Fischer-Tropsch Reactors

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sasol
reaching new frontiers

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Fischer-Tropsch technology

- Converts synthesis gas to liquid hydrocarbons
- $2H_2 + CO \rightarrow -CH_2- + H_2O$
- Product spectrum depends on:
  - temperature, catalyst, pressure, gas composition
- High temperature Fischer-Tropsch
  - 350 ^{o}C: gasoline and light olefins
- Low temperature Fischer-Tropsch
  - 250 ^{o}C: distillate and waxes

Fischer-Tropsch product Distribution

Product Distribution for Fe-catalyst

(per 100 carbon atoms)

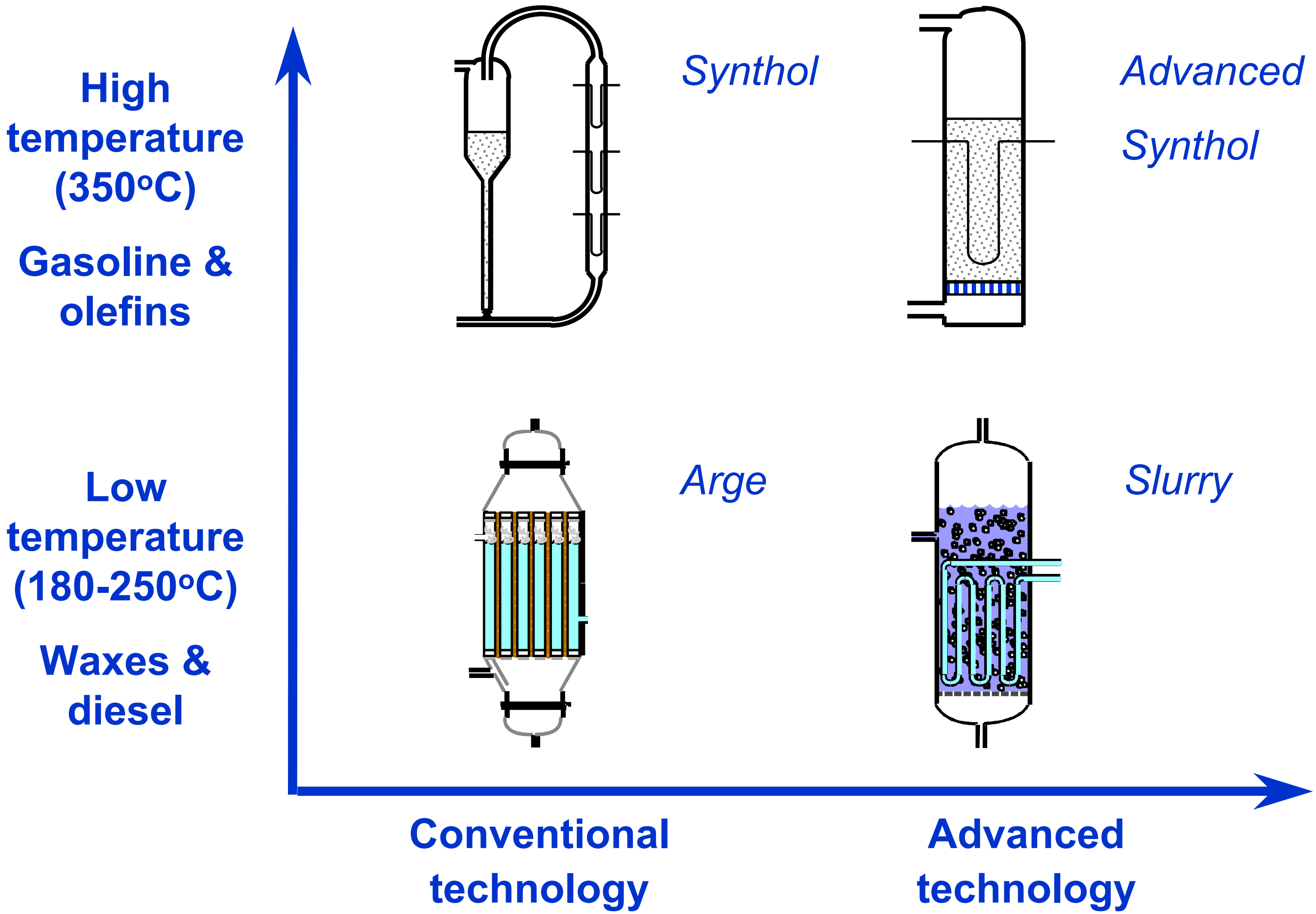
Product	**Low Temperature $220 - 250^{0}C$**	**High Temperature $330 – 350^{0}C$**
CH_4	4	7
C_{2-4} olefins	4	24
C_{2-4} paraffins	4	6
Gasoline	18	36
Distillate	19	12
Oils and waxes	48	9
Oxygenates	3	6

Worldwide Interest in Fischer-Tropsch

- LTFT
  - Conversion: stranded, remote NG to superior diesel
  - Several projects under consideration
  - Sasol – Qatar Petroleum: Oryx plant for start up in 2006
  - ~ $ 25 000 per daily barrel – <u>total</u> project cost

- HTFT
  - Less interest
  - Complex product slate
  - Techno-economic feasibility studies more complex
  - Initial investment higher
  - Provides interesting opportunities

Fischer-Tropsch reactors

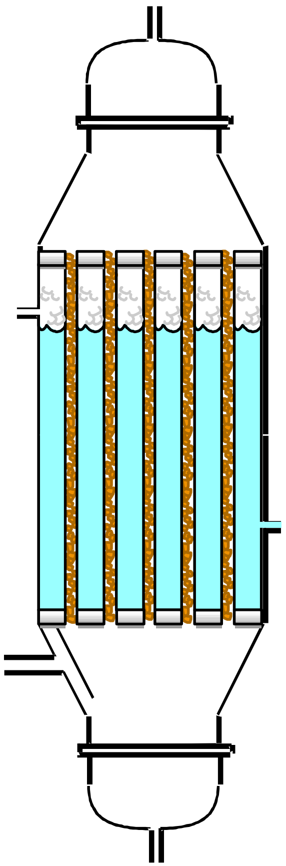


Design Issues

- Catalytic process
- Process conditions
- LTFT - Three phase
  - Multi Tubular Fixed Bed or Slurry Phase Reactors
  - hydrodynamics
  - solid separation
- HTFT – Two phase
- Heat removal – highly exothermal

Multi Tubular Fixed Bed Reactors

- Since 2nd WW used commercially by:
  - Sasol: Arge process (Fe)
  - Shell: SMDS process (Co)
- Heat removal through tube walls
- Gas recycle
  - Enhances heat transfer
  - Conversions: per pass, overall
  - Recompression costs
- Liquid recycle
  - Need for effective distributor
- Pressure drop

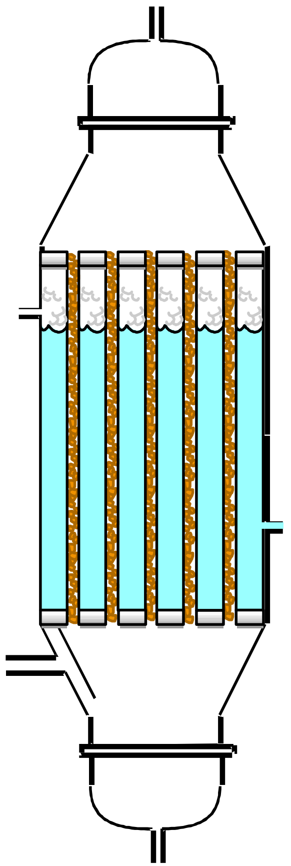


Multi Tubular Fixed Bed Reactors (cont.)

Axial and radial temperature profiles

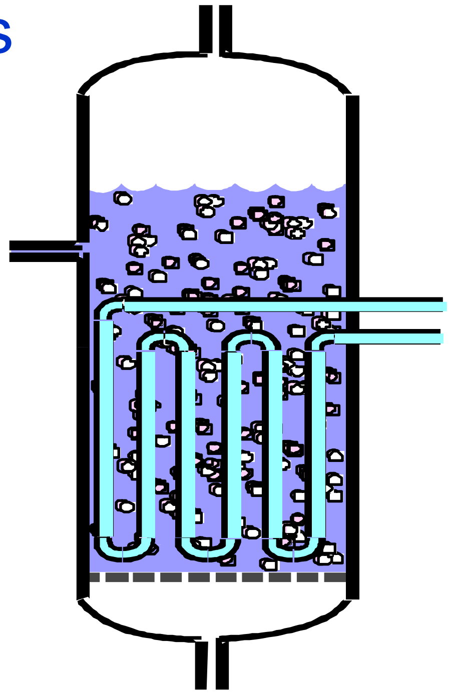
- catalyst activity
- temperature level
- gas & liquid flows
- tube diameters

- Optimise max. ave. and peak temperatures
- Plug flow?
- Cost of reactor
  - Mechanically complex
  - Scale up
  - Catalyst replacement



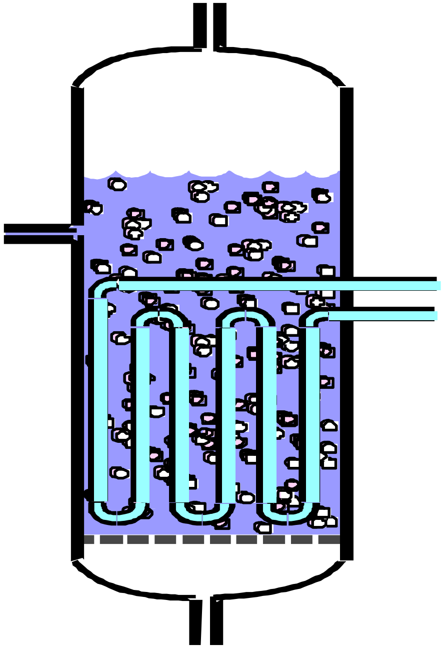
Slurry Phase Reactor

- Well mixed reactor
- High average temperature and reaction rates
- CSTR behaviour conversion, selectivity
- Easier control
  - virtually isothermal operation
- Higher volumetric conversion rates
- On-line catalyst removal and addition
  - selectivity control



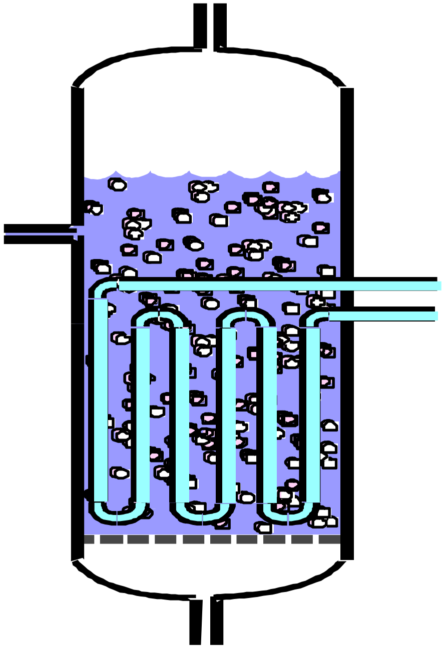
Slurry Phase Reactor (cont.)

- Lower operating cost
  - 70% less catalyst consumption
  - reduced maintenance costs
- Lower capital cost
  - simpler construction
- Solid Separation
  - internal devices
  - crucial development
  - optimisation of catalyst properties
  - effective and relatively cheap



Slurry Phase Reactor (cont.)

- High reactor capacity
- Good turndown ratio
- pressure drop reduced 65-85%
- Plug flow behaviour
  - staging in reactors
  - interstage fresh feed
  - series operation with water knock out



LTFT Catalysts

- Cobalt or Iron based
- Oxidized by water
- Co cat has longer life but more expensive
- Fe cat inhibited by water
- Fe cat has water gas shift activity
- Co cat more active at higher conversions
- Recycles or series reactors
- Water gas shift activity for low H_2/CO gas

LTFT Catalysts (cont).

- **Cobalt based**
  - conversion proportional to H_2/CO
  - selectivity(α) benefits from:
    - low H_2/CO
    - High partial pressure CO

- **Iron based**
  - conversion proportional to pp $(CO+H_2)$
  - selectivity benefits from
    - low H_2/CO
    - low temperature

Catalysts particle size and activity

Multi tubular fixed bed reactor

- Diameter > 1mm for acceptable pressure drop
- Effectiveness factor below unity
- Selectivity negatively affected by CO and H2 diffusivities
  - higher pressure for Co cat
  - lower temperature for Fe cat
- H_2/CO difficult to adjust
- Limited benefit from catalyst activity increases

Catalysts particle size and activity (cont).

Slurry phase reactor

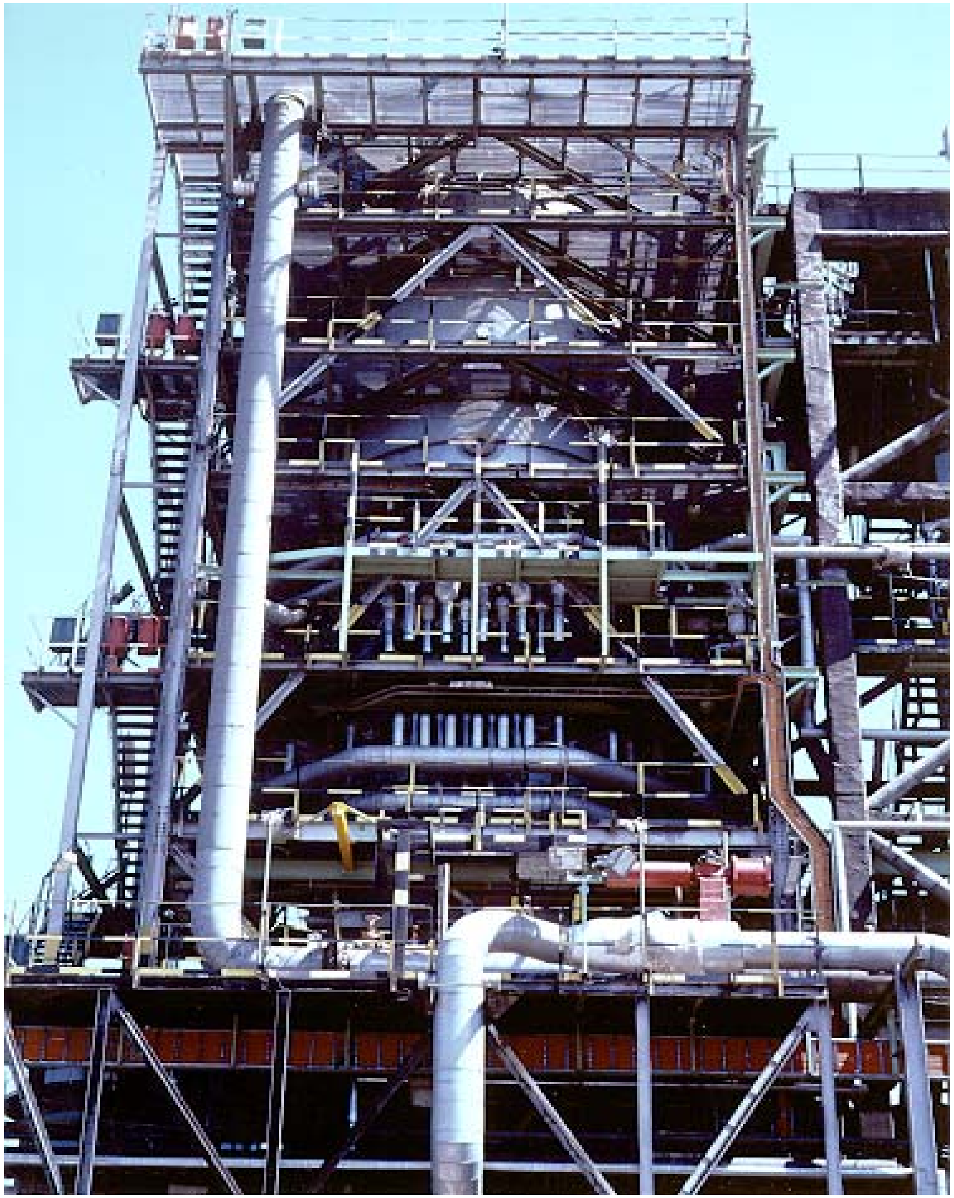
- 20 μm < diameter < 200 μm
  - lower limit due to solid separation
  - upper limit by
    - suspension of particles
    - effectiveness factor
- Effectiveness factor close to unity
- Effective use of increases in catalyst activity
- Benefits selectivity for Co catalyst

Reactor Capacities

- Capacities bbl/day

	MTFBR	SPR
Present	3 000	3 000
Announced	9 000	17 000
Potential	10 – 15 000	> 30 000

- Shop fabrication vs. on site assembly



Sasol's

2 500 bbl/day commercial Slurry Phase Distillate reactor

Reactor Capacities (cont).

Multi tubular fixed bed reactor :

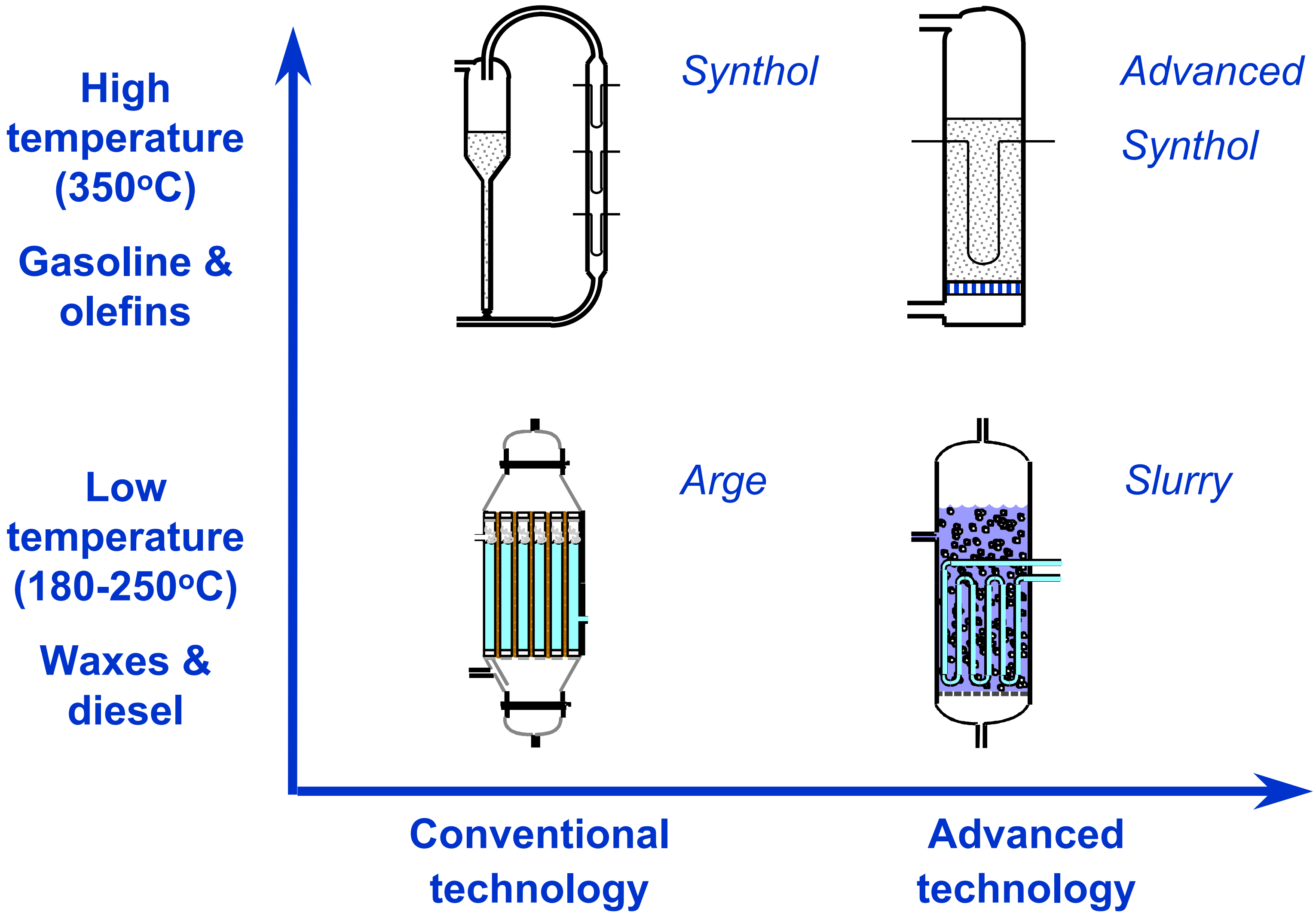
- Series reactors: 3 into 1
- Higher capacities due to :
  - better catalyst
  - optimised process conditions
  - optimised reactor
- Size limited by shop fabrication and transport limitations

Reactor Capacities (cont).

Slurry phase reactors :

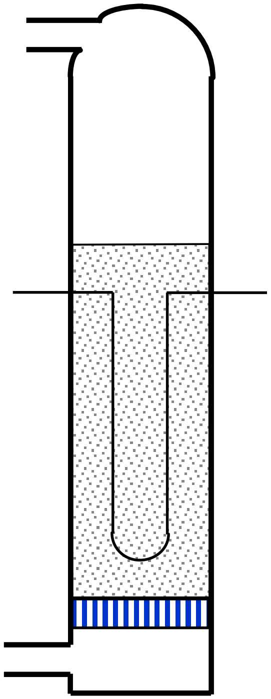
- Higher capacities due to:
  - simpler construction for easier scale up
  - higher activity catalyst can be utilized
  - internal staging – plug flow
  - interstage fresh gas feed – optimal use of reactor volume
  - series reactor configuration with condensing trains
    - reduces recycles
    - higher partial pressures of reagents
  - inter reactor fresh gas feed
- Optimisation of gas loop
- Especially valid for multi reactor plants
- Heat removal becomes limiting
- Early on learning curve

Fischer-Tropsch reactors



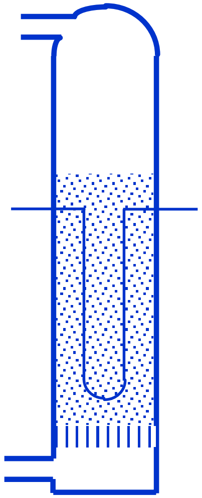
Sasol Advanced Synthol Reactor

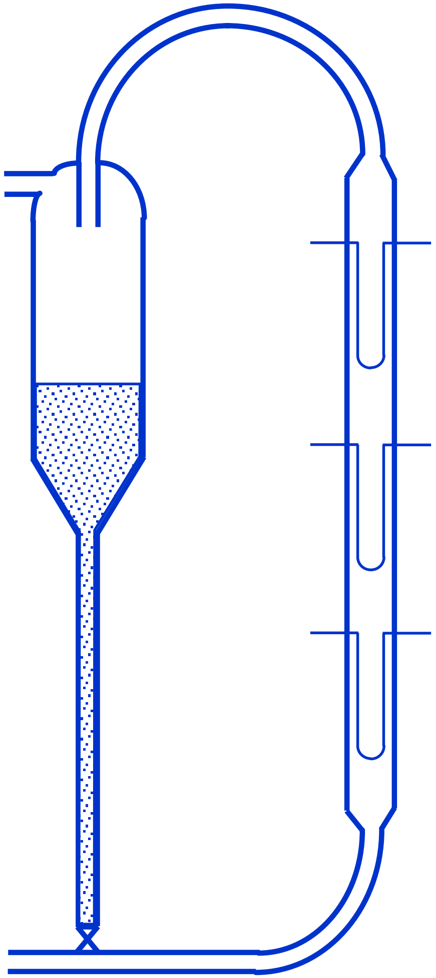
- 19 Synthol Circulating Fluidised Bed reactors used during 1955 – 2000
- 16 CFB replaced by SAS reactors:
  - Four 8 m reactors of 11 000bbl/day
  - Four 10 m reactors of 20 000bbl/day



Sasol Advanced Synthol Reactor
(cont).

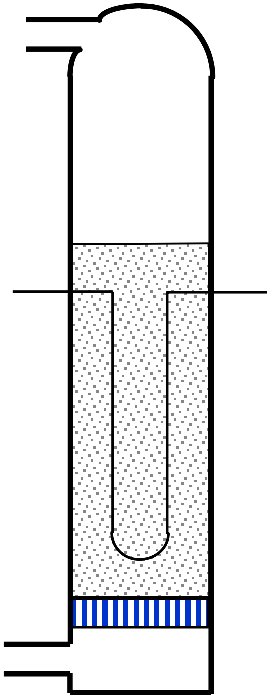
For the same capacity, the relative reactor sizes are:





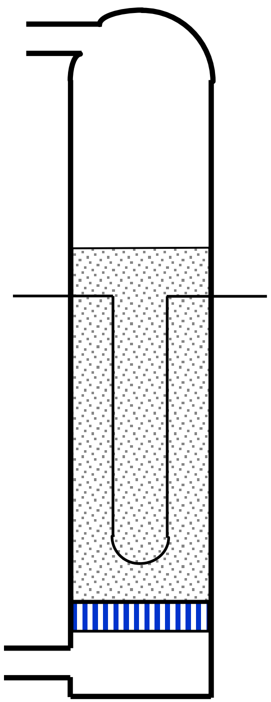
Sasol Advanced Synthol Reactor (cont).

- SAS reactors:
  - simpler structure and support
  - no circulating catalyst
  - all catalyst in use all the time
  - catalyst consumption reduced to 40%
  - easier to operate
  - cheaper – 40%
  - less maintenance - 15%
  - more heat transfer surface
  - greater capacity



Sasol Advanced Synthol Reactor (cont).

- SAS design geared to replace existing CFB reactors
- Catalyst not used optimally
- Fe cat inhibited by water
- Parallel operations – recycles
- Low conversions per pass
  - Recycle
  - Series reactors
- Interstage removal of water
- Can use higher activity catalyst
- > 20 000bbl/day reactors indicated



In Conclusion

- GTL technology at early stage of development
- Incentive for improved FT technology
- New FT reactors early on learning curve
- Opportunities from
  - better use of more active catalysts
  - series in stead of parallel configurations
  - debottlenecking new limiting mechanisms
    - e.g. heat removal
    - heat management in GTL plants
- Optimal FT reactor design not in isolation

  Part of philosophy of overall plant design
- **Early on learning curve – opportunities**