BT209

Bioreaction Engineering

12/04/2023

Heterogeneous reaction:
immobilized enzyme , immobilized cell

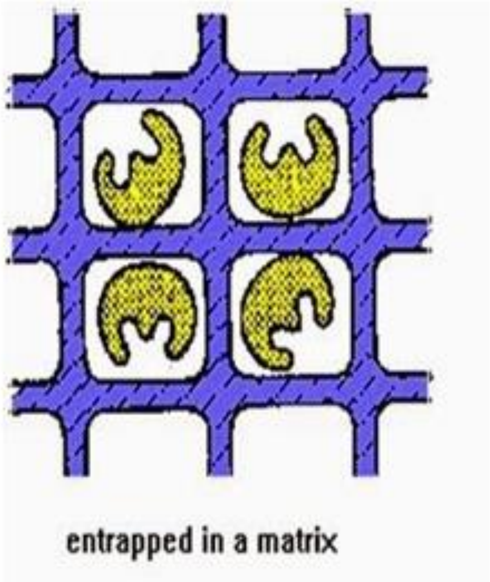
Heterogeneous reaction

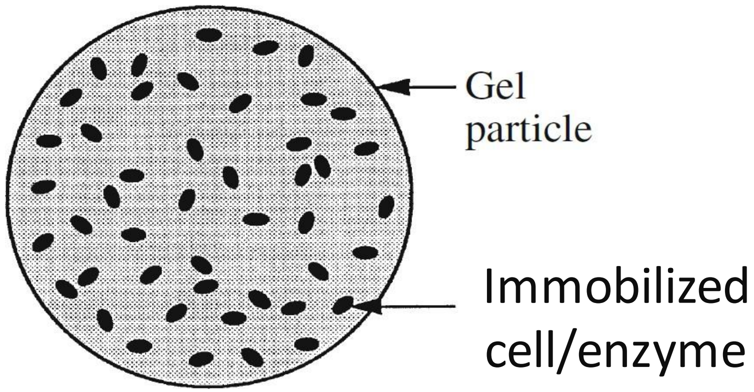
- Heterogeneous reactions occur in solid catalysts, not all reactive molecules are available for immediate conversion. Reaction takes place only after the reactants are transported to the site of reaction.

- Thus, mass transfer processes can have a considerable influence on the overall conversion rate.

- Reactions occurring in the presence of significant concentration or temperature gradients are called heterogeneous reactions.

- Here consider only concentration effect as biological reactions are not typically associated with large temperature gradients





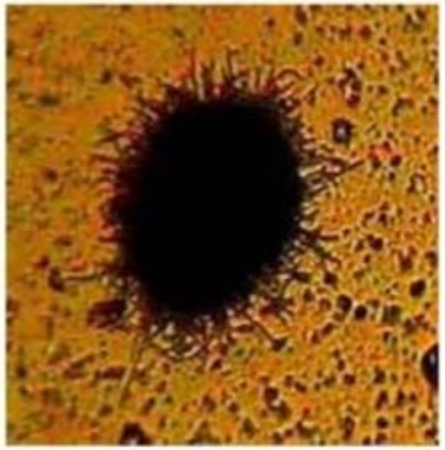
Heterogeneous reaction in bioprocessing

Natural process

- Macroscopic flocs, clumps and pellets by certain filamentous bacteria and fungi
    - Mycelial pellets are common in antibiotic production

Free dispersed mycelium cell

clump formation



Pellet formation

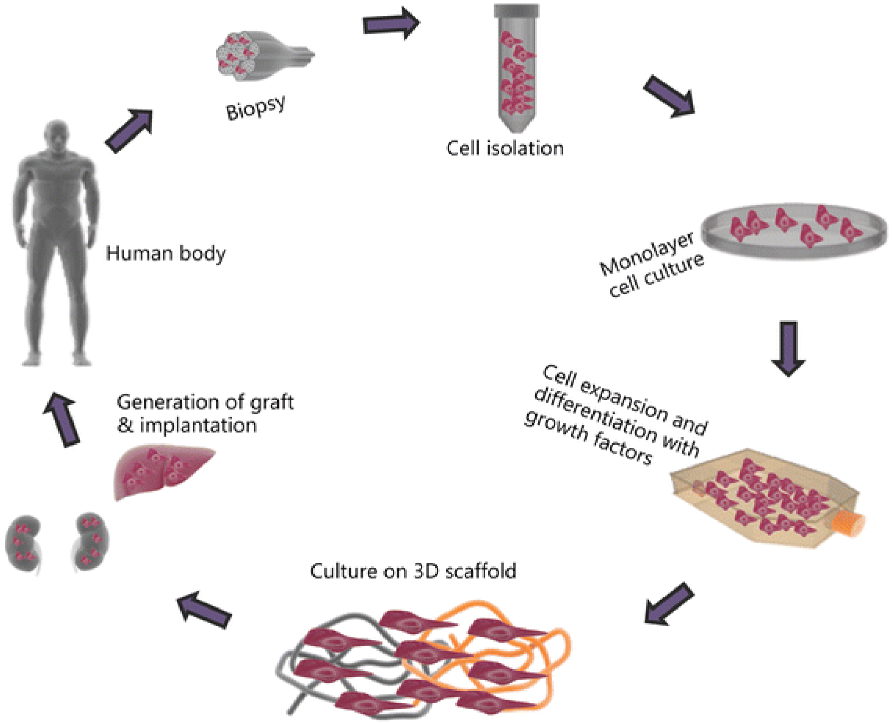
- Cells grow as biofilm on reactor walls
- Used in waste treatment process

Cont.

❑ Natural process

- Plant cells tend to form aggregates in suspension culture and their growth results in the change in cell aggregate sizes
  - ➢ The aggregation of the plant cells can also stimulate the secondary metabolite production (therapeutic product)

- In tissue engineering animal cell are culture in a 3D scaffolds for surgical transplantation and organ repair

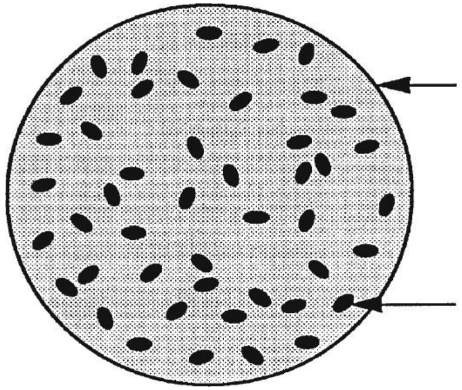


✓ **Rate of reaction depends on the rate of reactant mass transfer outside and within the solid catalyst**

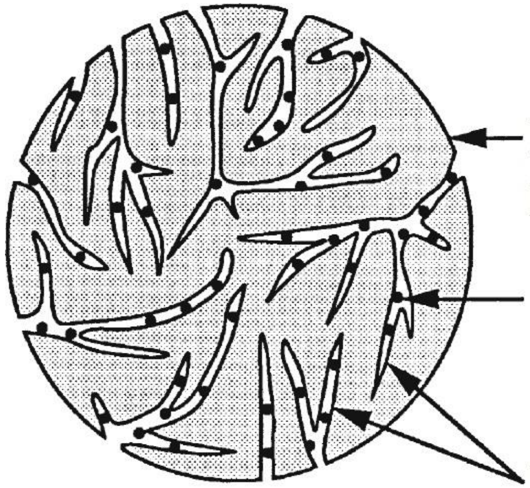
Artificial immobilization: Heterogeneous reaction in bio-processing

- **Induced to heterogeneous system (artificial immobilization)**

- Cell/enzyme immobilization
  - To reuse the enzyme or biocatalyst



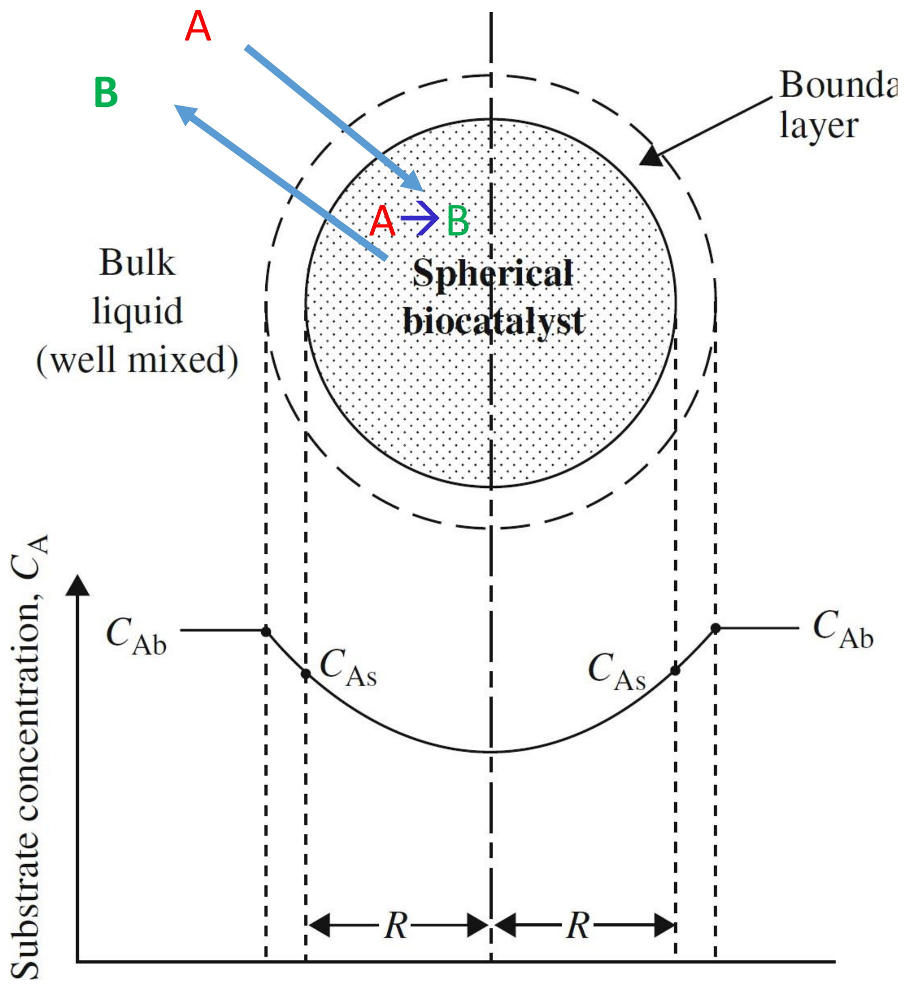
- Entrapment within gel such as alginate, agarose (crossed linked)
- Gel polymer must be porous and relatively soft to allow diffusion of reactants and products



- Entrapment within porous solids such as ceramics, porous glass, and resin bed
- Enzyme or cells migrate into the pores of these particles and attach to the internal beads (Adsorption)

Concentration gradient and reaction in solid catalyst

- A spherical biocatalyst immersed in well mixed liquid (contain substrate/reactant A)
- In bulk (away from particle) uniform concentration, C_{Ab}
- If particle inactive (no enzyme or cell), no consumption of A. the concentration of substrate inside the solid would reach a constant value in equilibrium with C_{Ab}
- If active (with enzyme/cell), C_A decreases within the particle.
- If uniform distribution of enzyme or cell, symmetric concentration profile with minimum at centre.
- Convective transport in bulk (NOT INSIDE SOLID)
- External diffusion through stagnant boundary layer (liquid film)
- Internal diffusion through internal pores



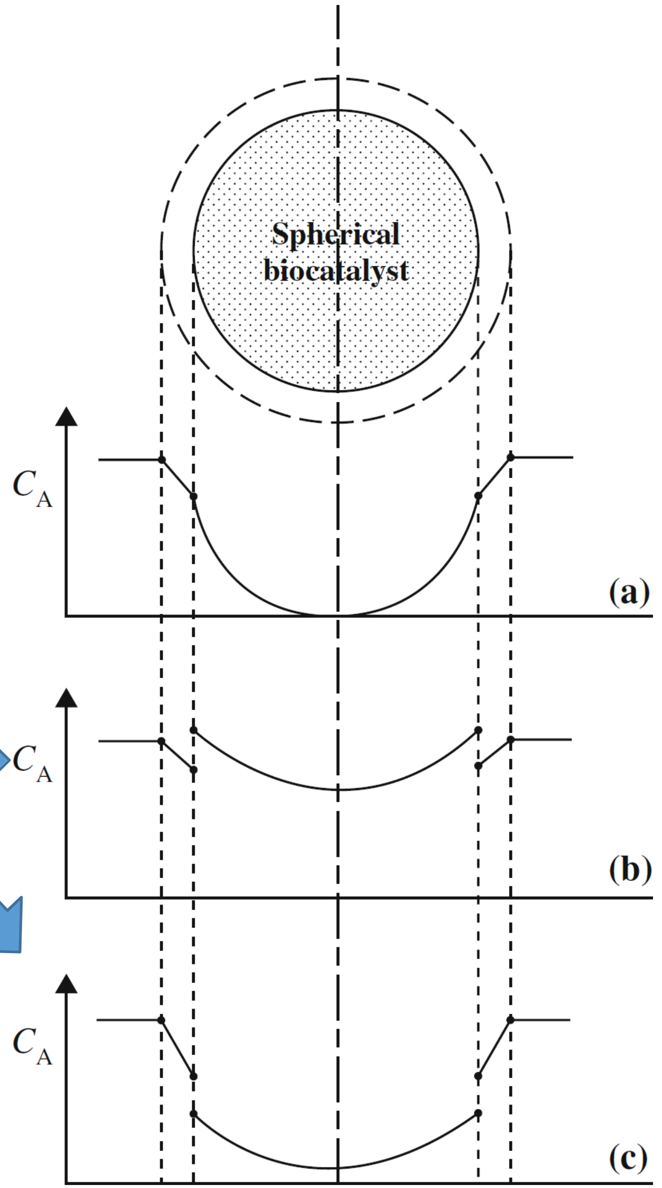
Cont.

- If mass transfer is much slower than reaction:
  - -all the substrate entering the particle may be consumed before reaching the center. The concentration falls zero within the particle and the core of particle become inactive

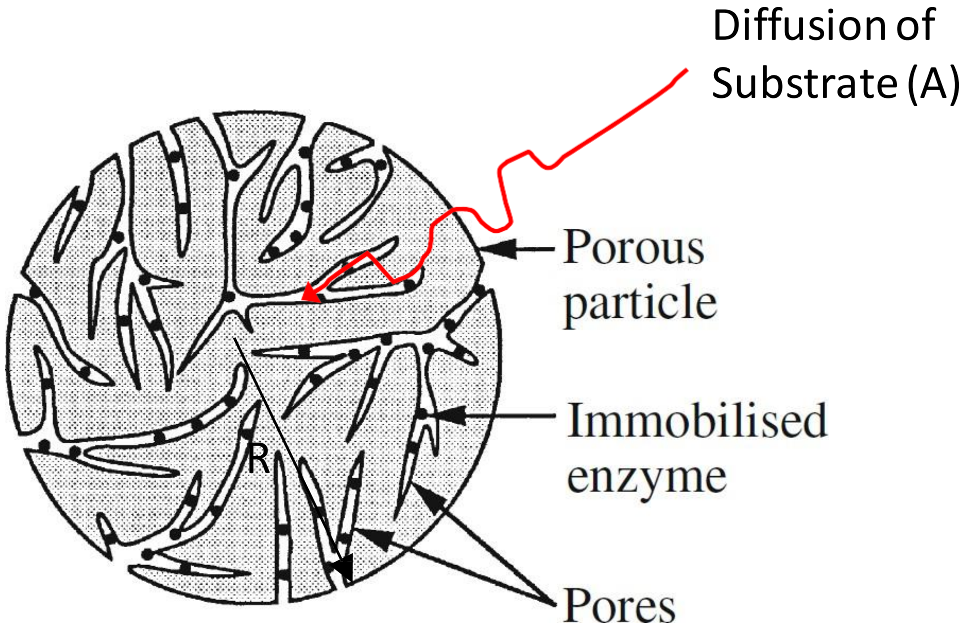
- Partition coefficient or distribution coefficient is not equal to one
  - - at equilibrium and in the absence of reaction the concentration of A in the solid is higher or lower than in the liquid

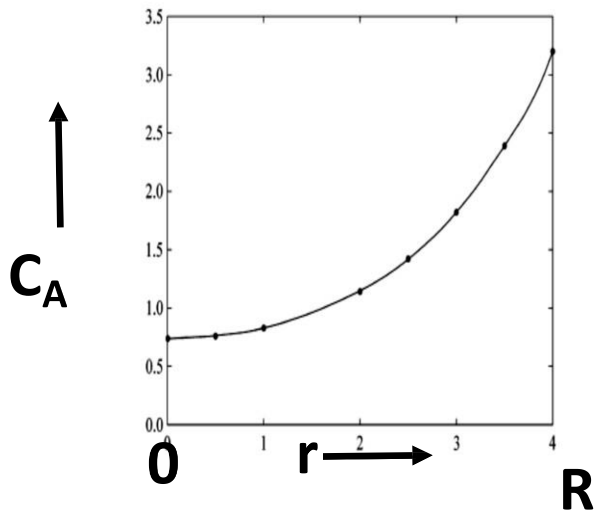
- Partitioning is important when A and solid are charged of if strong hydrophobic interaction cause repulsion or attraction.

- Most materials used for immobilization are very porous and contain high % water, partition effect can be neglected



True and observed reactionrate





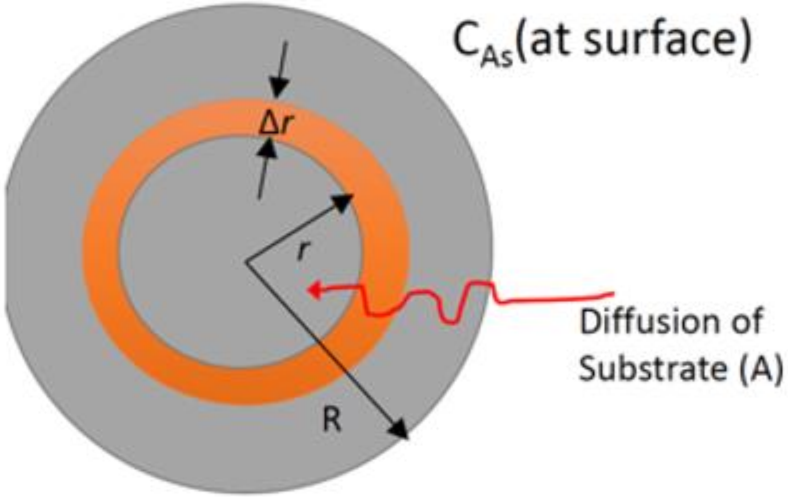
- Rate of reaction =f (C_A, T)
- Assume T (temperature) is not changing significantly here
- Rate of reaction depends on local C_A
- Normal rate expression can be used for **local rate of reaction** (**true reaction rate** in each point) like homogeneous reaction

$$r_A = kC_A{}^n \qquad r_A = \frac{v_{max}\, C_A}{K_m + C_A}.$$

- Very difficult to measure rate of reaction in each point (difficult to know local C_A)
- Measure overall reaction (observed) rate

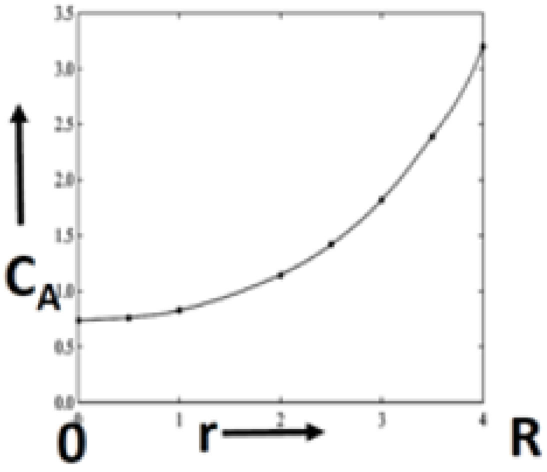
Cont.

- Concentration is changes across radius (r), C_A=f(r)
- Rate, r_A=K f(C_A) is different in different radial position



$$r_{A,obs} = \frac{4}{3}\pi R^3 \frac{\int_0^R r_A \, dV}{V - 0}$$

V: volume



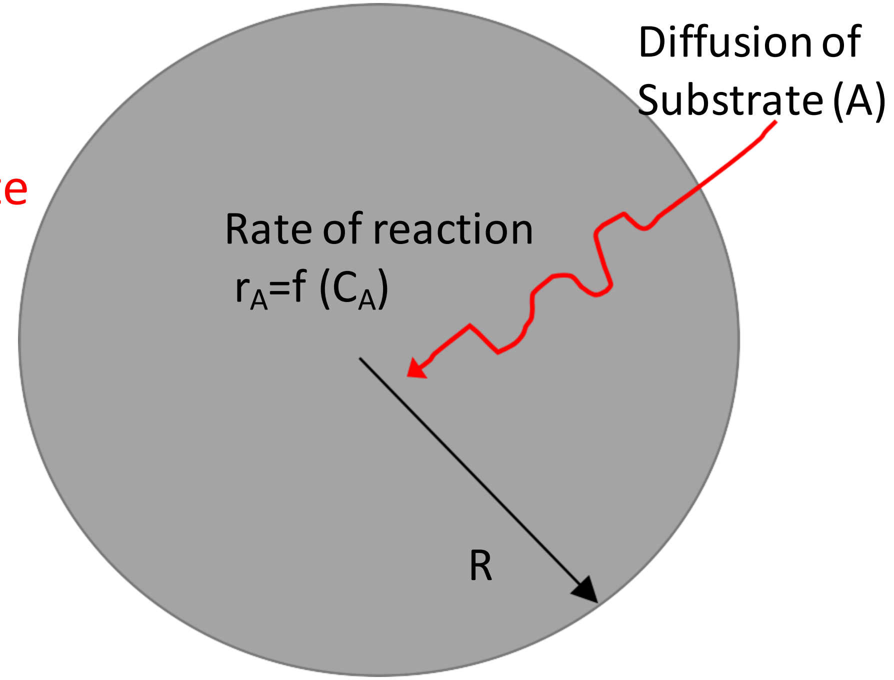
Internal mass transfer and reaction in heterogeneous systems

- Rates of reaction and substrate mass transfer are not independent

- The rate of mass transfer depends on the concentration gradient established in the system; this in turn depends on the rate of substrate depletion by reaction.

- On the other hand, the rate of reaction depends on the availability of substrate, which depends on the rate of mass transfer.

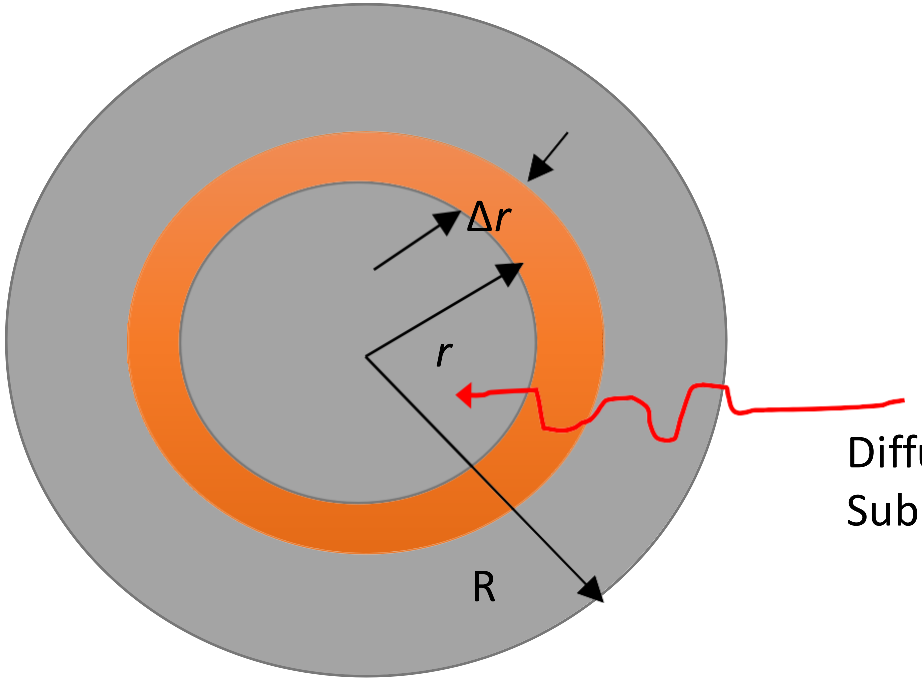
- Possible to determine the relative influences of mass transfer and reaction on observed reaction rates.



- If a reaction proceeds slowly even in the presence of adequate substrate, it is likely that mass transfer will be rapid enough to meet the demands of the reaction. In this case, the observed rate would reflect more directly the reaction process rather than mass transfer.

- Conversely, if the reaction tends to be very rapid, it is likely that mass transfer will be too slow to supply substrate at the rate required. The observed rate would then reflect strongly the rate of mass transfer.
- Improving mass transfer and eliminating mass transfer restrictions are desired objectives

Internal mass transfer and reaction



Assumption

- ✓ The particle is isothermal
- ✓ The particle is homogeneous
- ✓ Mass transfer occurs by diffusion only
- ✓ Diffusion can be described using Fick's law with constant effective diffusivity
- ✓ The substrate partition coefficient is unity
- ✓ The particle is at steady state

<u>For a shell mass balance on substrate A</u>

Rate of mass accumulation

= Rate of mass in - rate of mass out + rate mass of generation - rate of mass consumption

$$\left(\mathscr{D}_{Ae}\frac{dC_A}{dr}4\pi r^2\right)\Bigg|_{r+\Delta r} - \left(\mathscr{D}_{Ae}\frac{dC_A}{dr}4\pi r^2\right)\Bigg|_{r} + 0 - r_A 4\pi r^2 \Delta r = 0$$

D_{Ae} is the effective diffusivity of substrate A in the particle

Internal mass transfer and reaction

$$\left(\mathscr{D}_{Ae}\frac{dC_A}{dr}4\pi r^2\right)\Big|_{r+\Delta r} - \left(\mathscr{D}_{Ae}\frac{dC_A}{dr}4\pi r^2\right)\Big|_{r} + 0 - r_A 4\pi r^2 \Delta r$$

$$\lim_{\Delta r \to 0} \frac{\left(\mathscr{D}_{Ae}\frac{dC_A}{dr}4\pi r^2\right)\Big|_{r+\Delta r} - \left(\mathscr{D}_{Ae}\frac{dC_A}{dr}4\pi r^2\right)\Big|_{r}}{\Delta r} - r_A r^2 = 0$$

$$\frac{d}{dC_A}\left(r^2\frac{dC_A}{dr}\right) - r_A r^2 = 0$$

$$\mathscr{D}_{Ae}\left(\frac{d^2C_A}{dr^2}r^2 + 2r\frac{dC_A}{dr}\right) - r_A r^2 = 0$$