Design, Scale-Up and Troubleshooting of Packed Bed Reactors with Two Phase Flow: A Brief Review

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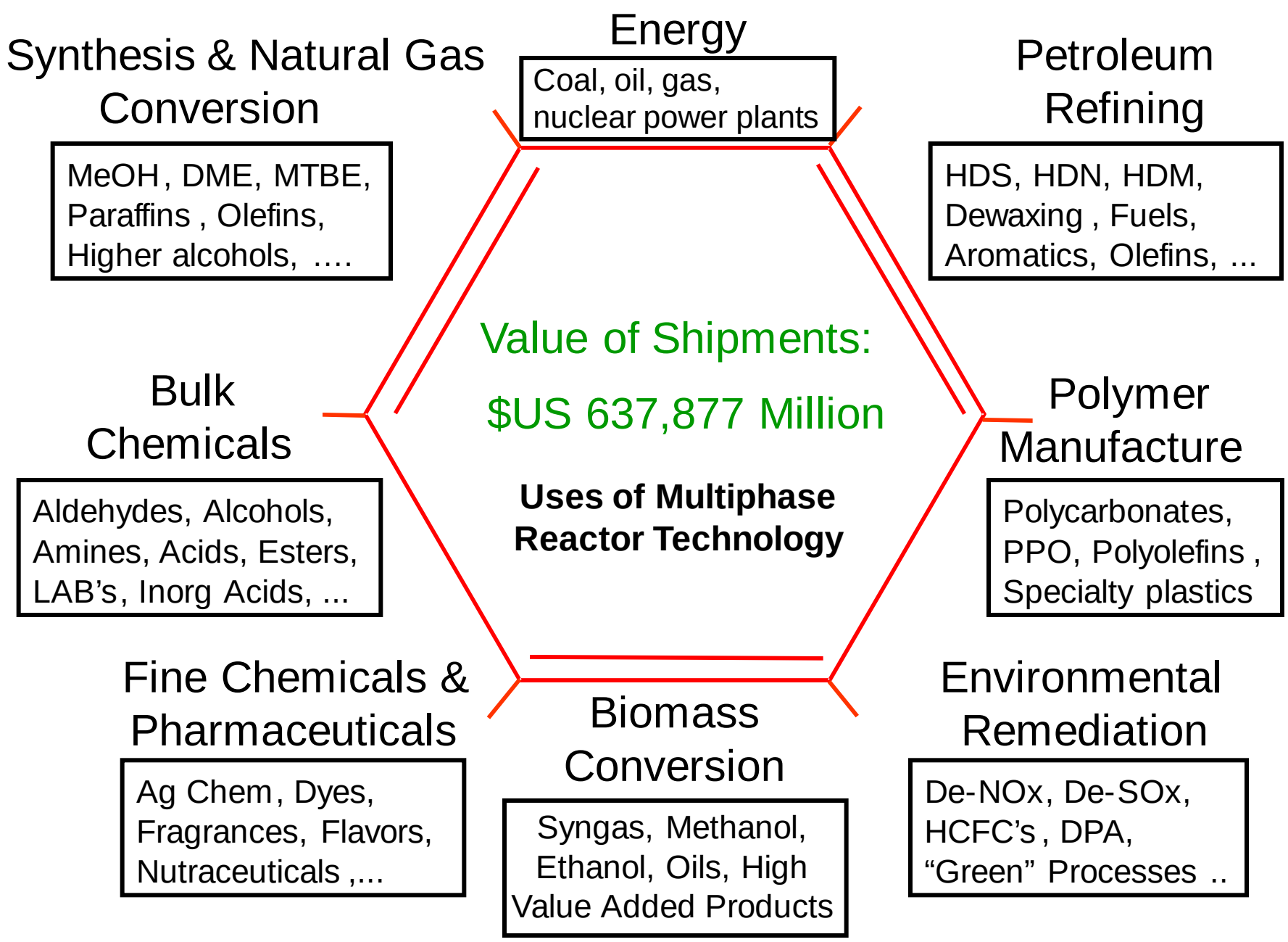
Workshop on
Multiphase Reactors Technology


Energy
Coal, oil, gas, nuclear power plants
Synthesis & Natural Gas Conversion
MeOH, DME, MTBE, Paraffins , Olefins, Higher alcohols, ….
Petroleum Refining
HDS, HDN, HDM, Dewaxing , Fuels, Aromatics, Olefins, ...
Value of Shipments:
$US 637,877 Million
Uses of Multiphase Reactor Technology
Bulk Chemicals
Aldehydes, Alcohols, Amines, Acids, Esters, LAB's, Inorg Acids, ...
Polymer Manufacture
Polycarbonates, PPO, Polyolefins , Specialty plastics
Fine Chemicals & Pharmaceuticals
Ag Chem, Dyes, Fragrances, Flavors, Nutraceuticals ,...
Biomass Conversion
Syngas, Methanol, Ethanol, Oils, High Value Added Products
Environmental Remediation
De-NOx, De-SOx, HCFC's , DPA, "Green" Processes ..

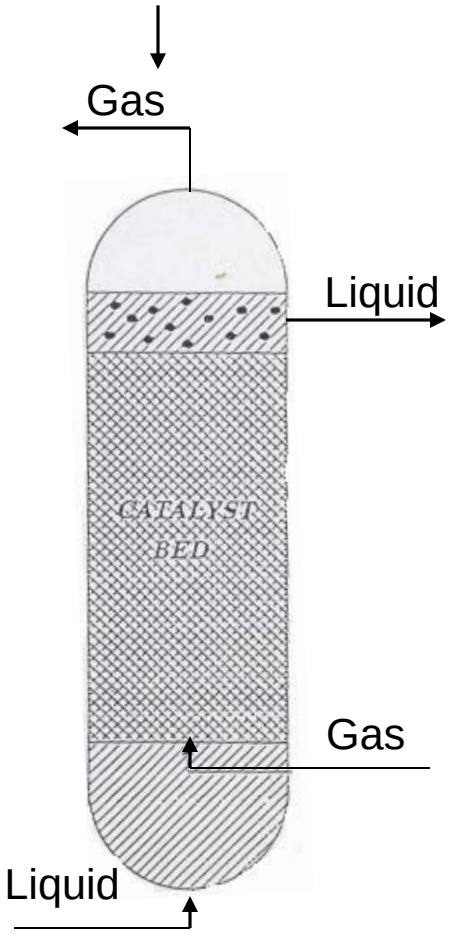
In heterogeneous systems the volume averaged reaction rate (volumetric productivity) is a function of:

- Molecular scale – kinetics and rate forms
- Single particle (single eddy) scale effects on diffusion and reaction in the particle, specific phase interfacial area effect on inter-phase mass and heat transfer
- Reactor scale effect via contacting pattern and phase RTD influence on the average rate and via flow regime effect on phase holdups and inter-phase transport coefficients.

Packed Catalyst Beds with Two Phase Flow

TRICKLE BED REACTOR

PACKED BUBBLE COLUMN



POSSIBLE MODE OF OPERATION:

Co-Current:

DOWNFLOW

-gas continuous
-plug flow of liquid and gas
-highest catalyst/liquid ratio
-potential for liquid maldistribution

UPFLOW

-liquid continuous
-some backmixing
-higher liquid holdup
-potential for undesired homogeneous reactions
-somewhat higher transport rates

Counter-Current:

-high P_{H_2} desired in region of high liquid conversion
-volatile product inhibits rate
-gas-liquid mass transfer limitations are present
-through-put constrained by flooding limits
-considerable backmixing
-highest pressure drop

TRICKLE BED REACTORS (TBR)

Advantages

- Plug flow
- High catalyst/liquid ratio
- Stationary catalyst
- Throughput range is wide
- Low dissipated power
- Heat of reaction can be used to volatize liquid
- No catalyst handling problems
- Flexibility of operation mode
- Lower capital and operating costs

Disadvantages

- Larger particles, low effectiveness (compared to slurry)
- Poor liquid-solid contacting
- High crushing strengths required of small particles
- Potential for reactor runaway
- Long catalyst life required
- Inability to handle liquids with solids
- Potential for liquid mal-distribution

PACKED BUBBLE COLUMNS (PBC)

Advantages

- Complete liquid-solid contacting
- Higher liquid holdup and better temperature control
- No problems with liquid mal-distribution
- Higher mass transfer rates

Disadvantages

- Higher dissipated power than in TBR
- Throughput limited by bed fluidization velocity
- Potential for runaway
- Undesired homogeneous reactions are promoted

Processes conducted in TBRs vary and include:

- Hydrotreating of petroleum
- Desulfurization, denitrogenation, demetalization of heavy petroleum residuals
- Hydrogenation of organic chemicals
- Hydrogenation of vegetable oils
- Oxidation
- Waste water treatment
- Electrochemical reactions
- Etc

HYDROGENATION REACTIONS:

-Saturation of carbon-carbon double bond

1) Volatile compound

Hydrogenation of alphamethylstyrene into cumene

2) Nonvolatile compound

Hydrogenation of maleic acid into succinic acid

-Hydrogenation of carbonyl-group

1) Volatile compound

Hydrogenation of methylethyl ketone into 2-butanol

2) Nonvolatile compound

Hydrogenation of dibutyl ketone to 5-nonanol

Hydrogenation of glucose into sorbitol

Hydrogenation of xylose into xylitol

All processes conducted in TBRs, irrespective of their chemistry, should be classified with respect to the expected volatilization of the liquid and rate limiting reactant.

1. Nonvolatile liquid reactant

Rate limiting reactant

- Liquid
- Gas
- Both

Reaction occurs only on wetted catalyst

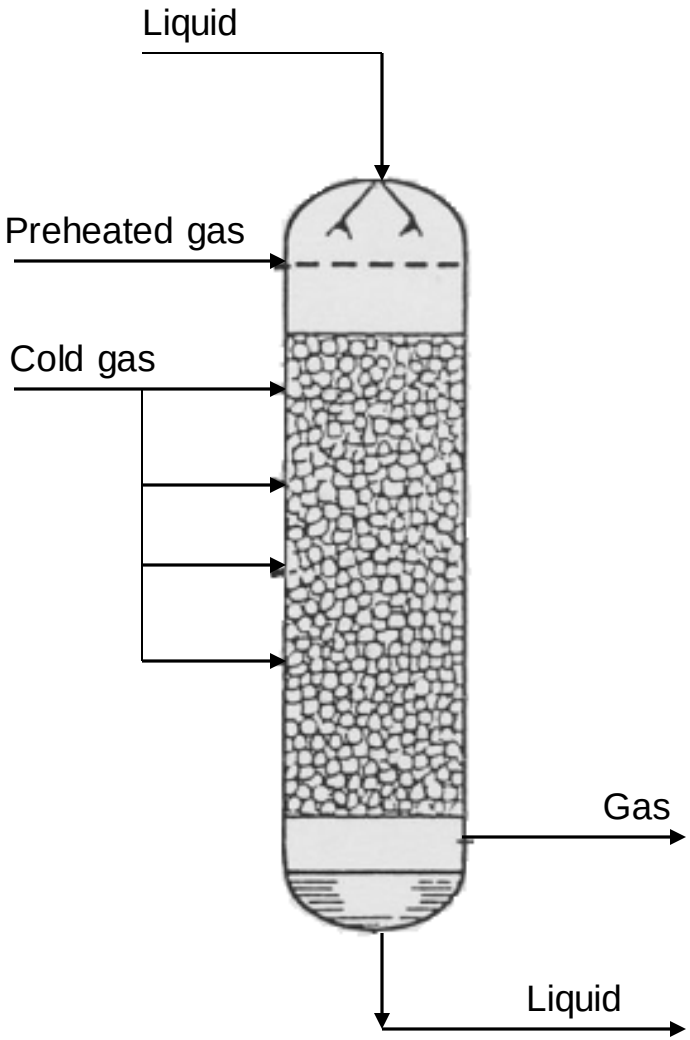
2. Volatile liquid reactant

Rate limiting reactant

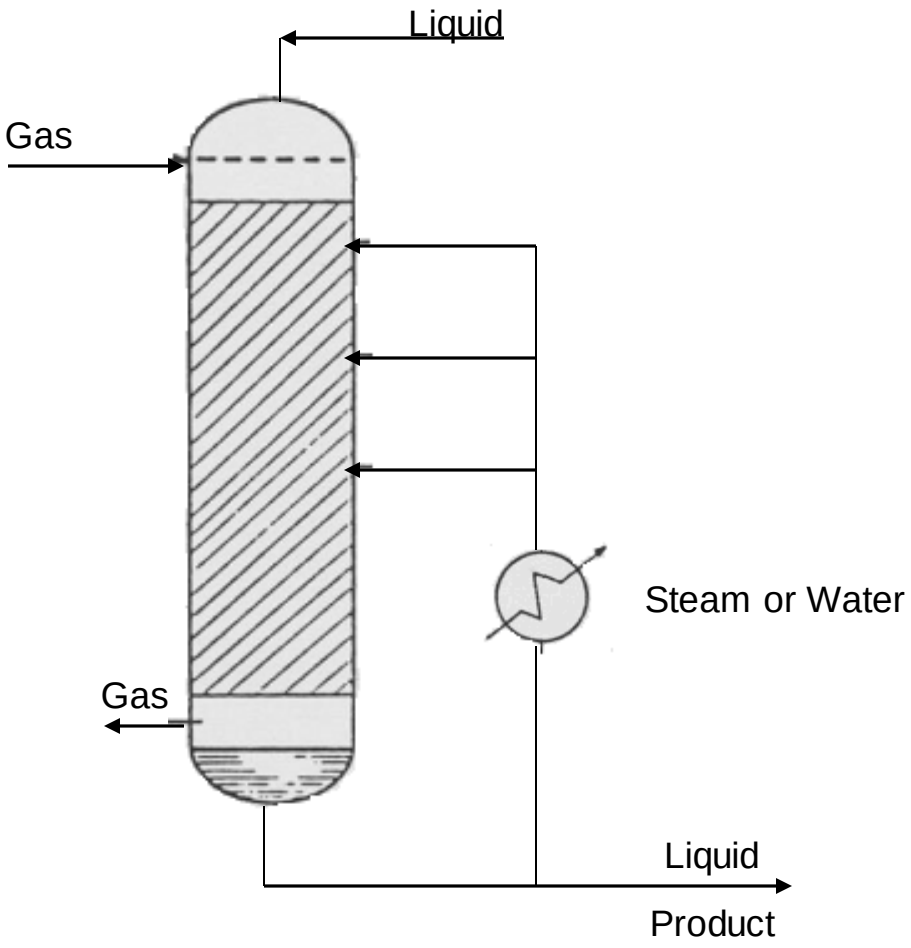
- Liquid or vapor
- Gas
- Both

Reaction occurs both on wet and dry catalyst

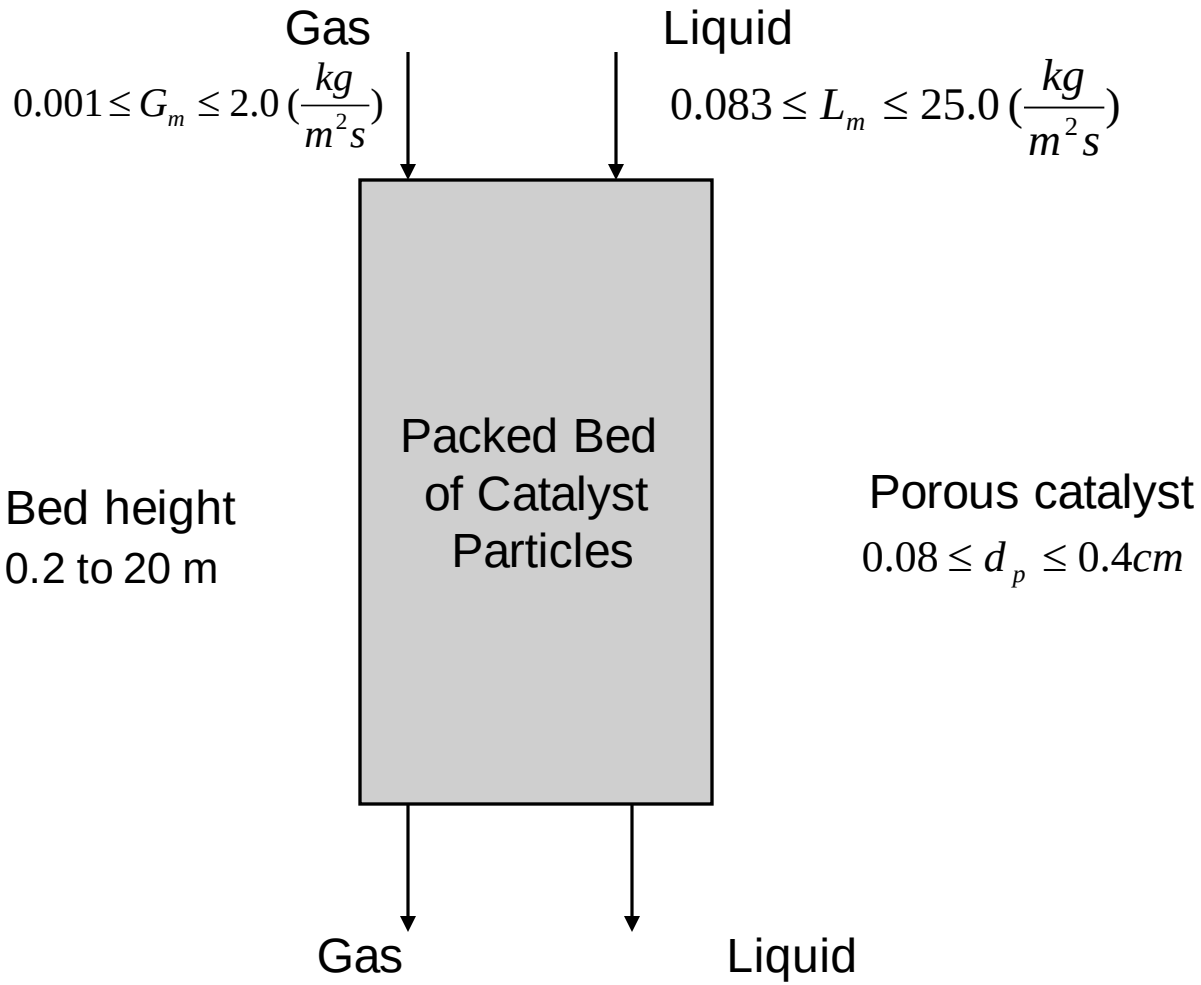
Temperature Control of TBR Using Cold Injections



Trickle Bed Reactor with Liquid Recycle for Temperature Control



Trickle Bed Reactors



Liquid hourly space velocity 0.5 to 10.0 hr^{-1}