.793	4.72

$$\Delta H_{VL}(CH_3COOH, 391.4K) = 5.83\ kcal/mol$$

$$\mathrm{C_{p,mean}}(CH_3COOH, liquid) = 36\ cal/mol \cdot K$$

Only use the 2 first terms for the heat capacities (a & b).