UNIVERSITEIT TWENTE.

Multiphase Reactor Technology
Packed bed reactors

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Introduction

- Introduction
  - Definition of packed bed
  - Applications of packed bed
  - Variation of packed bed reactors
  - Packing materials
  - Flow regimes
  - Pressure drop
  - Liquid and gas hold-ups
  - Residence time distribution
  - Mass transfer coefficients
  - Transfer area

Introduction

Further reading

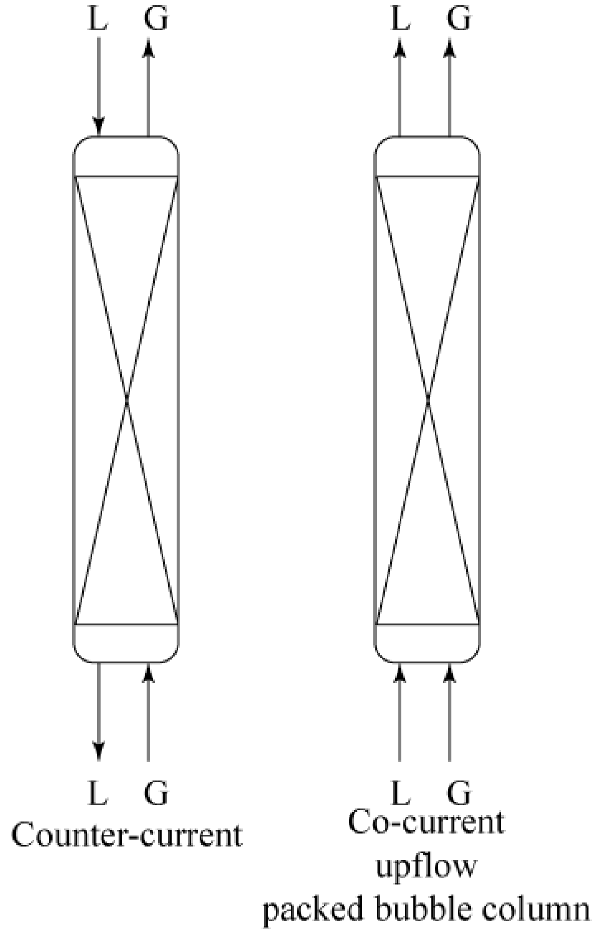
“Froment & Bischoff (chapter 14)”

“Gas-Liquid-Solid Reactor Design”, Y.T. Shah
Publisher: McGraw-Hill inc (1979)

“Multiphase chemical reactors”, A. Gianetto and P.L. Silveston

“Hydrodynamics in a cocurrent gas-liquid trickle-bed reactor at elevated pressures” WJA Wammes (UTwente dissertation 1990)

Introduction



Characteristics of packed bed

- Three operation modes:
  - Counter-current (L↑ and G↓)

  - Co-current upflow (L↑ and G↑)
    Packed bed column, liquid phase is the continuous phase

  - Co-current downflow (L↓ and G↓)
    Usually referred to as Trickle Bed Reactors

- Packing used for:
  - Creation interfacial contact area, inert material
  - Material catalytically active, application in three phase reactors (alternative for (fast reacting) slurry processes)

- Less hydrodynamic constraints compared to tray colums
- Phenomenon of dynamic and static liquid holdup

Characteristics of packed bed

Table 1-5 Advantages and disadvantages of trickle-bed reactors

Advantages

1. Flow is close to plug flow, allowing high conversion to be achieved in a single reactor.
2. Liquid-to-solid ratio is small, minimizing the homogeneous side reactions if possible.
3. Liquid flows as a film, thus offering very small resistance to the diffusion of gaseous reactant to the catalyst surface.
4. Flooding is not a problem. Pressure drop is lower than in cocurrent-upflow and countercurrent-flow reactors.
5. If temperature rise is significant, it may be controlled by recycling the liquid product or by the addition of "quenches" from the side of the reactor. The recycling of liquid would cause the reactor to behave more like a CSTR; hence, recycling will not be possible when high conversions are desired.
6. Can be operated as a partially or completely vapor-phase reactor. A trickle-bed reactor minimized the energy costs associated with reactant vaporization.
7. Lower pressure drop will allow an essentially uniform partial pressure of reactant across the length of the reactor.
8. In the commercial reactor, uniform distribution of gas and liquid are achieved. The catalyst is uniformly and effectively wetted by the liquid.

Disadvantages

1. Poor radial mixing of heat.
2. At low liquid flow rates, flow maldistributions such as channeling, bypassing, and incomplete catalyst wetting may occur. These adversely affect the reactor performance.
3. The catalyst particles cannot be very small. The intraparticle diffusion effects can be significant. The catalyst pore-mouth plugging can cause rapid deactivation.

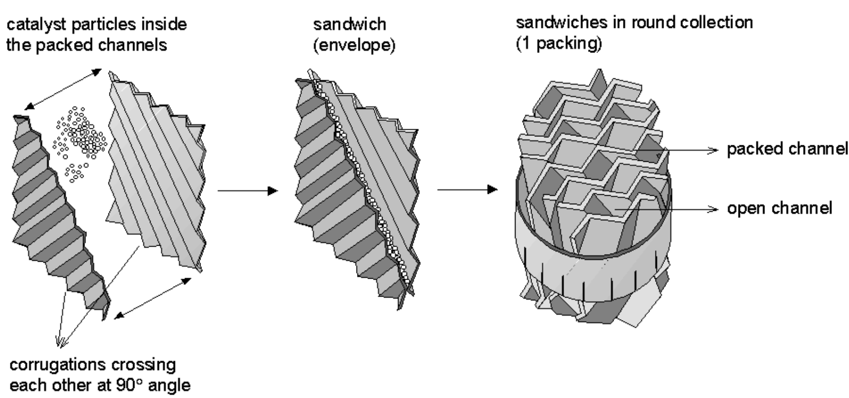
Characteristics of packed bed

Table 1-6 Upflow versus downflow cocurrent fixed-bed reactors

1. Larger pressure drop in an upflow reactor.
2. Better mixing in an upflow reactor. This may give better heat transfer, but larger axial mixing would give poorer conversion in an upflow reactor.
3. At low flow rates upflow behaves like a bubble column, i.e., gas as a dispersed phase, liquid as a continuous phase. In downflow trickle-bed operation, gas is a continuous phase and liquid flows as a film.
4. High pressure drop in an upflow reactor would cause significant drop in the partial pressure of the reactant across the length of the reactor.
5. Under similar flow conditions, a higher gas–liquid mass-transfer coefficient is obtained in an upflow operation than in a downflow operation.
6. High liquid holdup and liquid-to-solid ratio in an upflow reactor. High liquid holdup will offer more liquid-phase resistance to the mass transfer of the gaseous reactant to the catalyst surface. High liquid-to-solid ratio will give more importance to the role of possible homogeneous reactions.
7. At low liquid flow rates, upflow will provide better distribution of liquid and, thus, in many cases, better performance of the reactor than the downflow reactor under similar operating conditions.
8. If reaction is rapid and highly exothermic, heat transfer between liquid and solid is more effective in an upflow reactor.
9. In an upflow reactor, the catalyst must be kept in place by suitable mechanical methods, otherwise the bed will be fluidized. In a downflow reactor, the catalyst is held in place tightly by the flow. This may cause undesired cementation of the soft catalyst particles.
10. In an upflow reactor, the catalyst pores are more likely to fill completely with liquid than in a downflow reactor. The catalyst effectiveness factor is lower when the catalyst pores are completely filled with liquid compared to the case when they are only partially filled with liquid.
11. Better sweeping of the catalyst by liquid in an upflow reactor may sometimes give better aging of the catalyst. If a solid reactant is used (e.g., coal liquefaction) then an upflow would cause less solids plugging problems than the downflow operation.
12. In an upflow reactor, flooding may be a problem.

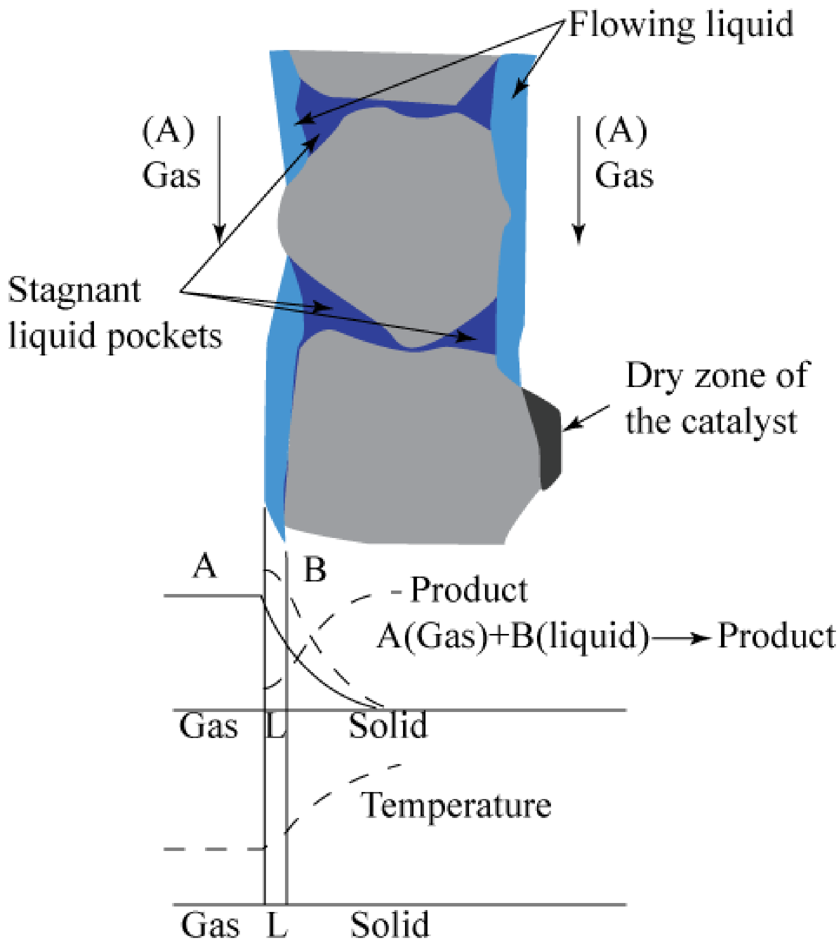
Packing configurations

- Various types of packing configurations



http://ct-cr4.chem.uva.nl/structuredbc/

Schematic presentation of the process



Design Features for Packed bed reactors

- Process information:
  - ✓ Kinetics
  - ✓ Equilibria/Thermodynamics
  - ✓ Physico-chemical constants

- Reactor information:
  - ✓ Knowledge of flow regime and flow uniformity
  - ✓ Wettability/Wetting Pressure drop
  - ✓ Volume reaction phase: Liquid hold-up
    Gas hold-up
    Solids hold-up
  - ✓ Residence time distribution (dispersion coefficients)
  - ✓ Mass Transfer: k_L k_G and a
    k_s and a_s
  - ✓ Heat Transfer

Homework

- Consider the hydrodesulphurization of oil in a trickle bed reactor
  - R-S(l) + H_2 (g)→ R(l)+ H_2S (g)

- Propose a 1D reactor model

- Find correlations for the hold-ups (specific areas), dispersion coefficients, what ever you need….