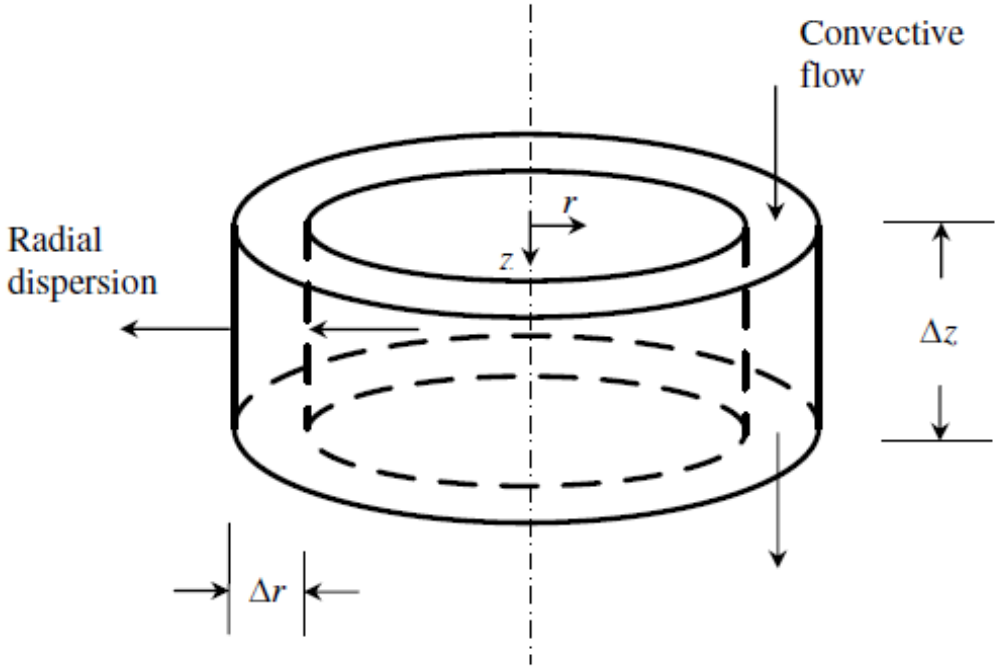
CHE 611
Advanced Chemical Reaction Engineering



Dr. Muhammad Rashid Usman

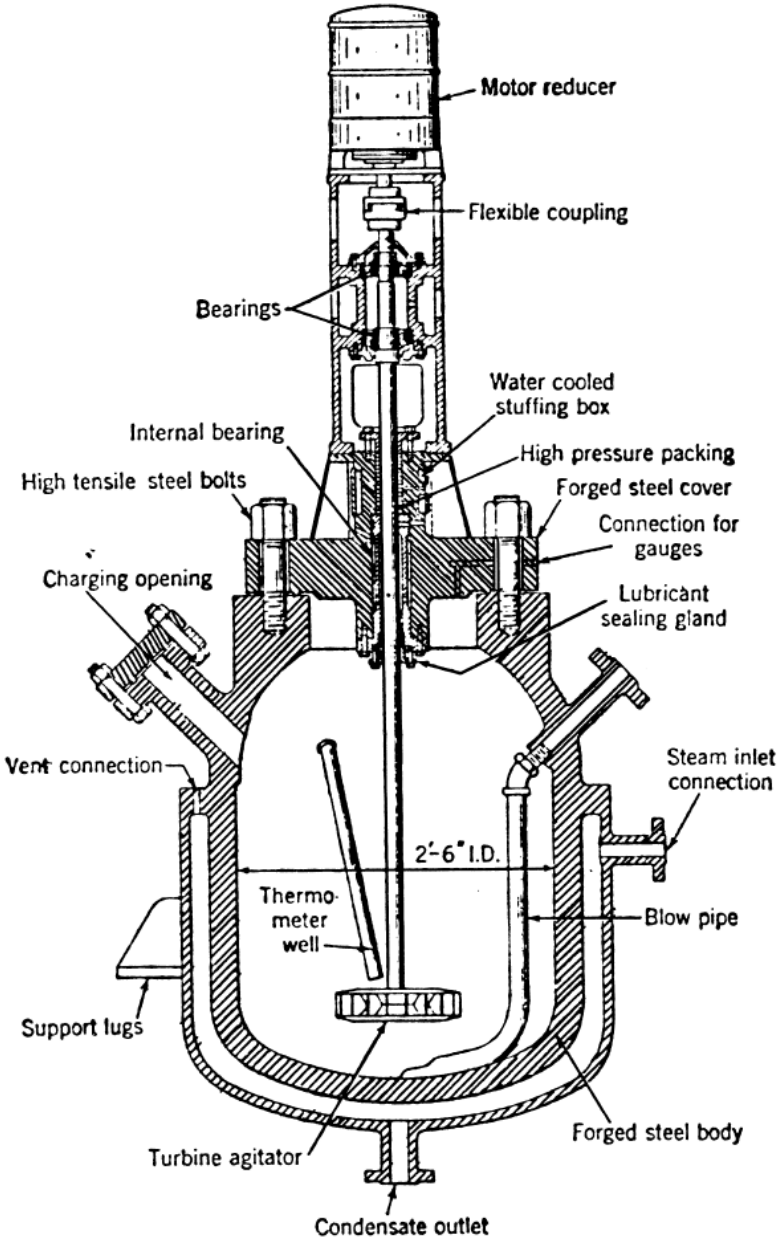
Institute of Chemical Engineering and Technology

University of the Punjab, Lahore 54590

mrusman.icet@pu.edu.pk

Reactor Types

An example Batch Reactor [p.602, 13]



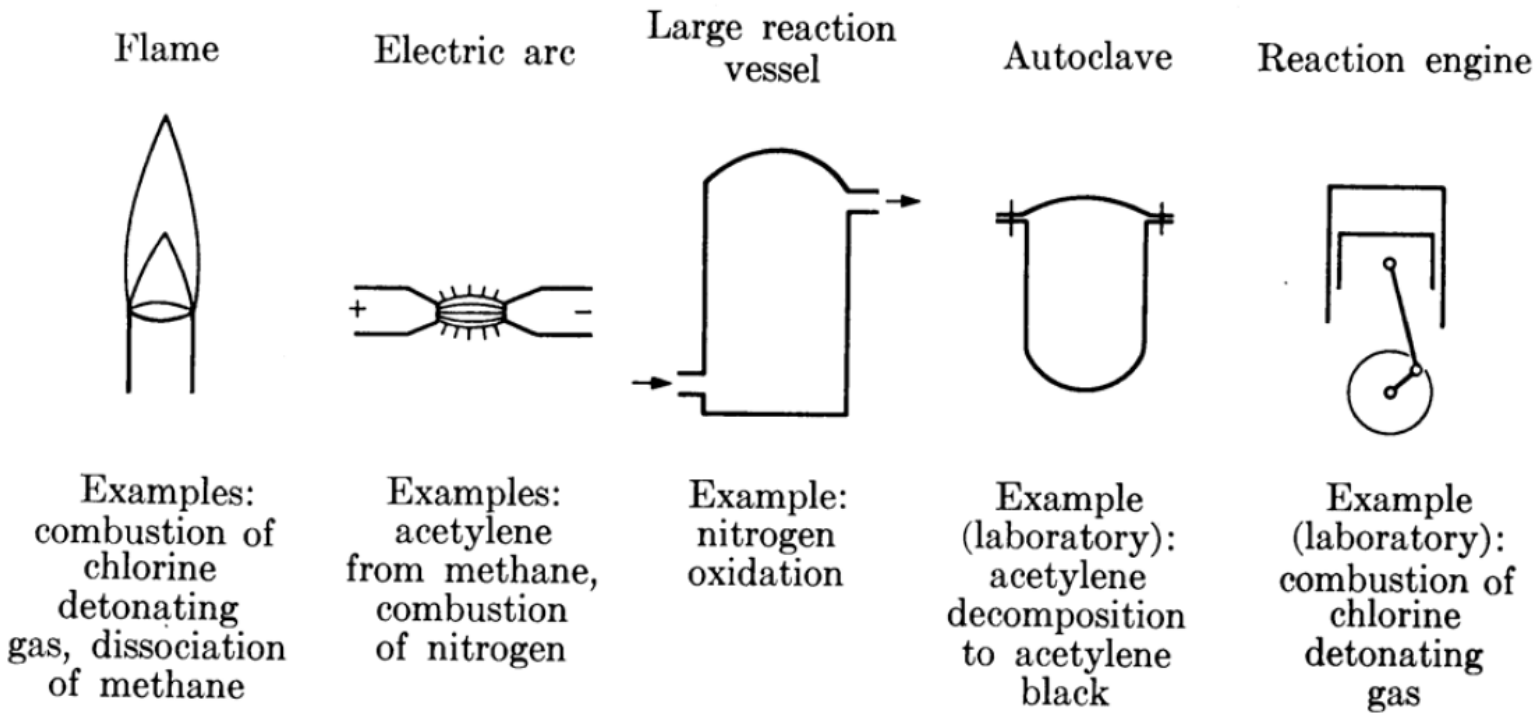
Designs of reactors

Based on the phases involved, reactors may adopt various shapes and designs depending upon the process requirements.

What is a phase?

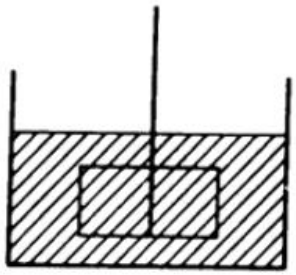
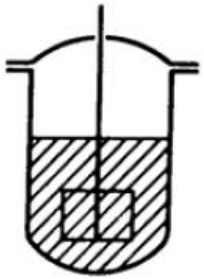
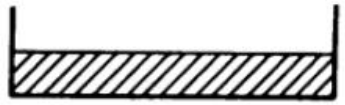
Reactors for gas phase only[15]

- If rate of the reaction is high, the reaction can be carried out in small reaction spaces e.g. in flames and arcs.
- For slower reaction larger reaction space is required.



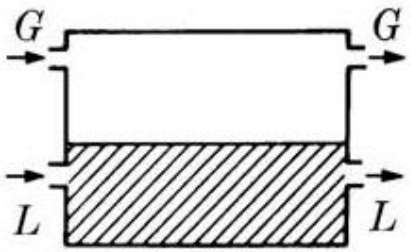
Reactors for liquid phase only[15]

- Batch operations are common.

Tank	Autoclave	Crucible	Vat
			
Examples: diazotization, dye coupling, potash recovery, benzene refining	Example: numerous organic processes	Examples: glass melting, Siemens-Martin furnace	Example: glass melting

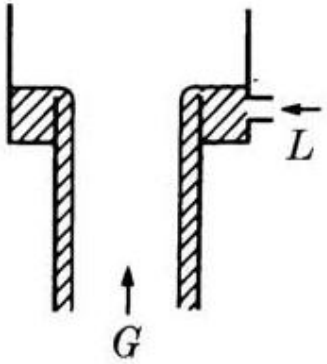
Gas-liquid reactors[15]

Surface contacter



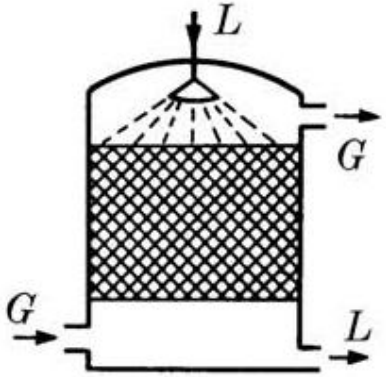
Example:
HCl absorption

Wetted-wall absorber



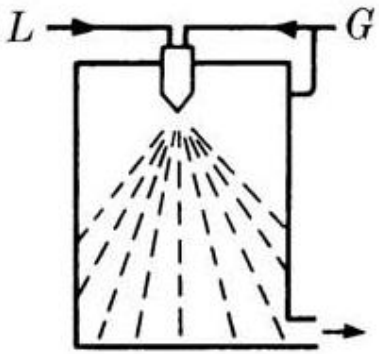
Example:
HCl absorption
in carbon
tubes

Packed-bed reactor



Example:
manufacture
of HCl, H_2SO_4,
and HNO_3

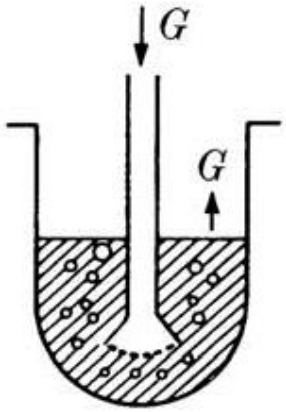
Spray reactor



Example:
manufacture
of phosphoric
acid

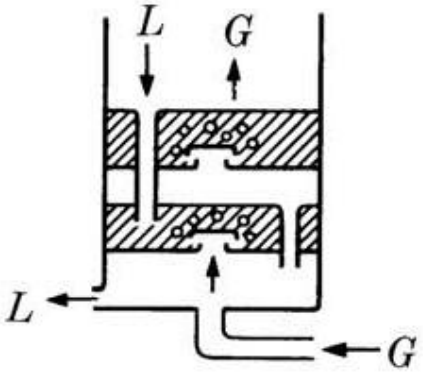
Gas-liquid reactors[15]

Submerged bell



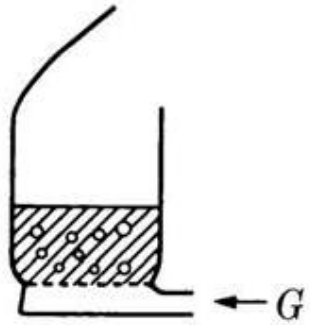
Example:
CO_2 scrubbing

Bubble-cap column



Example:
HCl absorption

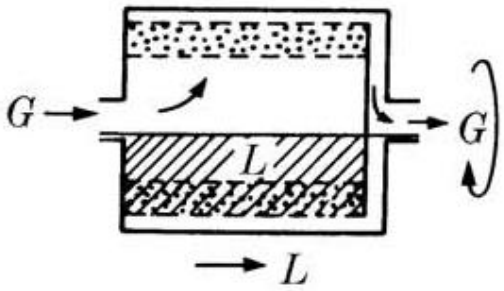
Converter



Example:
steel production

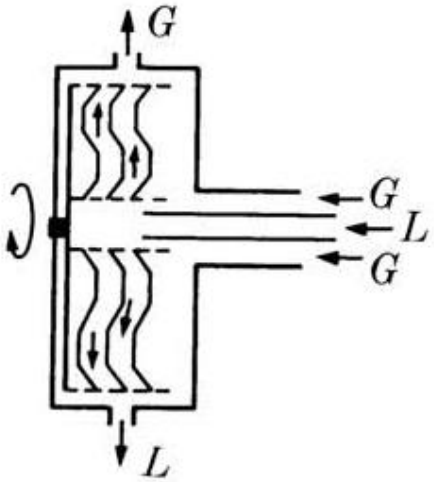
Gas-liquid reactors[15]

Drum scrubber



Example:
ammonia
scrubbing

Plate scrubber



Example:
separation of tar
from coke-oven gas

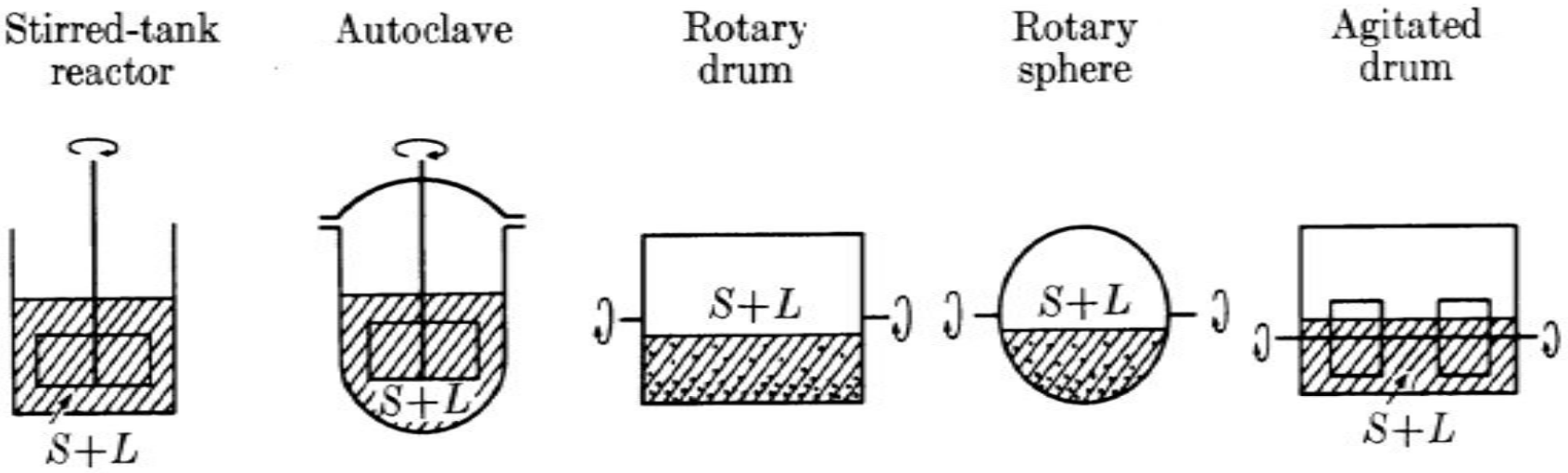
Rotary scrubber

Example:
SO_3 absorption

Gas-liquid reactors

Think other possible designs.

Liquid-solid reactors[15]

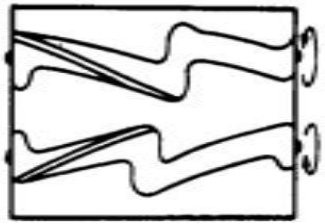


Liquid-solid reactors[15]

Reactor with circulation

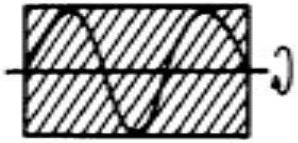
Example: cellulose digester

Kneader



Example: superphosphate from rock phosphate

Screw

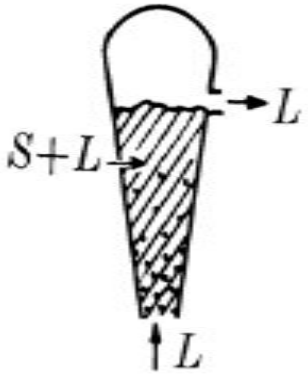


Example: Buna rubber polymeriza-tion

Spinning nozzle

Example: rayon production

Fluidized-bed reactor



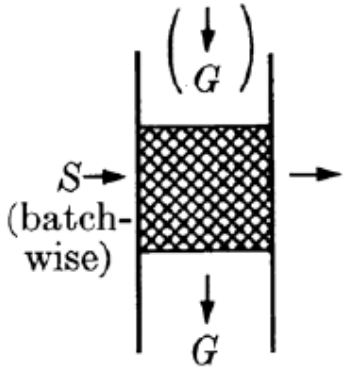
Example: water softening

Gas-solid reactors[15]

Reactor with fixed solids

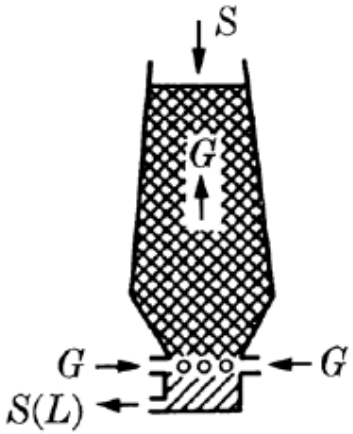
Examples:
$N_2 + 3H_2 \rightarrow 2NH_3$ (with catalyst), heat regenerator (with refractory material)

Batch reactor



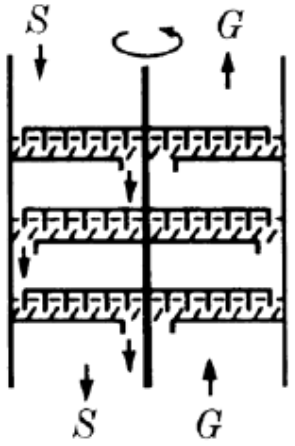
Example:
coking of coal

Moving-bed reactor



Examples:
iron smelting, calcination of limestone

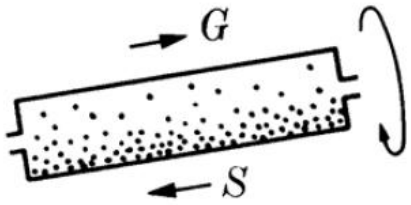
Multicompartment reactor



Example:
roasting of ore

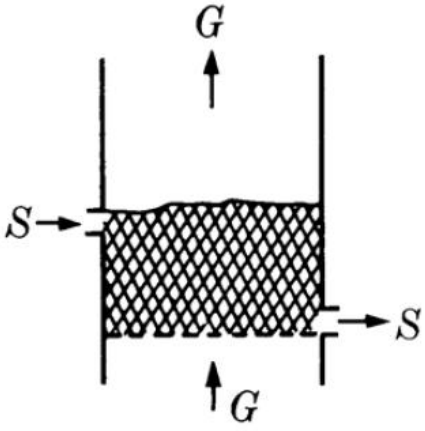
Gas-solid reactors[15]

Rotary kiln



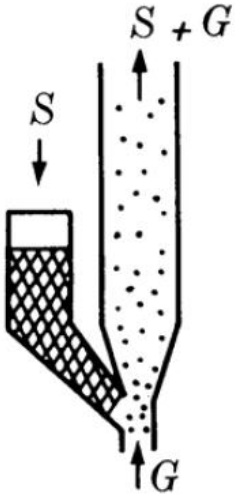
Examples:
roasting
of ore,
cement
manufacture

Fluidized-bed
reactor



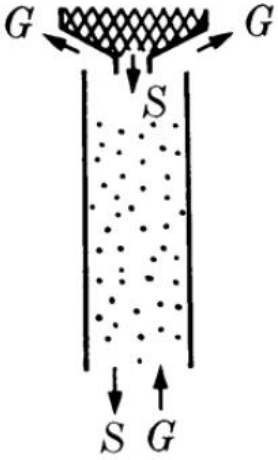
Examples:
coal gasification,
cracking,
roasting
of ore

Dilute-phase,
cocurrent-flow
reactor



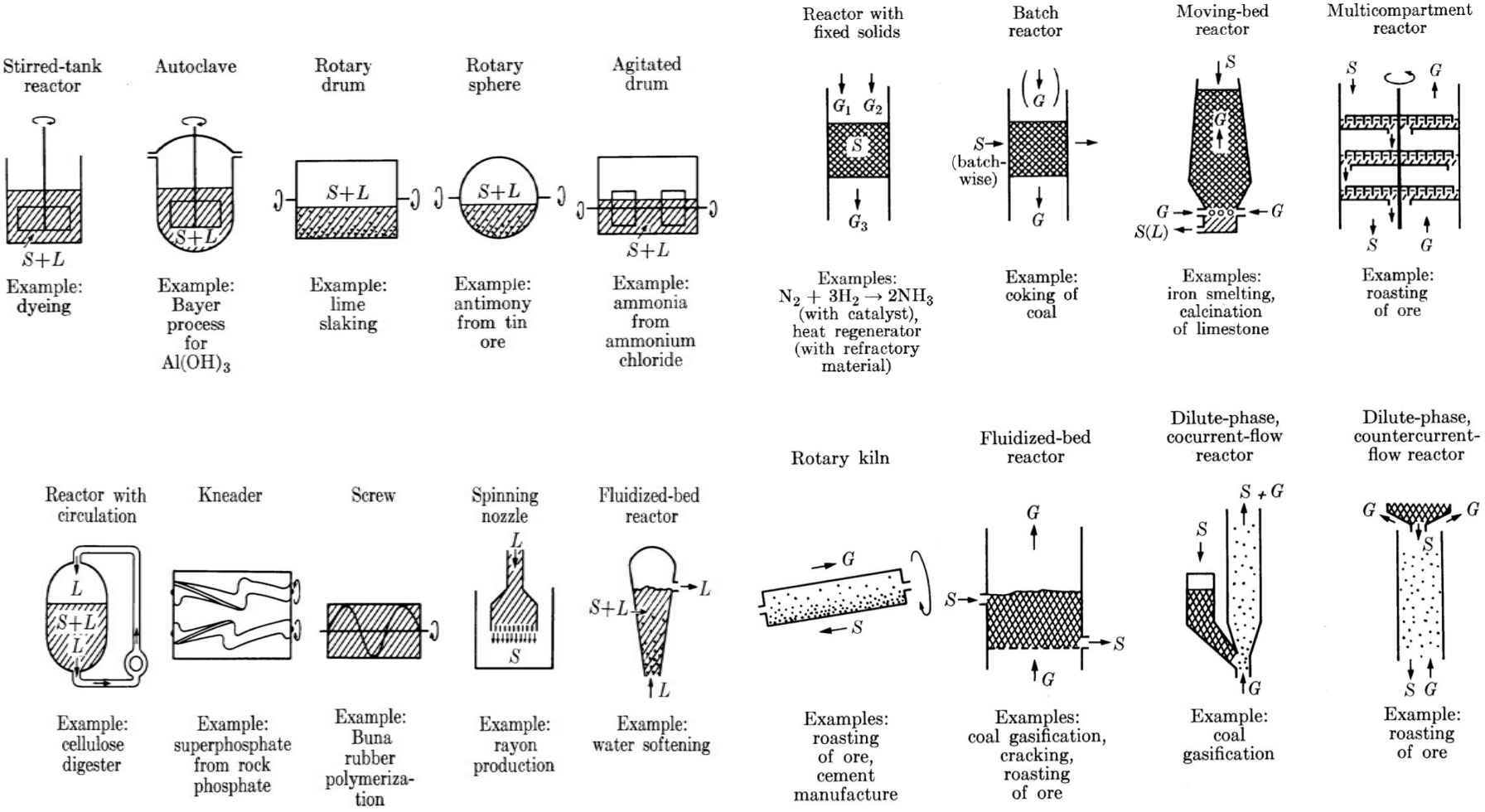
Example:
coal
gasification

Dilute-phase,
countercurrent-
flow reactor



Example:
roasting
of ore

Gas-Liquid-solid reactors[15]



Possible design of reactors

Think other designs.

Make your own designs.

You may have a **novel** idea.

Basic types of furnaces[14]

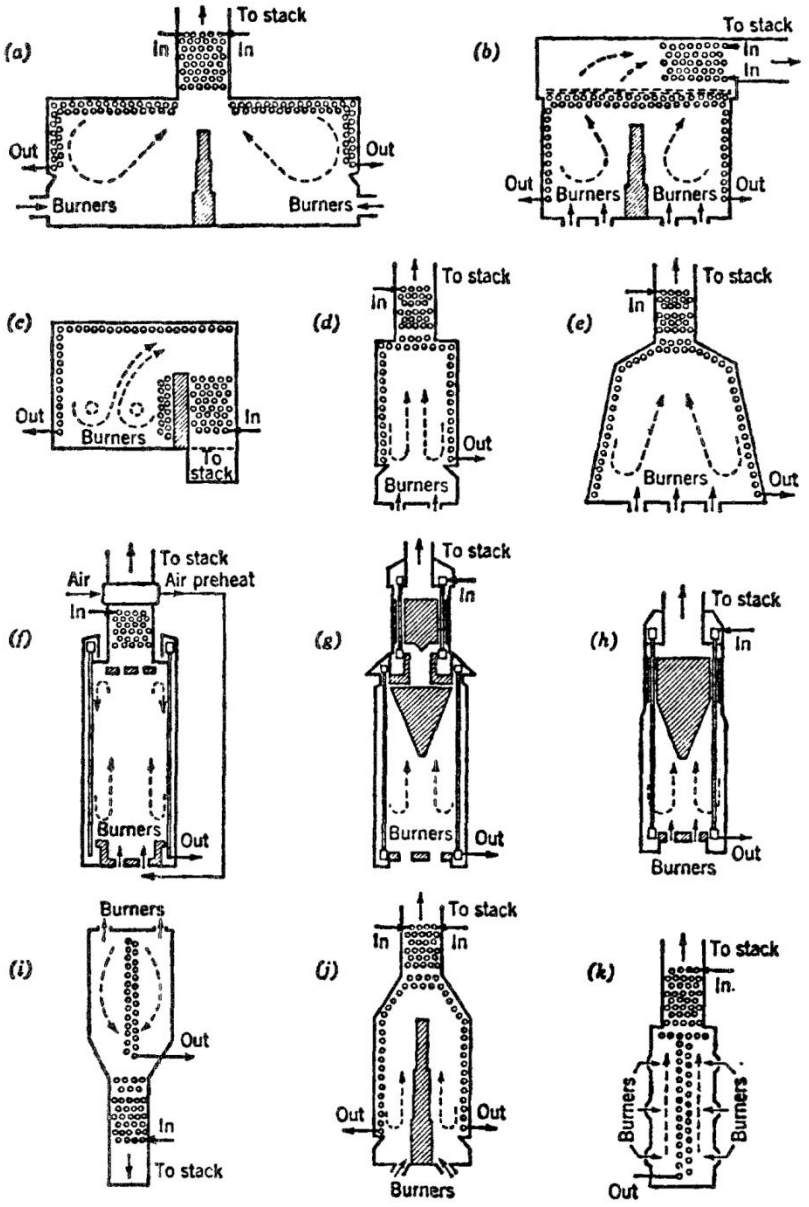
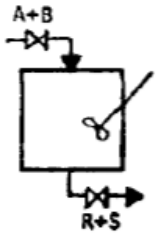
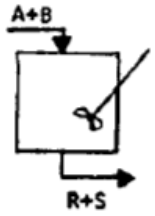
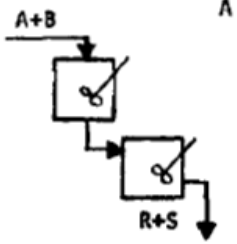
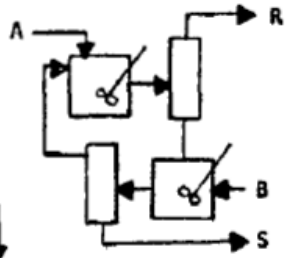
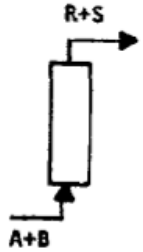
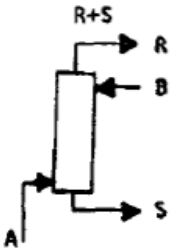


Figure 17.16. Basic types of tubular furnaces [*Nelson,* Petroleum Refinery Engineering, *McGraw-Hill, 1958. Courtesy McGraw-Hill, New York*].

Gas-Liquid-solid reactors[14]

CODE: Commonly used; Rarely used; Not feasible

MODE	BATCH	CONTINUOUS				
REACTOR TYPE	Tank	Tank	Tank battery		Tubular	
Phase \ Flow type	Agitated	Agitated	Parallel	Counter	Parallel	Counter
Gaseous						
Liquid	Gas continuous					
Gas-liquid						
Liquid-liquid						
Gas-solid						
Liquid-solid						
Gas-liquid-solid						
Flowsketch for the reaction $A + B \rightleftharpoons R + S$						

Design of a fixed bed reactor

A commonly used fixed bed reactor has the following features:

- The reactor is used for a fluid-solid contact though gas-solid systems are more common.
- The solid catalyst particles are arranged randomly in a cylindrical shell or tube, where the solid particles remain fixed with respect to each other as well with respect to the reactor wall.

How will you define moving bed reactor and fluidized bed reactor?

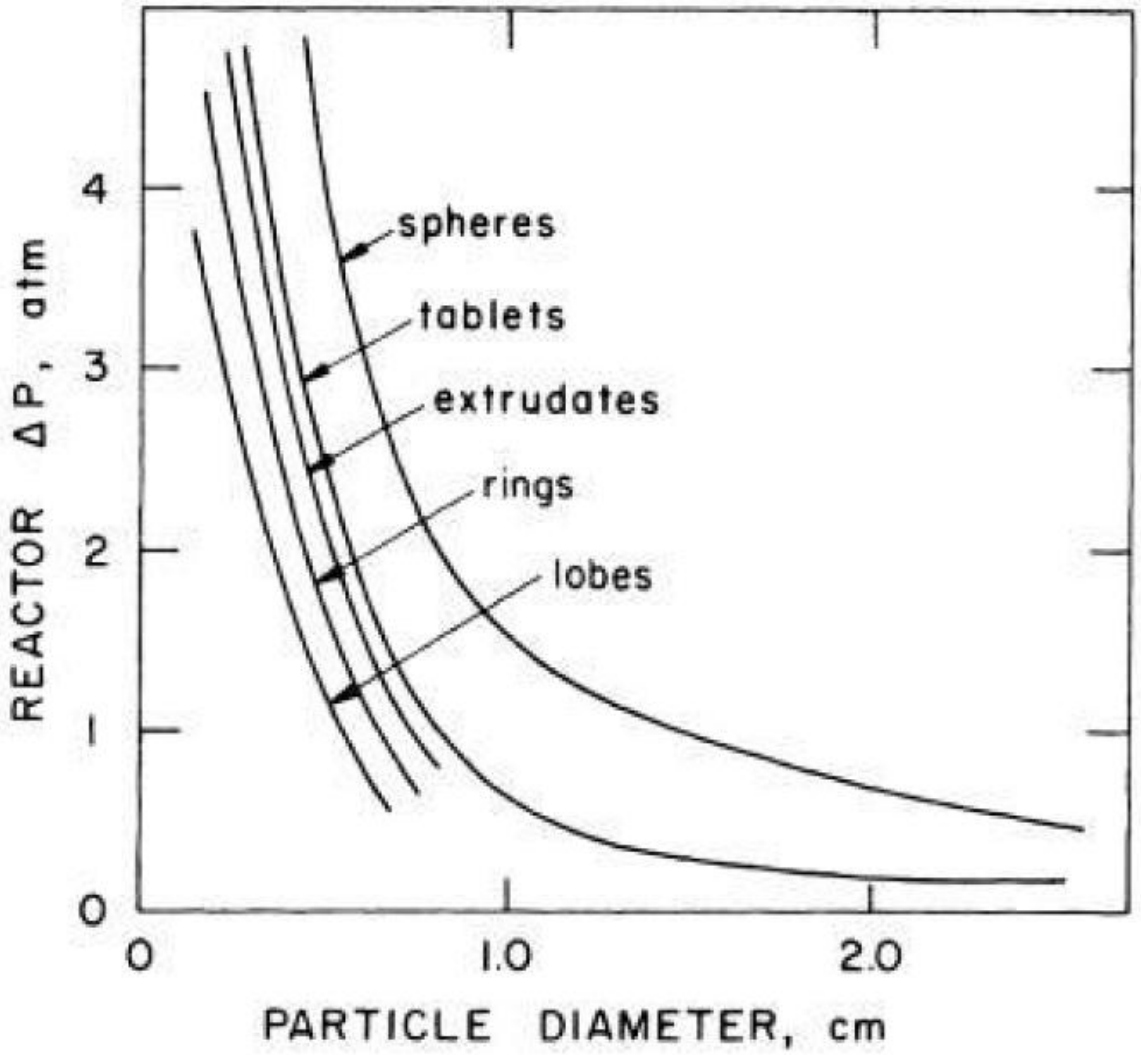
Design of a fixed bed reactor

- The gas or liquid flows from top to the bottom. The flow in upward direction may loosen the bed giving rise to attrition and fine particles may increase the pressure drop and may possibly be fluidized.
- Sulfuric acid production (SO_2 oxidation), methanol production, ammonia synthesis, manufacture of styrene by the dehydrogenation of ethylbenzene are some of the industrial examples that require a fixed bed reactor.
- The catalytic bed may be arranged in a single shell or single shells stacked one above the other.

Design of a fixed bed reactor

- The catalyst bed may be arranged in a multitubular geometry in which a set of tubes are placed inside a shell. This conforms to a shell and heat exchanger type assembly. The catalyst may be packed inside or outside of the tubes.
- A radial flow reactor may also be used where pressure drop is an issue.
- The usual catalyst particle size ranges between 2-6 mm. Various shapes of catalysts may be used. Spherical, solid cylindrical, hollow cylindrical (Raschig ring type), Lessing ring type, extrudates, etc., are the different kinds of shapes of catalyst that may be employed.

Variety of catalysts: pressure drop [17]

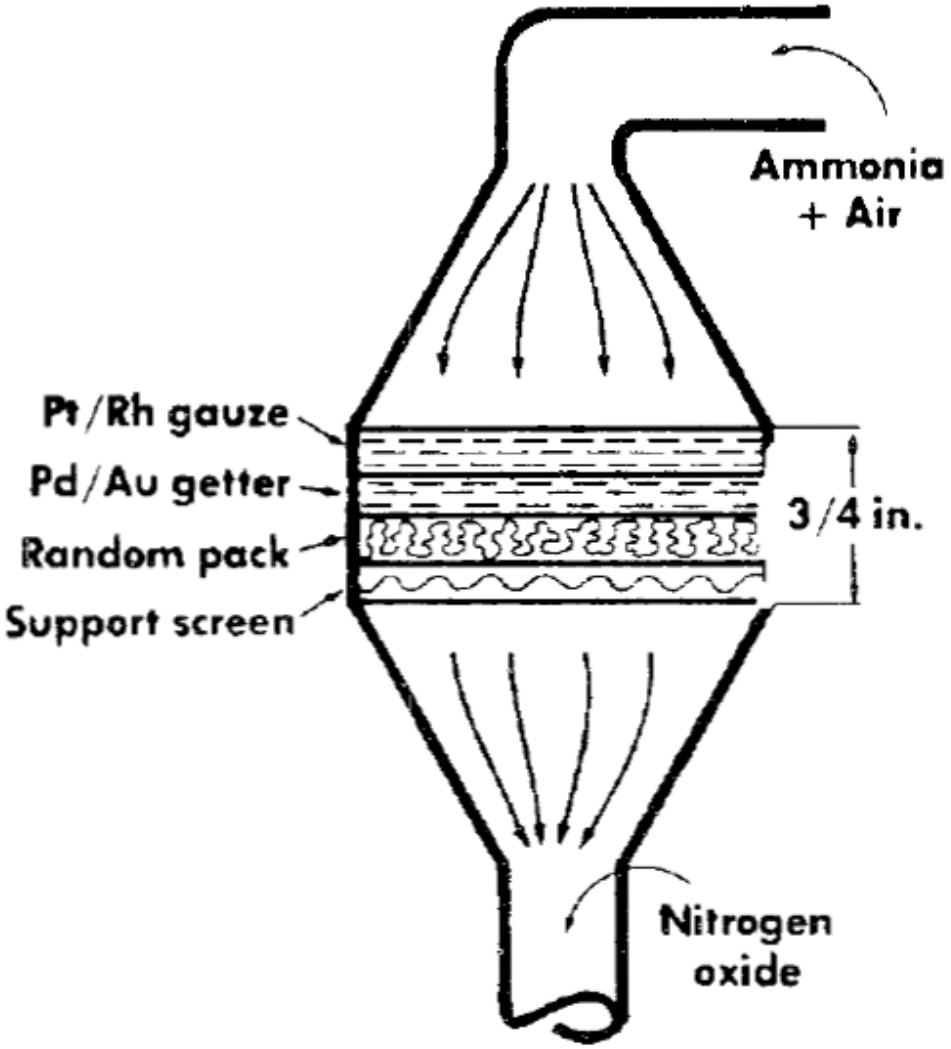


Design of a fixed bed reactor

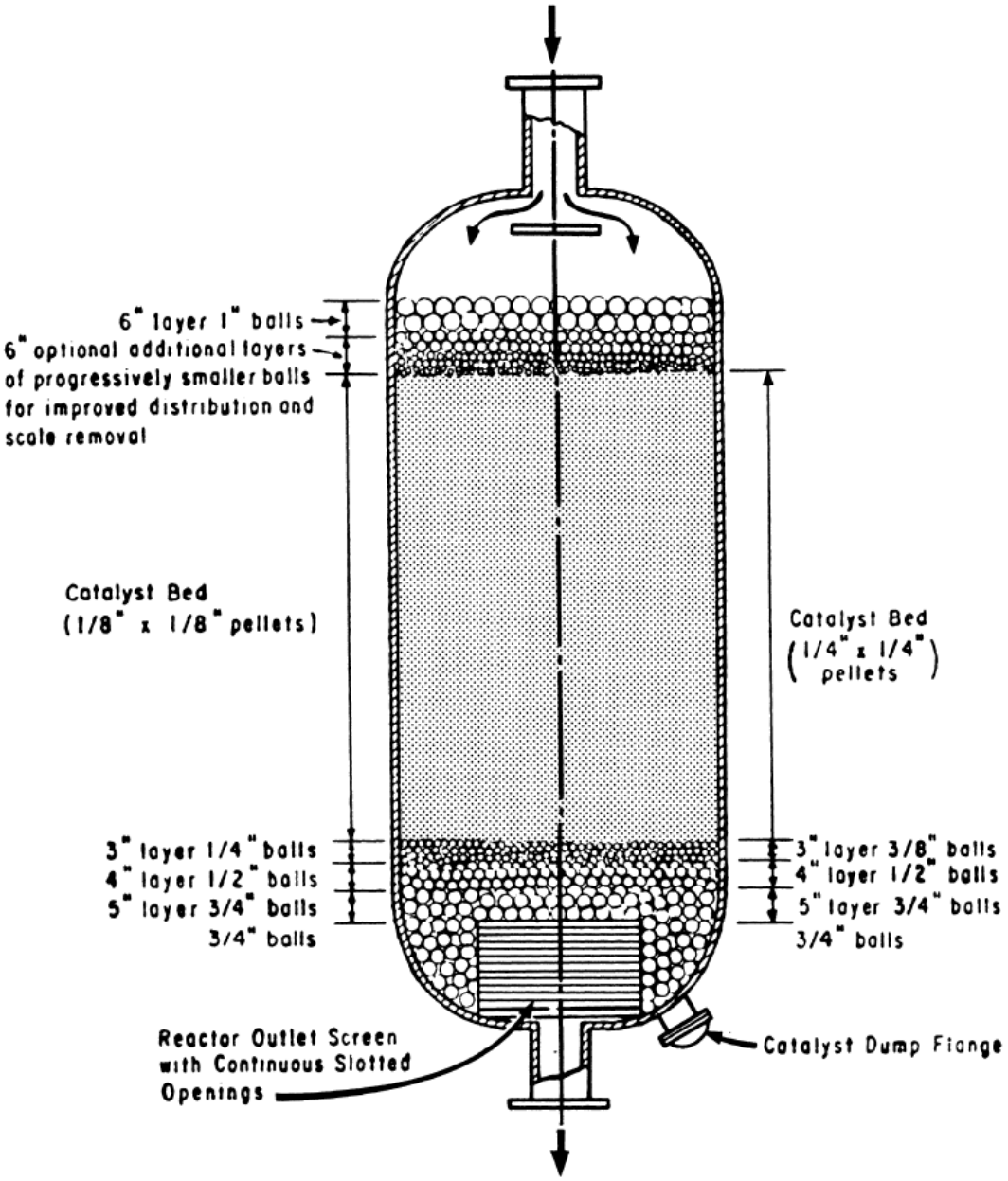
- Thermodynamics of the reaction (heat of reaction and chemical reaction equilibrium consideration)
- Reaction reversiblity
- Kinetics (rate) of the given reaction
- Feed composition and product specifications
- Flow requirement
- Thermal energy requirement
- Bed arrangement
- Properties of catalytic particles and catalytic bed
- Catalyst weight (size of the reactor)
- Length to diameter ratio
- Pressure drop
- Temperature and composition distributions

One or more of these requirements may be dependent on each other.

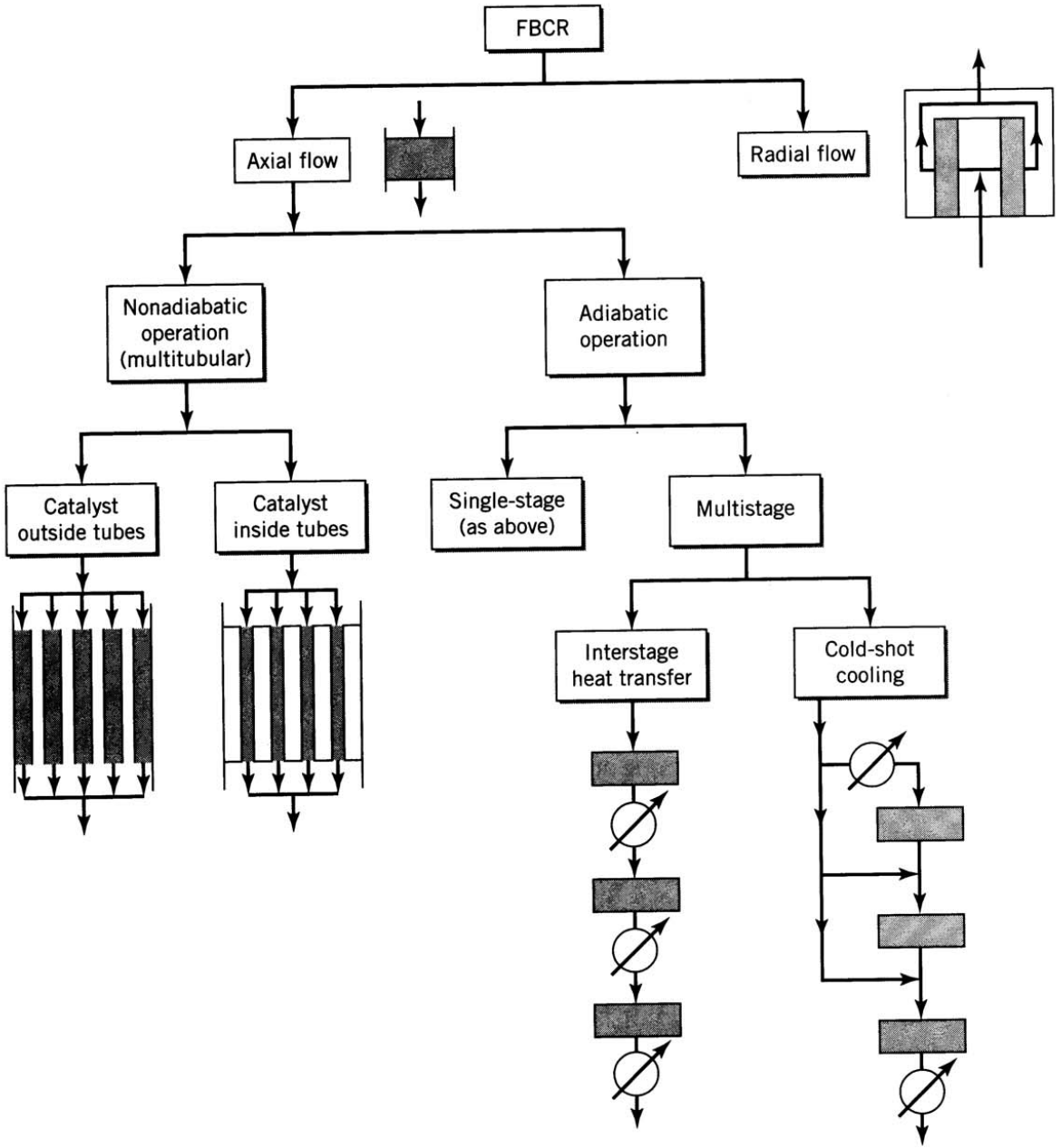
Example fixed bed reactor[14]



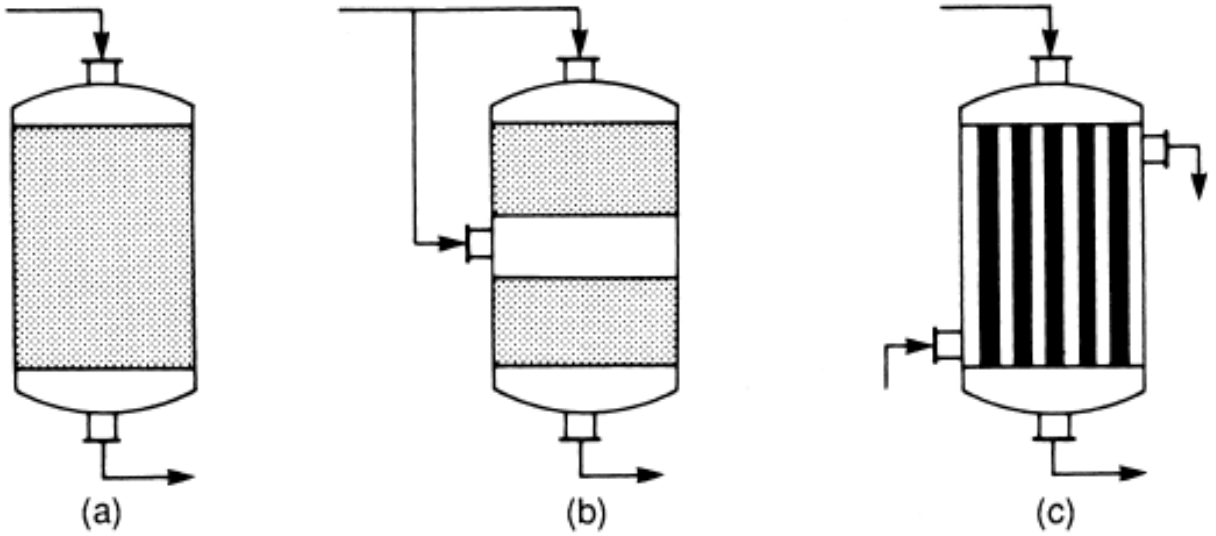
Example fixed bed reactor[16]



Various kinds of fixed bed reactors[10]



Various kinds of fixed bed reactors[14]



(a) adiabatic; (b) interbed coldshot injection; (c) shell and tube;

References

[1] Froment, G.F., Bischoff, K.B., and De Wilde, J. 2011. Chemical reactor analysis and design. 3rd ed. John Wiley & Sons, Inc.

[2] Fogler, H.S. 1999. Elements of chemical reaction engineering. 3rd ed. Prentice-Hall.

[3] Levenspiel, O. 1999. Chemical reaction engineering. 3rd ed. Wiley & Sons, Inc., Singapore.

[4] Catalysis looks to the future. 1992. Panel on New Directions in Catalytic Science and Technology, National Research Council, National Academy Press, Washington, D.C.

[5] Usman, M.R. 2011. Catalytic Dehydrogenation of Methylcyclohexane over Monometallic Catalysts for On-board Hydrogen Storage, Production, and Utilization. *Energy Sources A* 33, 2231–2238.

[6] Usman, M.R.; Aslam, R.; Alotaibi, F. 2011. Hydrogen storage in a recyclable organic hydride: Kinetic modeling of methylcyclohexane dehyrogenation over 1.0 wt% Pt/θ-alumina. Energy Sources, Part A 33, 2264–2271.

[7] Yaws, C.L. 1999. Chemical properties handbook. McGraw-Hill.

[8] Bird, R.B. Stewart, W.E. Lightfoot, E.N. (2002). Transport phenomena. 2nd ed. John Wiley & Sons, Inc. Singapore.

[9] Poling, B.E.; Prausnitz, J.H.; O'Connell, J.P. 2000. The properties of gases and liquids. 5th ed. McGraw-Hill.

[10] Missen, R.W., Mims, C.A., and Saville, B.A. 1999. Introduction to chemical reaction engineering and kinetics. John Wiley & Sons, Inc., New York.

[11] Satterfield, C.N.1970. Mass transfer in heterogeneous catalysis. MIT Press.

References

[12] Welty, J.R.; Wicks, C.E.; Wilson, R.E.; Rohrer, G.L. 2007. Fundamentals of momentum, heat, and mass transfer, 5th ed., John Wiley & Sons, Inc.

[13] Smith, J.M. 1981. Chemical engineering kinetics. 3rd ed. McGraw-Hill Int. Book Co., Singapore.

[14] Walas, S.M. 1990. Chemical process equipment: Selection and design. Butterworth-Heinemann, London.

[15] Brötz, W. 1965. Fundamentals of chemical reaction engineering. Addison-Wesley Publishing Company, Inc., Reading.

[16] Rase, H.F. 1990. Fixed bed reactor design and diagnostics: Gas-phase reactions, Butterworths, Boston.

[17] Richardson