Laboratory of
Computational
Systems
Biotechnology

EPFL

Introduction to Chemical Engineering

Teaching by:

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Office hours: Mondays 16h-19h (CH H4 625) or schedule by email

Fridays, 14h15 - 17h00
2024-2025

Course Schedule

Date	Subject
13-Sep	**1. Fundamentals of Material Balances** 1.1. Process definition and classification 1.2. Material balance calculations
20-Sep	1.3. Balances on multiple-unit processes
27-Sep	**Review on Mass Balances (non-reactive)**
04-Oct	1.4. Chemical reaction stoichiometry **1.5.1 Balances on reactive processes (part 1)**
11-Oct	**1.5.2 Balances on reactive processes (part 2)** **1.6. Balances on multiple unit reactive processes** **Review on Mass Balances (non-reactive & reactive)**
18-Oct	**2. Energy and Energy Balances** 2.1. Energy balances on closed systems 2.2. Open systems at steady state
01-Nov	**3. Balances on Non-Reactive Processes** 3.1. Energy balance calculation 3.2. Changes in Pressure, Temperature, Phases 3.3. Mixing and Solution
08-Nov	**4. Balances on Non-Reactive Processes** Problems: Mass and Energy Balances on non-Reactive Systems
15-Nov	**Midterm Exam: Mass & Energy Balances non-Reactive Systems**
22-Nov	**Review Midterm**
29-Nov	**5. Balances on Reactive Processes** 5.1. Heats of reaction/combustion 5.2. Combustion reactions 5.3. Enthalpy of reaction 5.4. Energy balance calculation
06-Dec	**6. Energy balances on mixing processes** **Review**
13-Dec	**Review and Study Session**

Recommended textbook:
Elementary Principles of Chemical Processes
Richard M. Felder & Ronald W. Rousseau

Session V: Friday 18 October 2024

After studying this session you will be able to:

1. Understand the concepts of work and heat (signs!), intrinsic and extensive properties

2. Identify non-reactive **closed** systems & Define an energy balance on them

3. Identify non-reactive **open** systems & Define an energy balance on them

1. Introduction

Introduction to energy balances

By performing energy balances, we answer questions like:

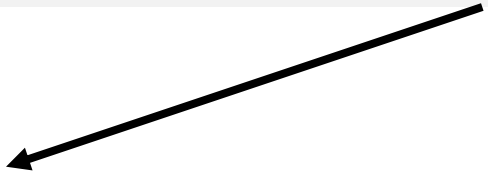
- How much energy is required for pumping 1000 m^3/h?
- What is the rate of energy supply in a distillation column?
- A→B exothermic and 75% conversion @400k, what is the rate of energy removal to achieve the target?
- …
- Is there a cheaper way of achieving my process specifications? → Energy is expensive!!!

In the design of a process, we must account for:

✓ the flow of energy into and out of each process unit

✓ the overall energy requirement of the process

Recalling the definition of a system



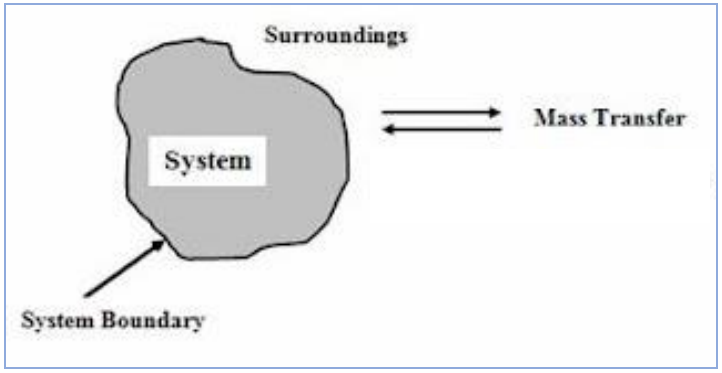
Flow of mass

Recalling the definition of a system

Flow of mass

Open

Closed



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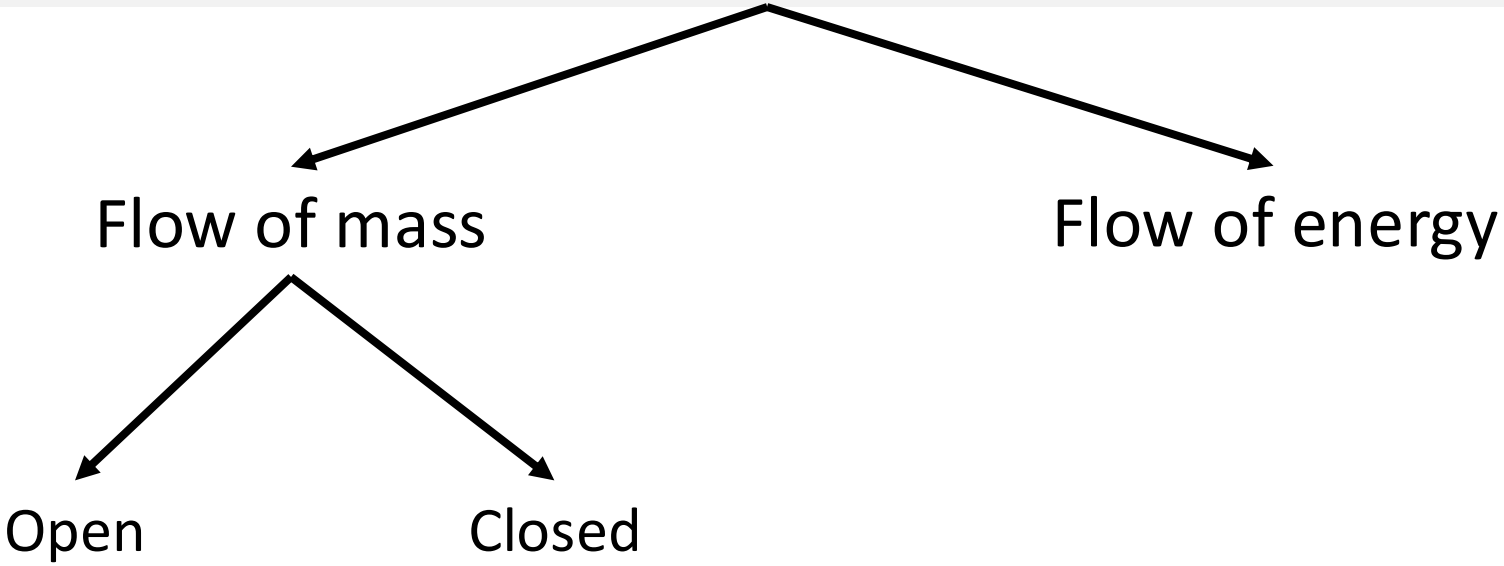

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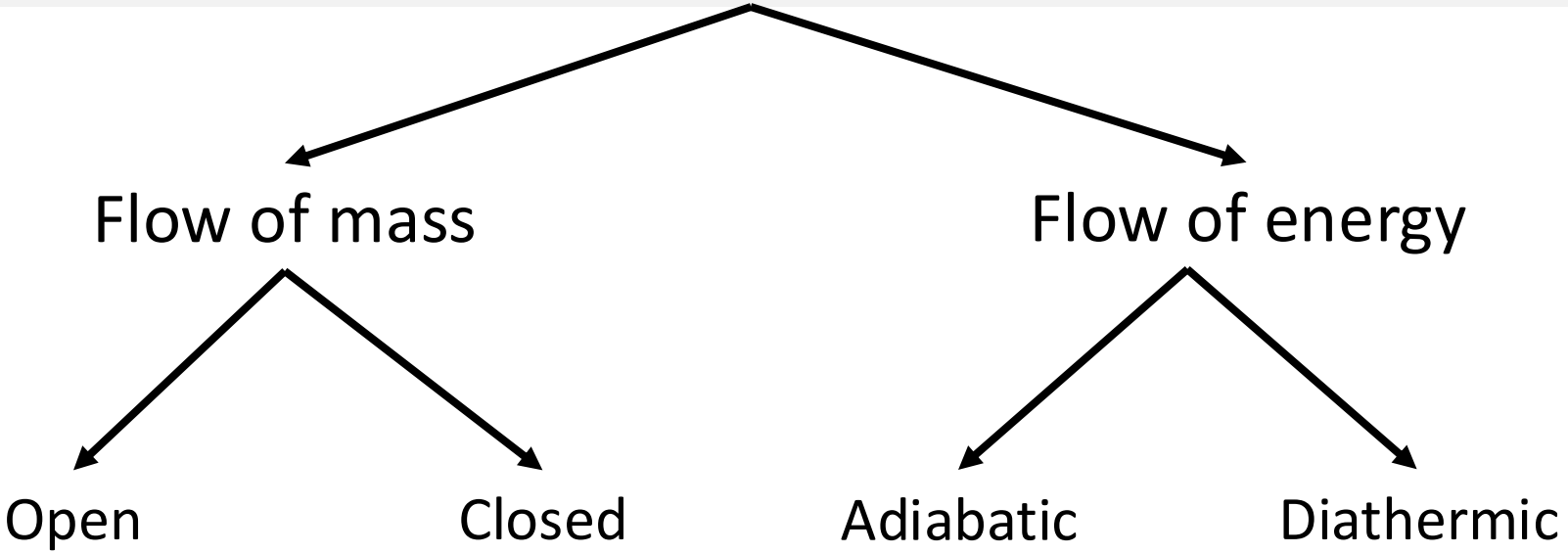


Recalling the definition of a system

Flow of mass

Flow of energy

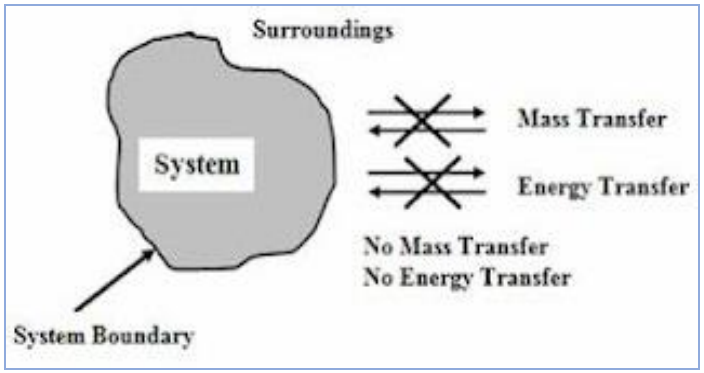
Open

Closed

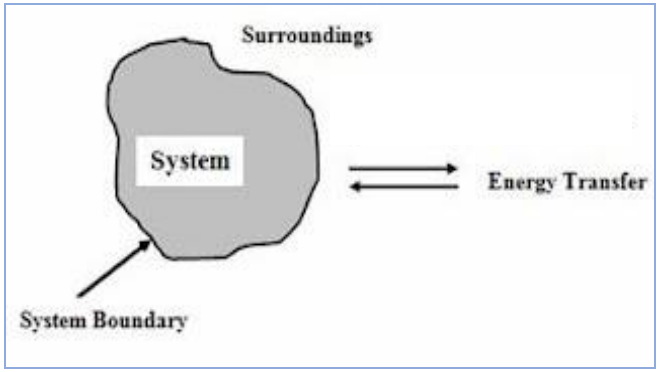
Adiabatic

Diathermic

Closed + Adiabatic



Closed + Diathermic



Forms and Transfer of energy of a system

The total energy of a system has 3 forms

❶ Kinetic energy

Energy associated with movement

❷ Potential energy

Energy in a potential field
Gravitational, electromagnetic, …

❸ Internal energy

“Everything else”
Molecular energy …

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The energy is transferred from the environment to a process system (and vice-versa) in 2 ways

Ⓐ Heat (Q): flow or exchange of energy due to ΔT

- Could enter the system via conduction, convection, or radiation

Ⓑ Work (W): flow or exchange of energy due to "driving forces" other than temperature (e.g.: voltage, force)

- Could be done on, or by, the system

Clarifications

- Q, W are transferred energies: a system does not possess heat or work

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  Heat is positive because the system in effect gains energy when heat enters

  - Q<0 : heat leaving the system

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- Q, W are transferred energies: a system does not possess heat or work

- Signs of Q and W according to this course **conventions**:

  - Q>0 : heat entering the system

  Heat is positive because the system in effect gains energy when heat enters

  - Q<0 : heat leaving the system

  - W>0 : work done BY the system
  - W<0 : work done ON the system

  The choice for the sign of work is arbitrary but facilitates the reading of the expression of energy transferred to the system (see next slides):

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

Types of work

- W_m : mechanical work which is due to movement of the boundary, (e.g., piston)
- W_{el} : electrical work (e.g., electrical generator)
- W_s : shaft work (e.g., mixing, turbine, pump)
- W_{fl} : flow work
  - Work done to push a fluid into system (use example of pistons moving fast)
  - Work done to push fluid out of system

Example 1: Determine the sign of the work transferred to the system in the following cases:

- a piston compress the system
- a generator gives energy to the system
- a pump applies work into a stream (system)
- a turbine acts on a stream (system)
- a fluid (system) flows into a piston

Classification of properties

- Intensive property: is a physical property of a system that does not depend on the system size or the amount of material in the system.

  E.g.: density, P, T

- Extensive property: is a property that is directly proportional to the amount of material in the system.

  E.g.: mass and volume, internal energy (U)

- Specific property: is a property that depends on, or is calculated based on, another measurable property, and are denoted with a "^".

  E.g.: density is considered 'specific' because it can be calculated from volume and mass

How to calculate an extensive property for the whole system?

- for internal energy of the system: $U(J) = m\,(kg)\ \hat{U}\,(J/kg)$
- for the continuous flow: $\mathring{U}(J/s) = \dot{m}\,(Kg/s)\ \hat{U}\,(J/kg)$

Defining the energy balance on a system

Recall the mother of all equations for conservation of mass:

Acc = In - Out + Gen - Cons

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Law of conservation of energy:

This states that: if E is the entire amount of energy in the system, then:

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

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

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

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

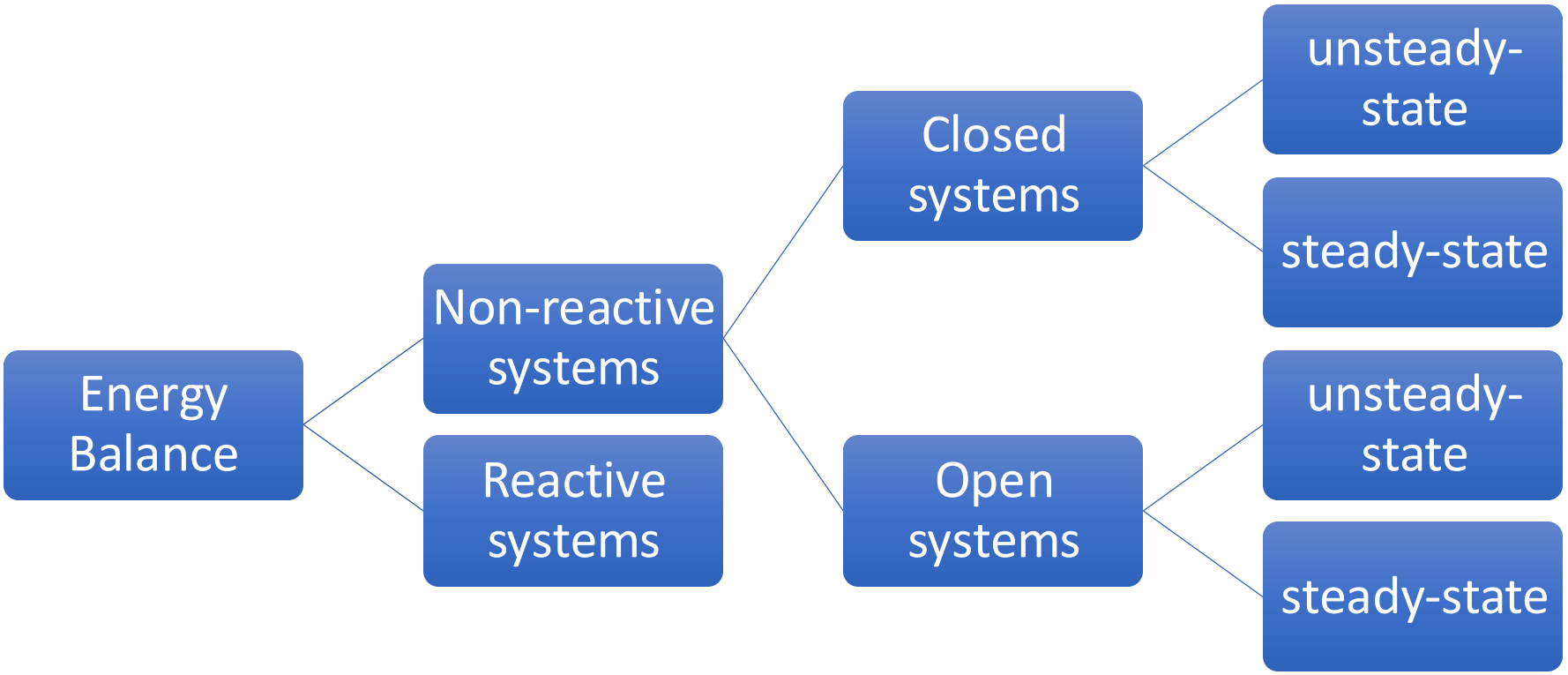
Q: heat transferred **<u>to the system</u>** from its surrounding (+ sign: gain of energy)

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

Energy balances overview

Depending on the system under study, the energy balance equation will simplify:

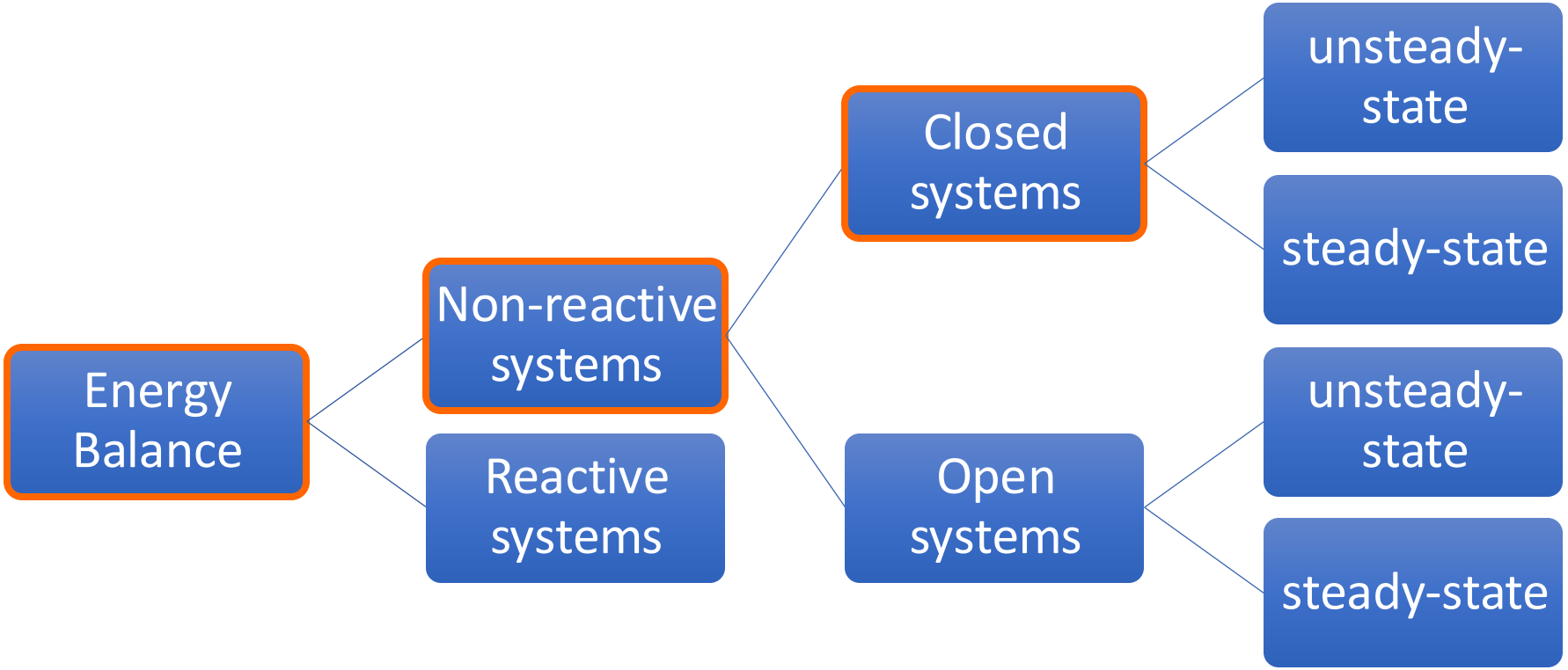
$$E_{accumulated} = E_{input} - E_{output} + E_{gen} + E_{transferred}$$



2. Energy balances on closed non-reactive systems

Energy balances on closed non-reactive systems

The simplest case consists in closed systems:



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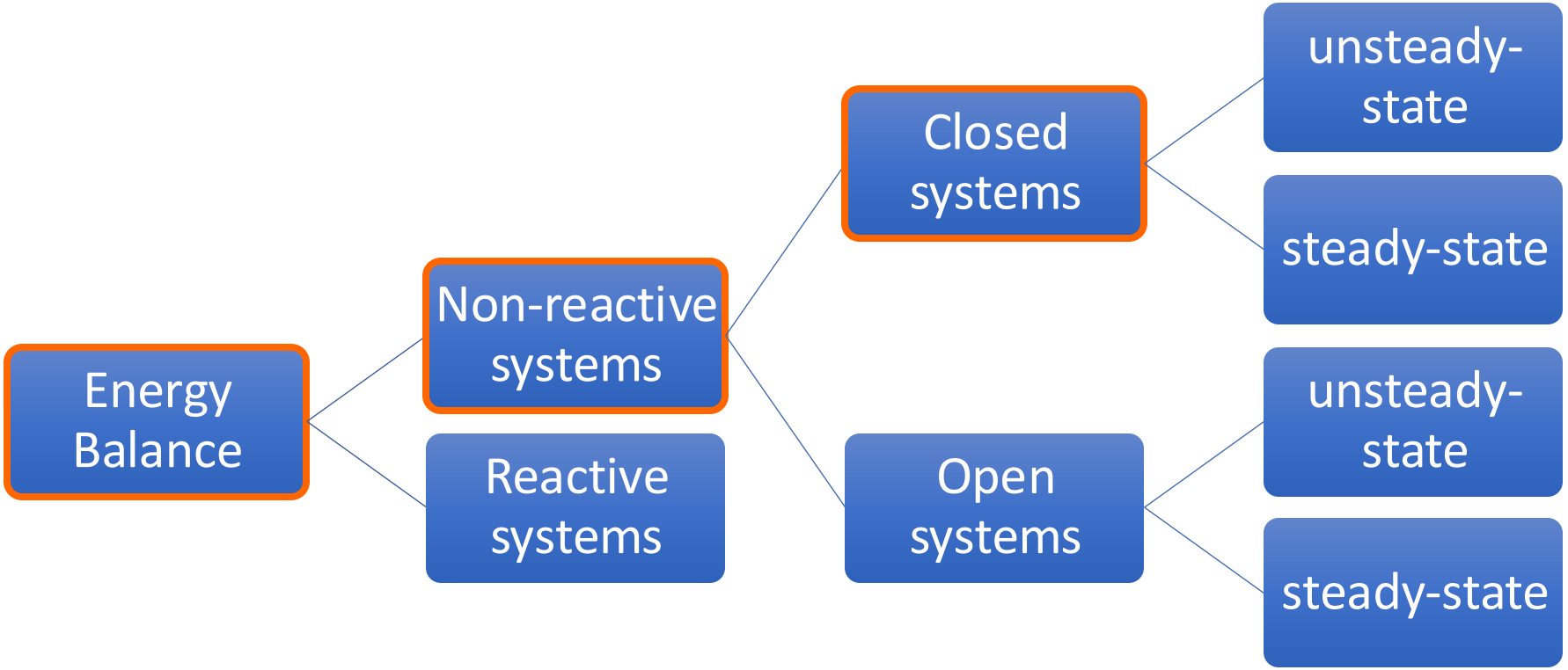

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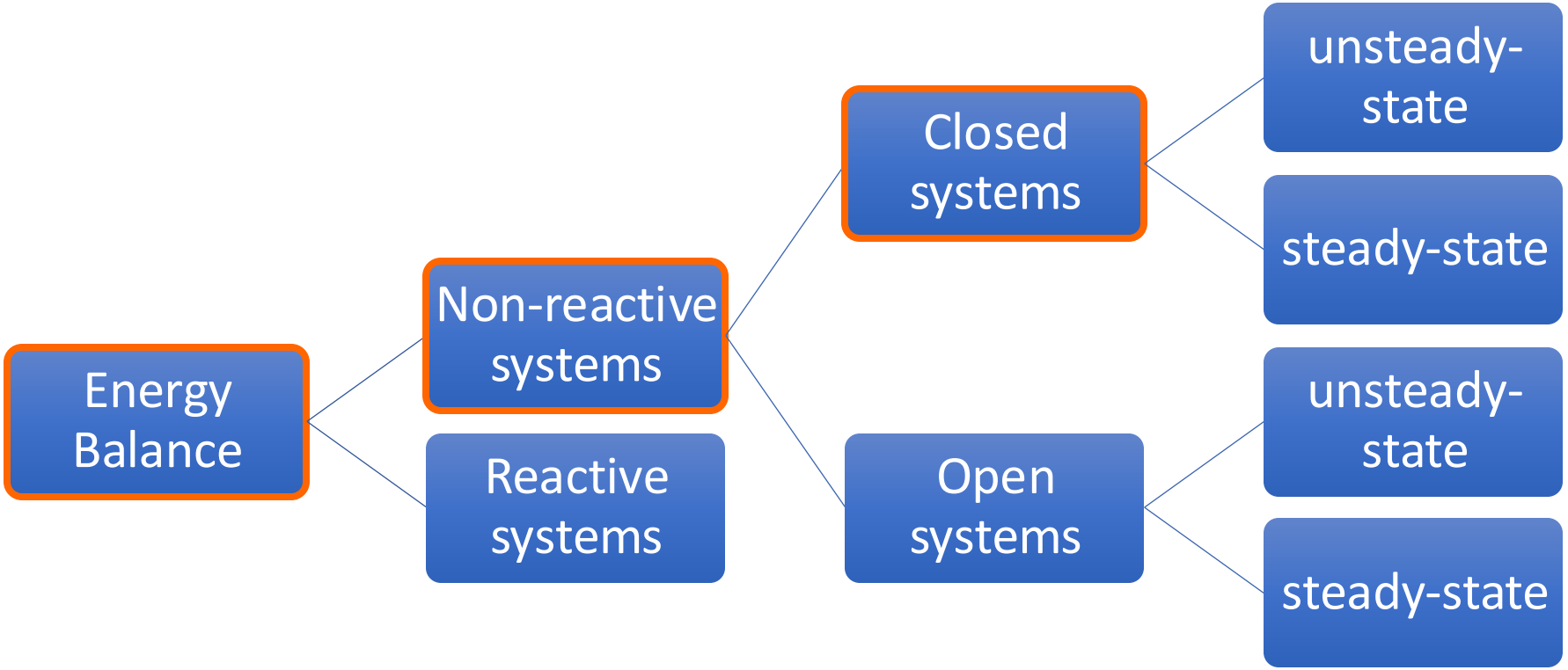


$$E_{accumulated} = \cancel{E_{input}} - \cancel{E_{output}} + \cancel{E_{gen}} + E_{transferred}$$

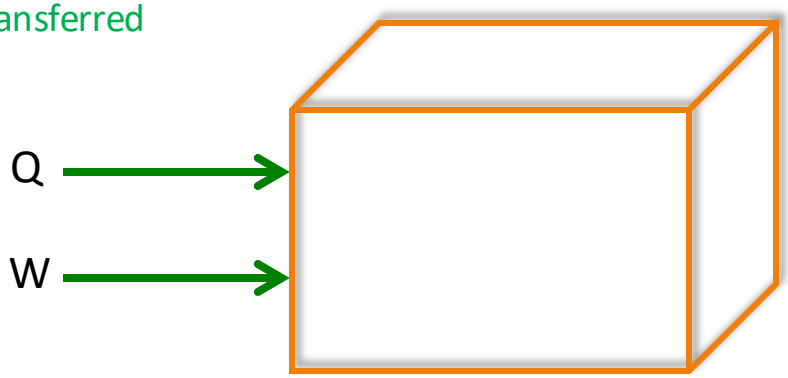
$$E_{accumulated} = E_{transferred}$$

Energy Balance on a Closed System

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

$$E_{accumulated} = E_{transferred} = \Delta E$$

$$\Delta E = Q - W$$



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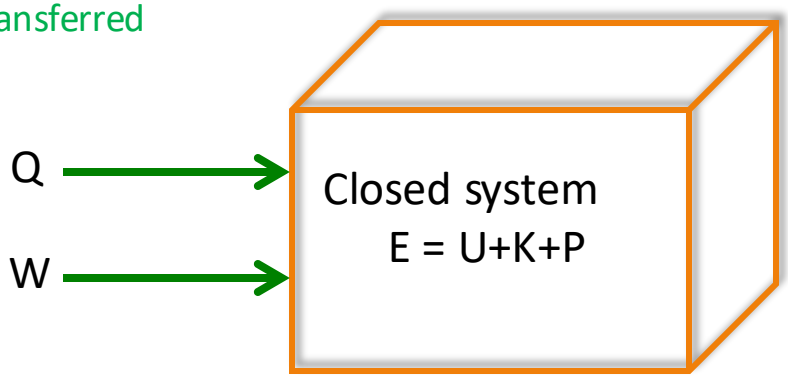


The total energy (E) may be regarded as composed of many forms. Obvious contributions to the total energy arise from the internal, kinetic and potential energies

$$Q - W = \Delta U + \Delta E_k + \Delta E_p$$

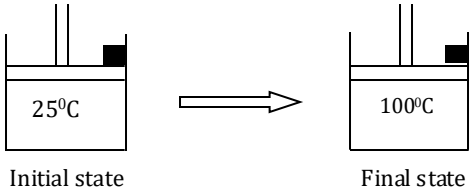
- ΔE_p is change in potential energy
- Q is heat transferred to the system
  - If the system is adiabatic, there is neither gain by the system not heat loss and Q is zero
- W is work done by the system
  - If there are no moving parts, then W=0

Example: Energy Balance on a Closed System

1 mole of gas contained in a cylinder fitted with movable position:

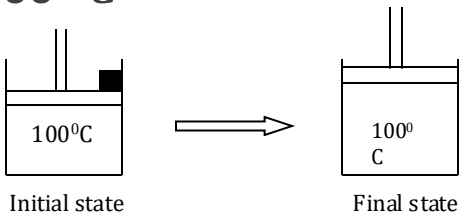
The cylinder is placed in boiling water and

I) Equilibrated: to 100 ^{o}C



II) The piston is then released, and the gas does 100 J of work to move the piston to its new equilibrium position.

The final gas temperature is 100 ^{o}C



Write and solve energy balances. For two stage with assuming:

- No changes in m, E_k & E_p
- Ideal gas
- $\hat{C}_v$ = 2 kcal.mol-1.k-1

Example: Energy Balance on a Closed System (Continued)

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

$E_{accumulated} = E_{transferred}$

$\Delta U + \Delta E_k + \Delta E_p = Q - W$

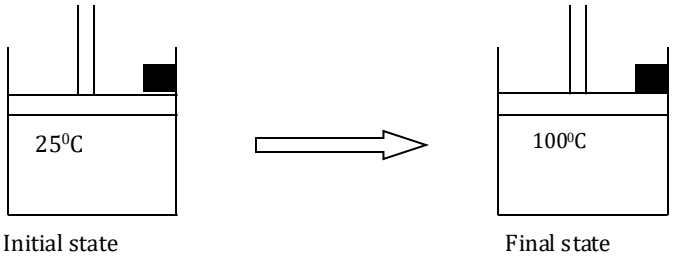
$m\,\Delta\hat{U} + m\,\Delta\hat{E}_k + m\,\Delta\hat{E}_p = Q - W$

$m\,(\hat{U}_f - \hat{U}_i) + m\,(\hat{E}_{k,final} - \hat{E}_{k,initial}) + m\,(\hat{E}_{pf} - \hat{E}_{pin}) = Q - W$ (0, 0, 0)

$m\,(\hat{U}_f - \hat{U}_i) = m\,\Delta\hat{U} = Q$

$\Delta\hat{U} = \hat{C}_v\,(\Delta T) = 2.\ 75\ k = 150\ kcal = 627.6\ kJ$

$\hat{C}_v$ for 1 mol of gas= $2\ kcal.mol^{-1}.k^{-1} \cdot 1\ mol = 2\ kcal.k^{-1}$



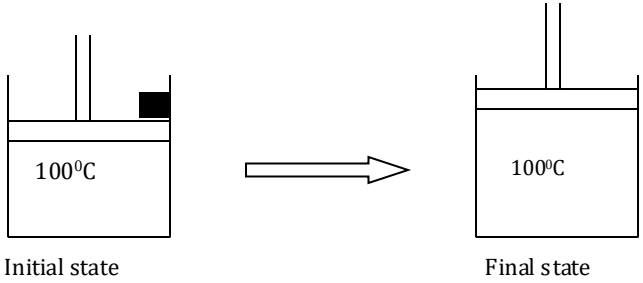
- No changes in m, E_k & E_p
- Ideal gas
- $\hat{C}_v$ = 2 kcal.mol-1.k-1

II) $U_{final} = U_{initial}$, because $\Delta T = 0$

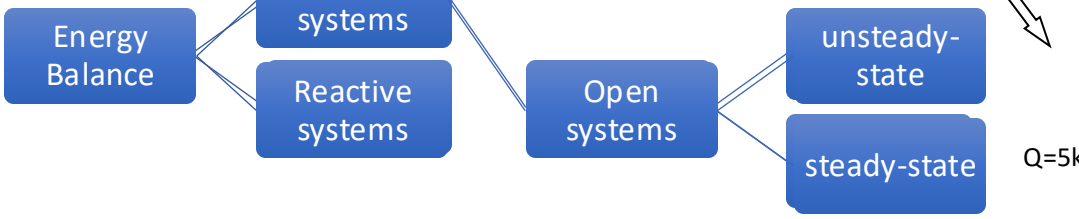
$\Delta U + \Delta E_k + \Delta E_p = Q - W$ (0, 0, 0) boundaries move so W =/= 0!

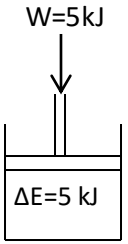
$\Rightarrow 0 = Q - W \Rightarrow Q = W = 100\ J > 0$

What does Q > 0 mean? The system further absorbs energy in form of heat to do work

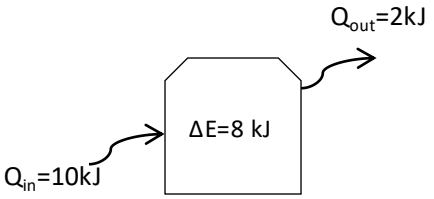


Examples of closed systems

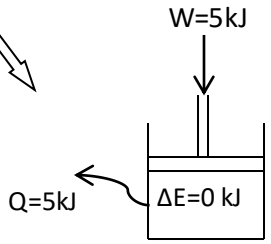




Compressing a gas in a cylinder



Heating water in a closed vessel



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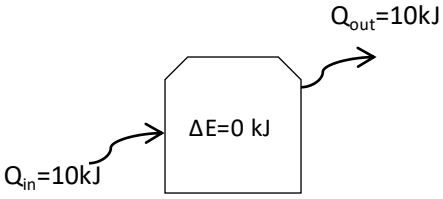
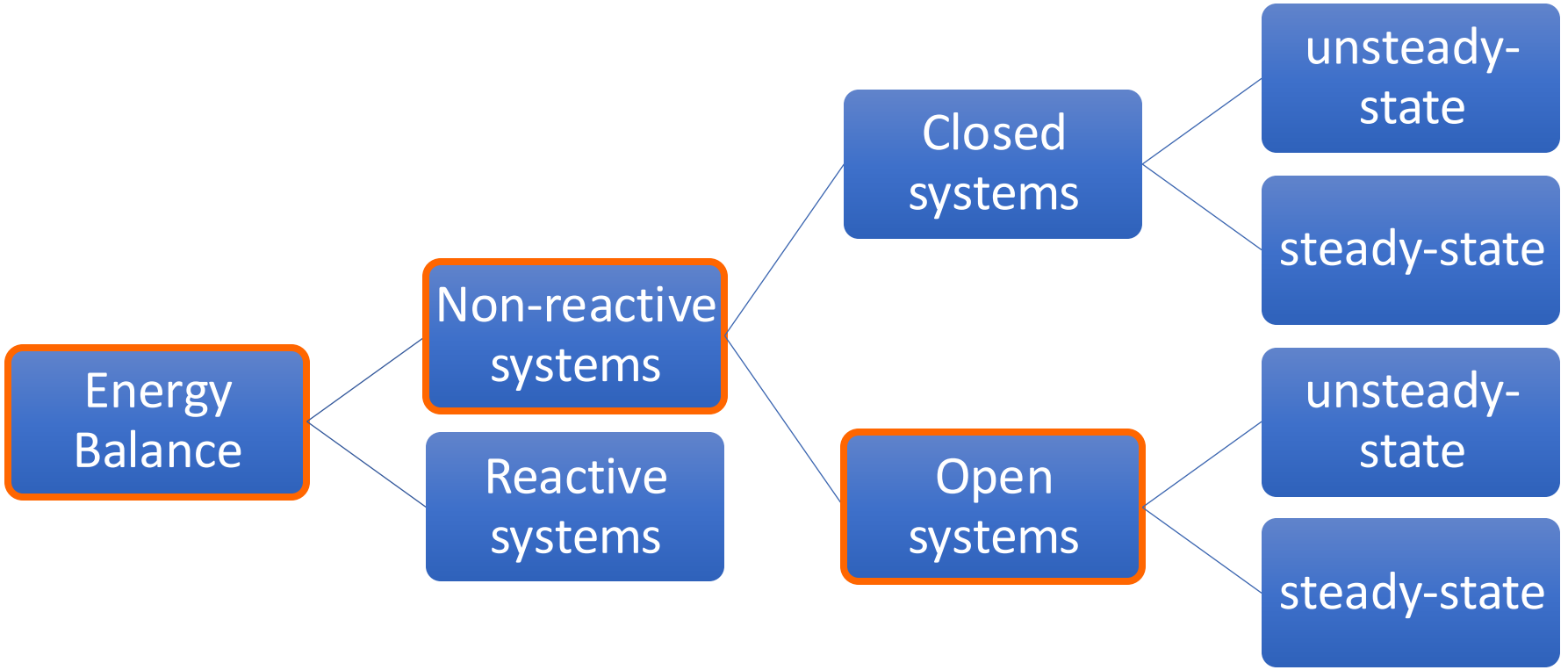


Heating water in a closed vessel

3. Energy balances on open non-reactive systems

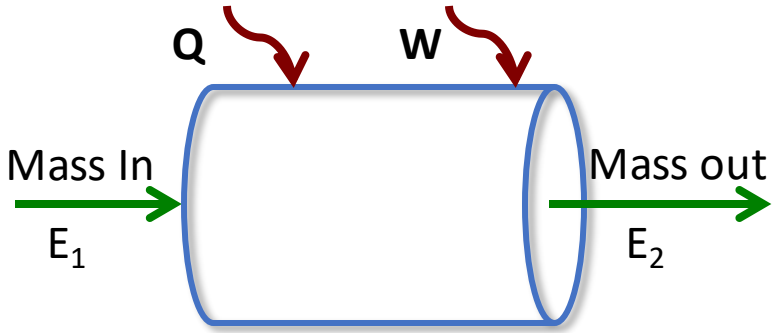
Energy balances on open non-reactive systems



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

Energy Balance on an Open System

A system is open if mass crosses the system boundary



law of conservation of energy:

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

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

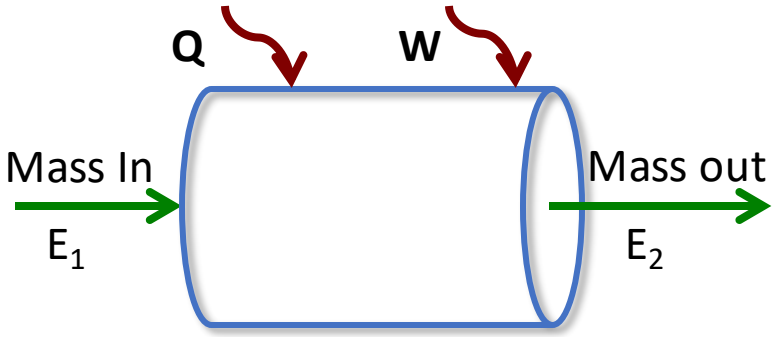
$$E_{transfer} = Q - W$$

$$\overline{m}_{sys}\, \hat{E}_{acc} = \overline{m}_{in}\, \hat{E}_1 - \overline{m}_{out}\, \hat{E}_2 + Q - W$$

(hat indicates energy per unit mass)

Energy Balance on an Open System

$$\dot{m}_{sys}\hat{E}_{acc} = \dot{m}_{in}\hat{E}_1 - \dot{m}_{out}\hat{E}_2 + Q - W$$



- For such a system, work must be done on the fluid mass to push it into the system; flow work
- Work could also be done by the fluid mass on moving parts of the system (example: steam driving a turbine); shaft work

$$W = W_s + W_{fl}$$

Accumulation=0

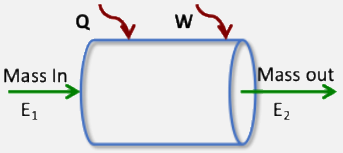
$$\dot{m}_1(\hat{U}_1 + \hat{E}k_1 + \hat{E}p_1) - \dot{m}_2(\hat{U}_2 + \hat{E}k_2 + \hat{E}p_2) + \dot{Q} - (W_s + W_{fl})$$

$m_1 = m_2 = m$

if W_s, E_k, E_p =0

$$\dot{m}\,D\hat{U} + Q - W_{fl} = 0$$

What is W_{fl}?



Work required to push the mass in = $P_{in} V_{in}$ ($N/m_2 * m^3 = N.m = J$)

Work done by the fluid exiting the system = $P_{out} V_{out}$

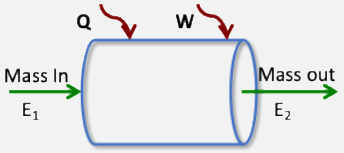
The net rate of work done by the system = $W_{fl} = P_{out} V_{out} - P_{in} V_{in}$

$$\dot{m}\,D\hat{U} + \dot{Q} - W_{fl} = \dot{m}_1\,\hat{U}_1 - \dot{m}_2\,\hat{U}_2 + \dot{Q} - P_{out}V_{out} + P_{in}V_{in} = 0$$

$P_{out} V_{out}$ → Work done <u>by</u> system to push **out**

$P_{in} V_{in}$ → Work done <u>on</u> system by pushing **in**

Definition of Enthalpy



$$\dot{m}\,\mathrm{D}\hat{U} + \dot{Q} - W_{fl} = \dot{m}_1\,\hat{U}_1 - \dot{m}_2\,\hat{U}_2 + \dot{Q} - P_{out}V_{out} + P_{in}V_{in} = 0$$

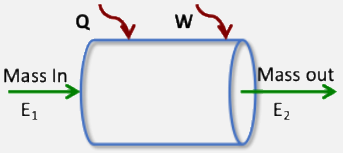
$$\dot{m}_1\,\hat{U}_1 - \dot{m}_2\,\hat{U}_2 + \dot{Q} - \dot{m}_2 P_2 \hat{V}_2 + \dot{m}_1 P_1 \hat{V}_1 = 0$$

$$\Rightarrow \quad \dot{m}_1(\hat{U}_1 + P_1\hat{V}_1) - \dot{m}_2(\hat{U}_2 + P_2\hat{V}_2) + \dot{Q} = 0$$

$$\hat{U} + P\hat{V} = ?$$

$$\dot{m}_1\hat{H}_1 - \dot{m}_2\hat{H}_2 + \dot{Q} = 0$$

Definition of Enthalpy



$$\hat{U} + P\hat{V} = ? \Rightarrow \hat{U} + P\hat{V} = \hat{H} \qquad \dot{m}_1\hat{H}_1 - \dot{m}_2\hat{H}_2 + \dot{Q} = 0$$

- **So, using the enthalpy of streams takes into account the W_{fl} for streams in** open systems

- Û is specific internal energy, P is pressure, and $\hat{V}$ is specific volume
- It is not possible to know or estimate the absolute values of **internal energy and enthalpy**. We need to <u>find only the change in these properties</u> to make an energy balance
- The general energy equation for an open system with flow work, shaft work, kinetic energy changes, potential energy changes and heat transfer becomes:

$$\Delta\dot{H} + \Delta\dot{E}_k + \Delta\dot{E}_P = \dot{Q} - \dot{W}_s$$

Remarks

Closed system : $\Delta U + \Delta E_k + \Delta E_p = Q - W$

Open system: $\Delta\dot{H} = \Sigma_{out}\, \dot{n}_i \hat{H}_i - \Sigma_{in}\, \dot{n}_i \hat{H}_i$ or $\Delta\dot{H} = \Sigma_{out}\, \dot{m}_i \hat{H}_i - \Sigma_{in}\, \dot{m}_i \hat{H}_i$

Open system : $\Delta\dot{H} + \Delta\dot{E}_k + \Delta\dot{E}_P = \dot{Q} - \dot{W}_s$

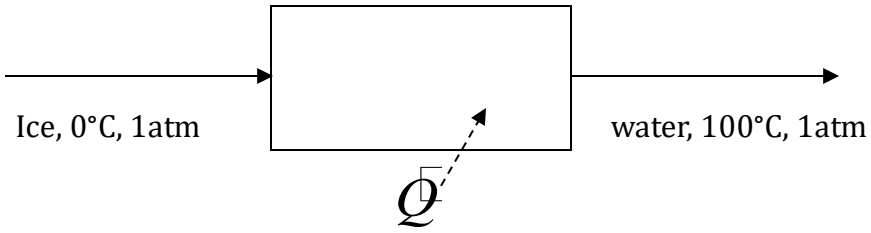
ΔU only depends on the temprature: $\Delta\hat{U} = \int_{T1}^{T2} (C_v)_T \, dT$

so for <u>constant T</u>: $\Delta U = 0 \rightarrow \Delta H = \Delta U + \Delta(PV) = V\Delta P$

For the ideal gas, liquds and solids:

- For the solids and liquds : $C_p = C_v$
- For the gases : $C_p = C_v + R$ (from thermodynamics course!)

Example: Energy balance on an open system



The process is st.st and it reach to a final stable situation

$\dot{Q}$= ? Kcal / min kg H_2O

$$\Delta \dot{H} + \Delta \dot{E}_k + \Delta \dot{E}_p = \dot{Q} - \dot{W}_s$$

$$\dot{m}_{out}\,\hat{H}_{out} - \dot{m}_{in}\,\hat{H}_{in} = \dot{Q}$$

$$\rightarrow \quad \dot{Q}/\dot{m} = \hat{H}_{out} - \hat{H}_{in}$$

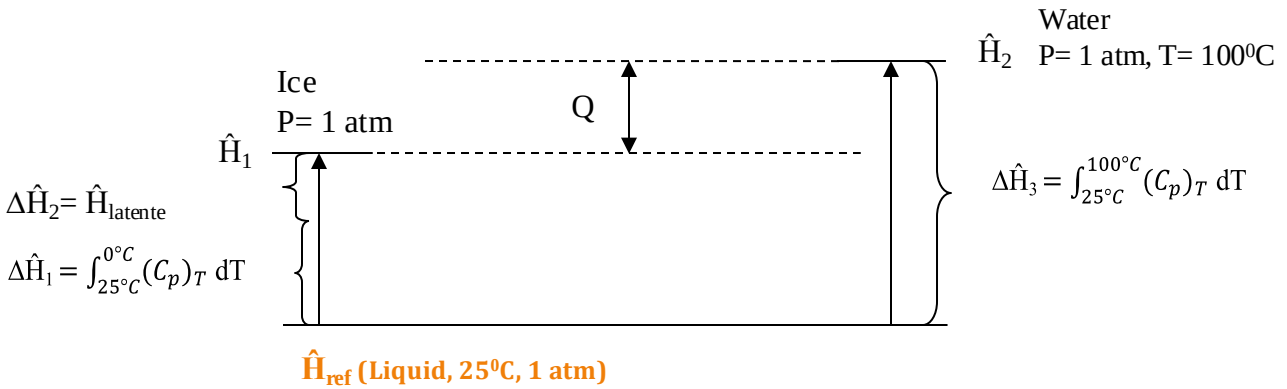
For a system with one flux in and one flux out without any accumulation: the mass in the system $\dot{m}_{in} = \dot{m}_{out} = \dot{m}$

$$\dot{Q} / \dot{m} = \hat{H}_{out} - \hat{H}_{in}$$

- To **get the thermodynamic properties**
  - using the tables, for a substrate by knowing T and P, we get ($\hat{H}$, $\hat{U}$, V, $\hat{C}_p$, $\hat{C}_v$)
  - given information for the reference state (P,T)

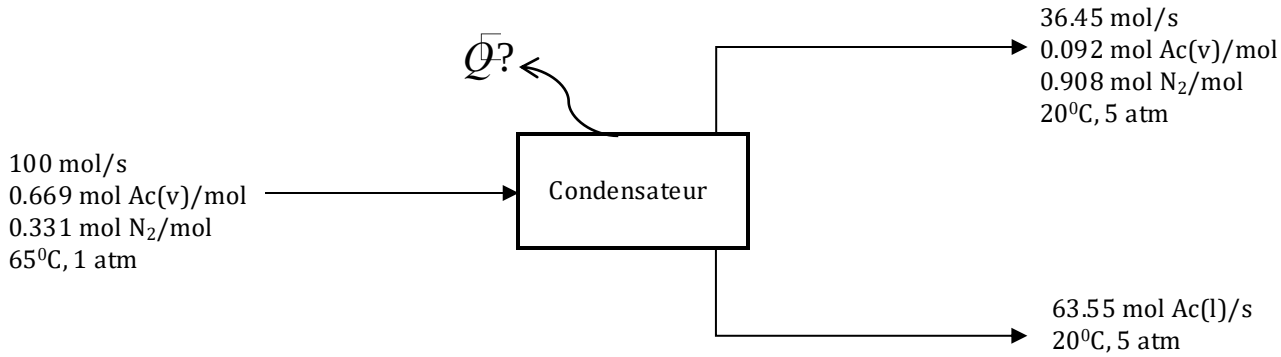
Species	$\dot{m}_{in}$ (mole/h)	$\hat{H}_{in}$ (KJ/mole)	$\dot{m}_{out}$ (mole/h)	$\hat{H}_{out}$ (KJ/mole)
$H_2O(s)$	$\dot{m}_1$	$\hat{H}_{water(s)}$ ($\hat{H}_1$)	–	–
$H_2O(l)$	–	–	$\dot{m}_2$	$\hat{H}_{water(l)}$ ($\hat{H}_2$)

- We need a **reference state** to calculate $\hat{H}$ for the corresponding T and P
  - $\hat{H}_1 = \Delta\hat{H}_1 + \Delta\hat{H}_2$
  - $\hat{H}_2 = \Delta\hat{H}_3$



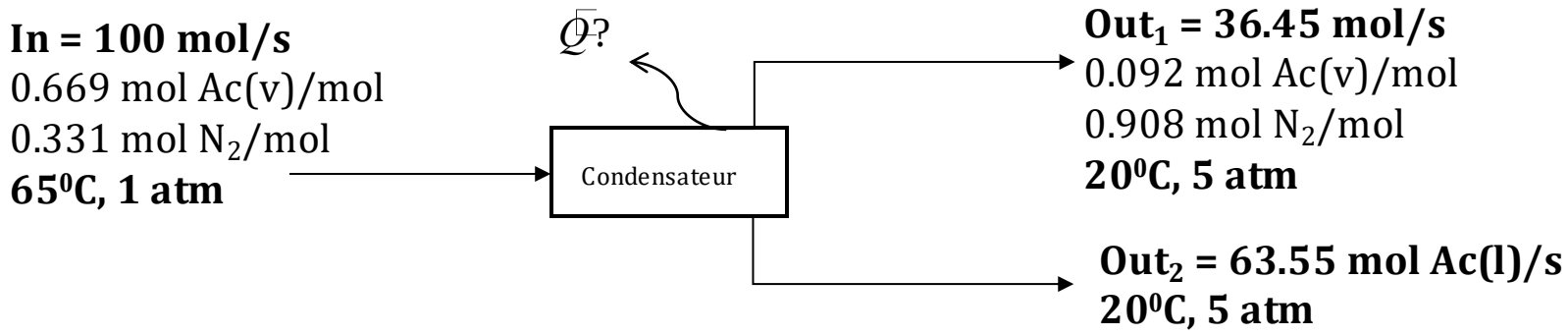
Example: Energy balance on a NR Open System

A mixture of Acetone and Nitrogen is entering in a cooling system (condenser) to separate the Acetone. based on the information given on the flowchart, calculate the Q needed to be removed from the system for this separation process.



1. Mass balance : already done
2. From the general **energy balance equation to the simplified system energy balance equation**

$$\Delta H + \Delta E_k + \Delta E_p = Q - W_s \xrightarrow{(\Delta E_k = 0,\ \Delta E_p = 0,\ \dot{W}_s = 0)} Q = \Delta H = \sum_{out} n_i \hat{H}_i - \sum_{in} n_i \hat{H}_i$$



3. Reference states (for each specie in the system):

Ac **(liq, 20°C, 5atm),** N_2 **(gas, 25°C, 1atm)**

4. Open systems → **inlet-outlet enthalpy table**

Species	$\dot{n}_{in}$ (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	$\hat{H}_4$

All the species in the system

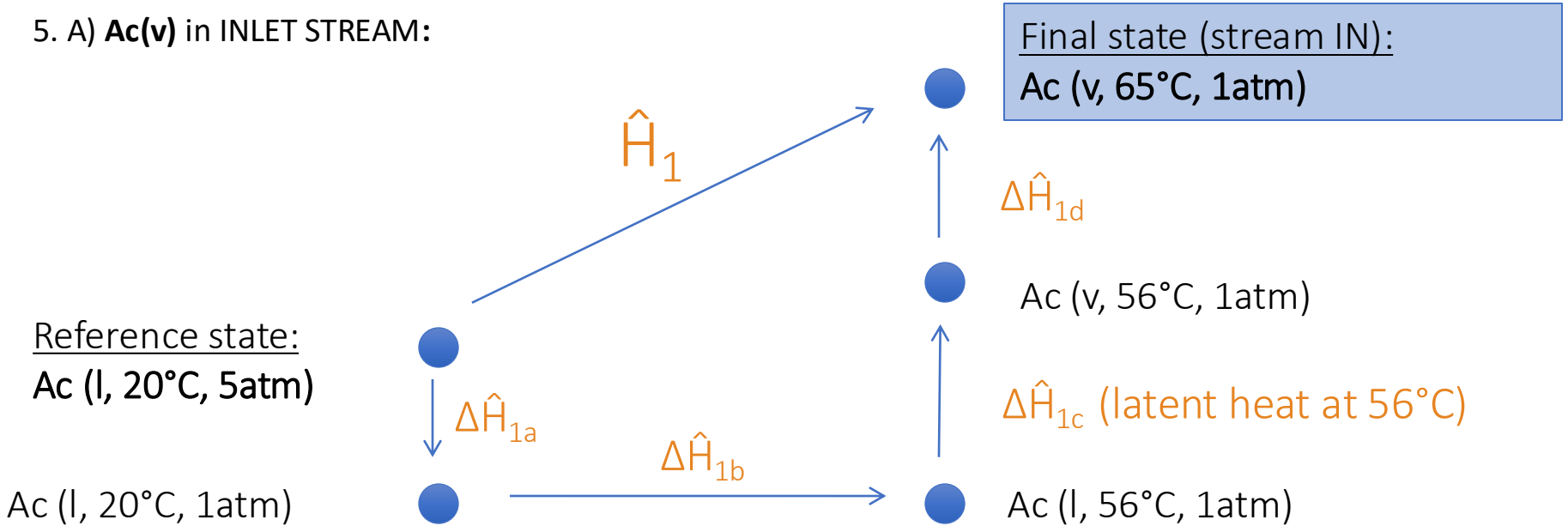
INLET stream(s): Flowrates and specific enthalpies*

OUTLET stream(s): Flowrates and specific enthalpies*

* $\hat{H}_i$ (specific enthalpy of specie i): should be calculated at the state of that specie in the inlet and outlet streams

5. Construct **process paths:** calculate the **specific enthalpies**

5. A) **Ac(v)** in INLET STREAM**:**



$\hat{H}_1 = \Delta\hat{H}$ for Ac (l,20°C, 5atm) → Ac (v, 65°C, 1atm)

$$\hat{H}_1 = \Delta\hat{H}_{1a} + \Delta\hat{H}_{1b} + \Delta\hat{H}_{1c} + \Delta\hat{H}_{1d}$$

Recalling: Enthalpy and internal energy are **state properties**. In other words, the change in enthalpy of a specie depends only on the final and initial states and not on how the final state is reached from the initial state, **they are path independent**

Ac (l, 20°C, 5atm) $\xrightarrow{\Delta\hat{H}_{1a}}$ Ac (l, 20°C, 1atm) $\xrightarrow{\Delta\hat{H}_{1b}}$ Ac (l, 56°C, 1atm) $\xrightarrow{\Delta\hat{H}_{1c}}$

Ac (v, 56°C, 1atm) $\xrightarrow{\Delta\hat{H}_{1d}}$ Ac (v, 65°C, 1atm)

CHANGE IN PRESSURE AT CONSTANT TEMPERATURE (LIQUID PHASE → CONSTANT VOLUME):

$\Delta\hat{H}_{1a} = \hat{V}\Delta P$ (the specific gravity of Ac is 0.791 and the MW is 0.058 kg/mol ,

so $\hat{V}$ = 0.0734 L/mol)

$$\Delta\hat{H}_{1a} = \frac{(-4\times10^5\ \mathbf{Pa}) \times (0.0734\times10^{-3}\ \mathbf{m^3/mol})}{1000} = -0.0297\mathbf{kJ/mol}$$

Pay attention to units! to find $\Delta\hat{H}_{1a}$ in KJ/mol, $\hat{V}$ should be in m^3/mol and ΔP in Pa

CHANGE IN TEMPERATURE AT CONSTANT PRESSURE (LIQUID PHASE):

- from table B.2: Ac (l) : C_p (*kJ/mol °C*) = 0.123 + 18.6 × 10^{-5} T, for T in °C

$$\Delta\hat{H}_{1b} = \int_{20°C}^{56°C} (C_p)_{Ac(l)}\ \mathrm{dT} = 4.68\ \mathrm{kJ/mol}$$

CHANGE OF STATE (LATENT HEAT) AT CONSTANT PRESSURE AND TEMPERATURE:

$\Delta\hat{H}_{1c}$ = 30.2 kJ/mol (latent heat at boling point, from Table B.1)

CHANGE IN TEMPERATURE AT CONSTANT PRESSURE (GAS PHASE):

- from table B.2: Ac (v) : C_p (*kJ/mol°C*) = 0.07196 + 20.10 × 10^{-5} T – 12.78 × 10^{-8} T^2 + 34.76 × 10^{-12} T^3

$$\Delta\hat{H}_{1d} = \int_{56°C}^{65°C} (C_p)_{Ac(v)}\ \mathrm{dT} = 0.753\ \mathrm{kJ/mol}$$

$\hat{H}_1$ = (-0.0297 + 4.68 + 30.2 + 0.753) = 35.6 kJ/mol

5. A) **N_2** in INLET STREAM**:**

$\hat{H}_2 = \Delta \hat{H}$ for N_2 (g, 25°C, 1atm) → N_2 (g, 65°C, 1atm)

CHANGE IN TEMPERATURE AT CONSTANT PRESSURE (GAS PHASE):

From Table B.2: $C_{p,N2,g} = 0.029 + 0.2199 \times 10^{-5}T + 0.5723 \times 10^{-8}T^2 - 2.871 \times 10^{-2}T^3$

$$\hat{H}_2 = \int_{25°C}^{65°C} (C_p)_{N2(g)}\, dT = 1.16\ \text{kJ/mol}$$

5. B) **Ac(v)** in OUTLET STREAM**:**

CHANGE OF STATE (LATENT HEAT) AT CONSTANT PRESSURE AND TEMPERATURE:

$\hat{H}_3 = \Delta\hat{H}$ for Ac (l, 20°C, 5atm) → Ac (v, 20°C, 5atm)

$\hat{H}_3$ = 32 kJ/mol (creating a path, since we only have the latent heat at the b.p.)

5. B) **N_2** in OUTLET STREAM**:**

$\hat{H}_4 = \Delta\hat{H}$ for N_2 (g, 25°C, 1atm) → N_2 (g, 20°C, 5atm)

$\hat{H}_4$ = N_2 (g, 25°C, 1atm) → N_2 (g, 20°C, 1atm) → N_2 (g, 20°C, 5atm)

CHANGE IN TEMPERATURE AT CONSTANT PRESSURE (GAS PHASE):

$$\hat{H}_4 = \int_{25°C}^{20°C} (C_p)_{N2(g)}\, dT = -0.1\ \text{kJ/mol}$$

CHANGE IN PRESSURE AT CONSTANT TEMPERATURE (GAS PHASE):

For N_2 (g, 20°C, 1atm) → N_2 (g, 20°C, 5atm) there is a very small change of enthalpy that can be neglected

6. **Solve the simplified energy balance** equation:

$$\dot{Q} = \Delta H = \sum_{out} n_i \hat{H}_i - \sum_{in} n_i \hat{H}_i$$

Species	$\dot{n}_{in}$ (mol/s)	$\hat{H}_{in}$ (kJ/mol)	$\dot{n}_{out}$ (mol/s)	$\hat{H}_{out}$ (kJ/mol)
Ac(v)	66.9	$\hat{H}_1 = 35{,}6$	3.35	$\hat{H}_3 = 32$
Ac(l)	–	–	63.55	0
N_2	33.1	$\hat{H}_2 = 1{,}16$	33.1	$\hat{H}_4 = -0{,}1$

$$\Delta\dot{H} = [(3.35)(32.0) + (63.55)(0) + (33.1)(-0.10)]\ \text{kJ/s} + \ldots$$

$$\ldots - [(66.9)(35.6) + (33.1)(1.16)]\ \text{kJ/s} = -2320\ \text{kJ/s}$$

$$\Delta H = Q = -2320\ \text{kJ/s} = -2320\ \text{kW}$$

Thermodynamics data

- **Enthalpy and internal energy** are state properties. In other words, the change in enthalpy of a species depends only on the final and initial states and not on how the final state is reached from the initial state, **they are path independent**

- Enthalpy and internal energy of species could be tabulated with respect to a **reference state** (temperature, pressure and phase)

- There are **"tables"** at the end of the book that the thermodynamic properties can be looked up from them instead of calculating them every time

- You should get used to knowing how to **read these tables**!!

Procedure for Energy Balance Calculations

1. Make **material balance** calculations and find **flow rates** (or masses) of all streams

2. Write the generalized **energy balance equation** and cancel all the terms that are either zeros or can be neglected

3. Choose **reference states for each specie** involved. By reference state we mean **T, P and the phase** of the species. A proper choice of the reference states enables easy calculation of enthalpies and hence, energy balances

4. For **open systems**: construct an **inlet-outlet enthalpy table** with mass or molar flow rates

   For **closed systems**: the table should contain **initial-final amounts of species** and **internal energies**

5. Estimate the specific enthalpies or internal energies and insert the values in the Table constructed in step 4. You need to **construct process paths to determine specific enthalpies and internal energies**

6. **Solve** the simplified **energy balance** equation (from step 2) and calculate the unknowns