UNIVERSITY OF PADERBORN

An update on dividing wall column technology

Chair of Fluid Process Engineering
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Introduction

Process Intensification and dividing wall column

- Current economic, ecological and societal development results in rising energy consumption
- More “efficient” and “clean” energy is required
- Significant impact of Process Industries via *Process Intensification (PI)*
- It is particularly important for energy intensive operations

→ **Dividing wall column (DWC) represents a response to these demands!**

Intensification of distillation

- Distillation is known for its extreme energy demand: it covers 40-70% of investment & operating costs of a typical chemical plant and requires about 3% of world's energy consumption!

- Distillation is inefficient from the energetic point of view, since the heating energy for the reboiler is supplied at high temperatures, whereas at the condenser, it is removed at low temperatures (mostly useless)

- Significant energetic improvements of conventional distillation sequences are both desirable and possible

- One of the major ways towards intensification of distillation is INTEGRATION
  - thermal (heat streams)
  - material
  - equipment-related (separation units)

→ **Dividing wall column (DWC)!**

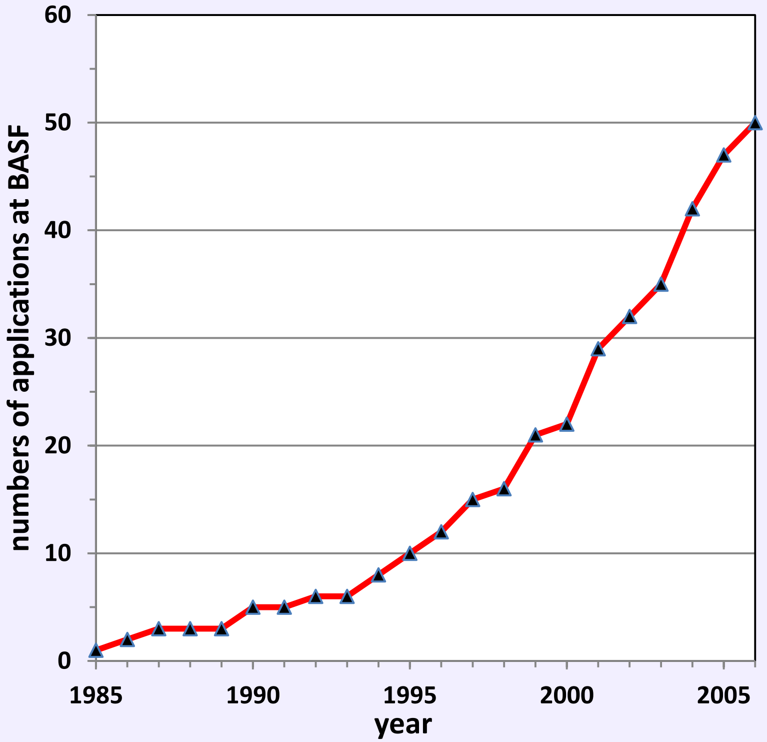
Some history

Main discoveries and rediscoveries

- E.W.Luster, Standard Oil Company. A US patent in 1933. Origins of a DWC
- A.J.Brugma, A Dutch patent in 1936 and a US patent in 1942. The idea of using one heat flux for more than one separation task. Brugma should be credited as inventor of thermal coupling in distillation
- R.O.Wright, A US patent in 1949. The DWC for general purposes
- R.P.Cahn et al. Esso R&E Co. A US Patent in 1962; F.B.Petlyuk. Publications in 1960s. Rediscovery of thermal coupling
- V.A.Giroux, Phillips Petroleum Company. A US Patent in 1980. Conventional DWC
- G.Kaibel, BASF SE. Two European patents in 1984. Extension of basic ideas to systems with more than three components and to reactive systems

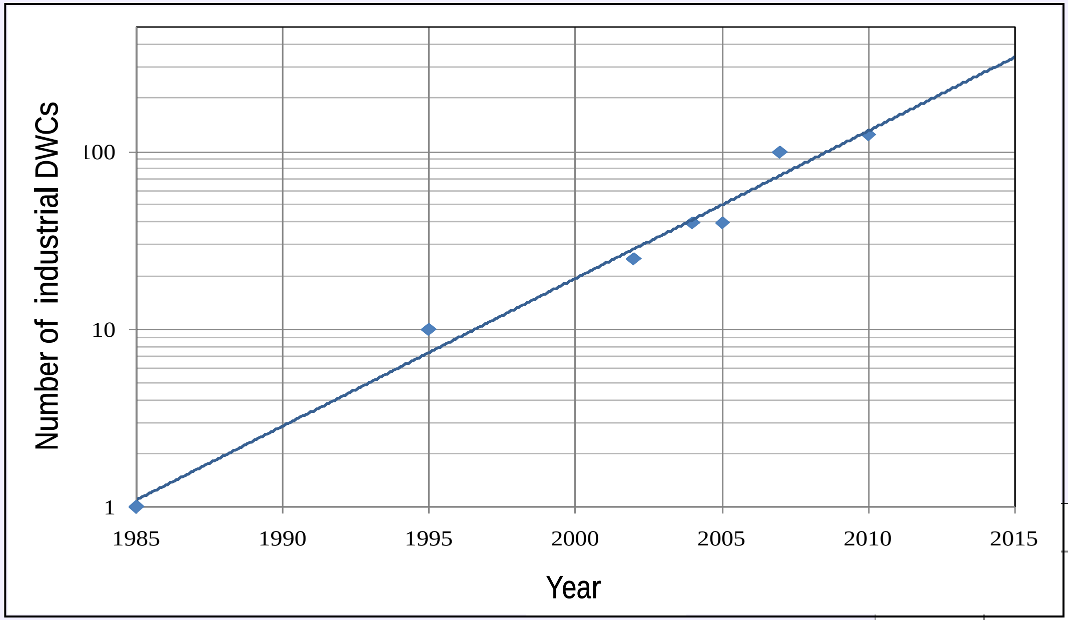
Fast grow in the last years

- First industrial application at BASF SE in 1985
- 50 DWCs in use at BASF and 5 at other companies in 2006
- Diameter 0,6 - 5,0 m; height 10 - 107 m; pressure 2 mbar - 10 bar
- In 2010 already over 100 DWC applications
- Different internals – gauze wire and metal sheet structured packing, random packings, trays



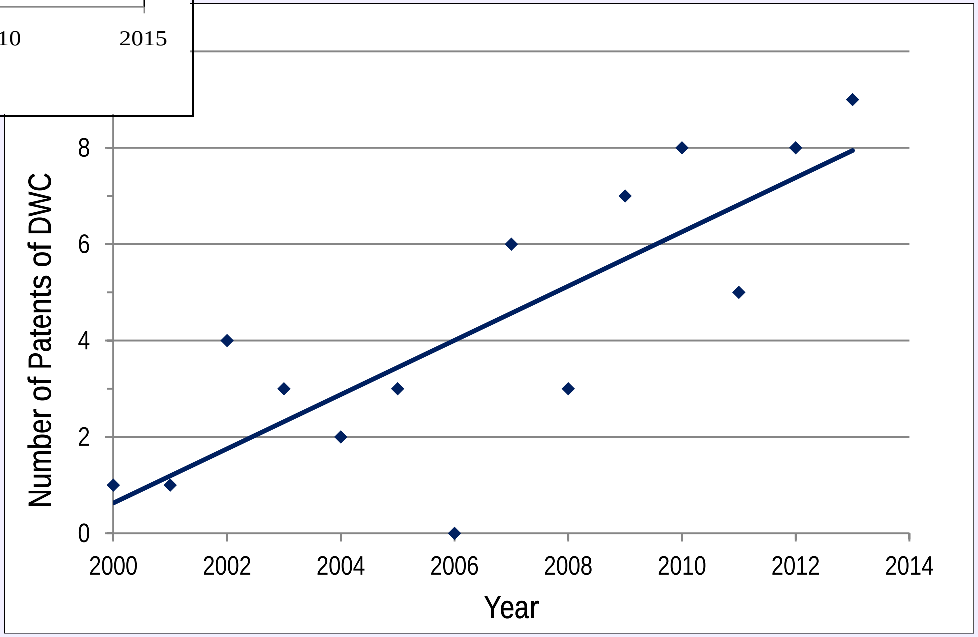
- According to *Schulz et al.* (2002), the DWC will become a standard distillation tool in the next 50 years

Fast grow in the last years



- DWC applications worldwide (exponential grow!)

- DWC patents



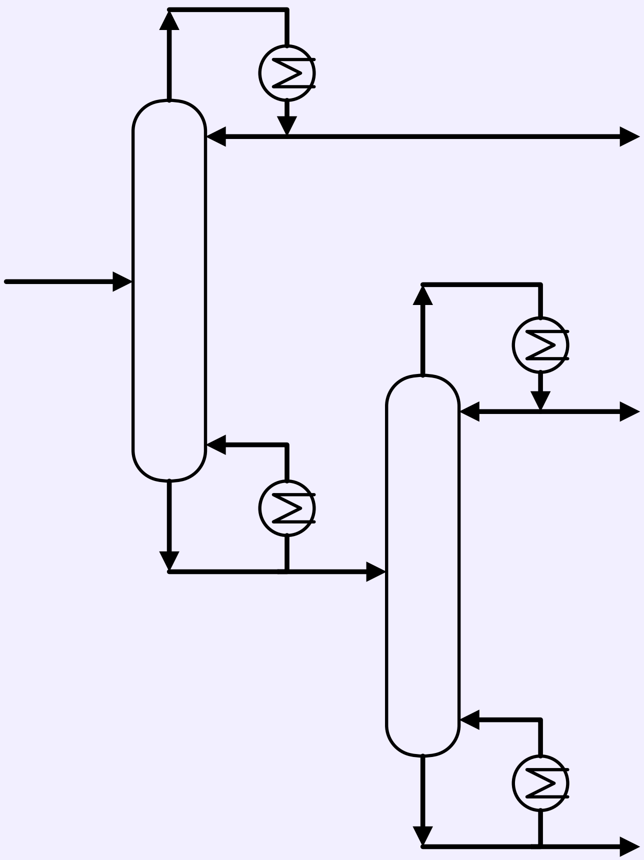
Fast grow in the last years

- Nevertheless, up to now – only half-hearted implementation (except BASF)!

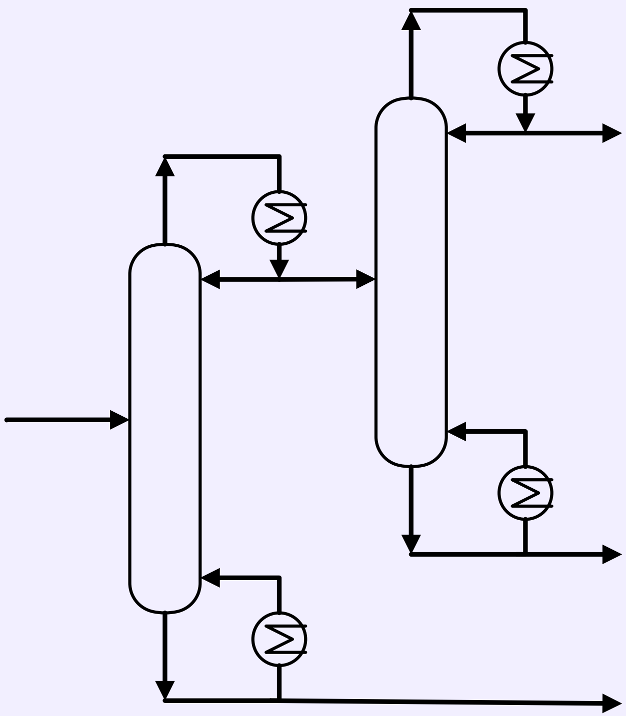
Principle and designs

Separation of three-component mixtures

- Two column set-up: classical concepts



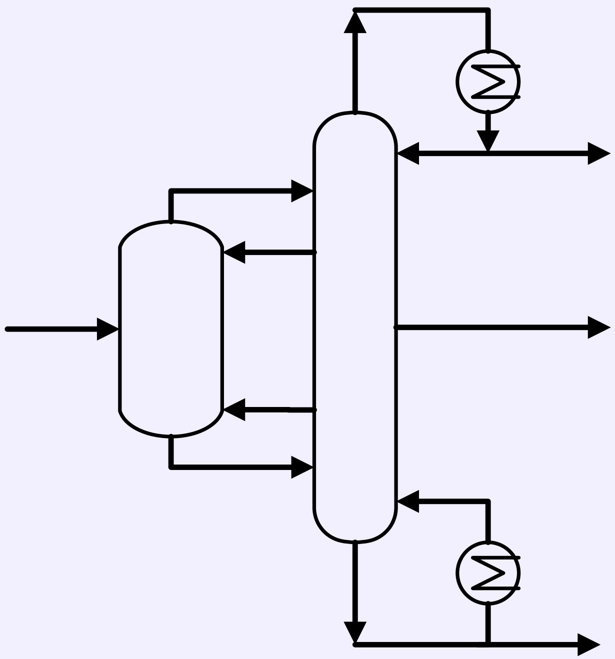
Direct sequence



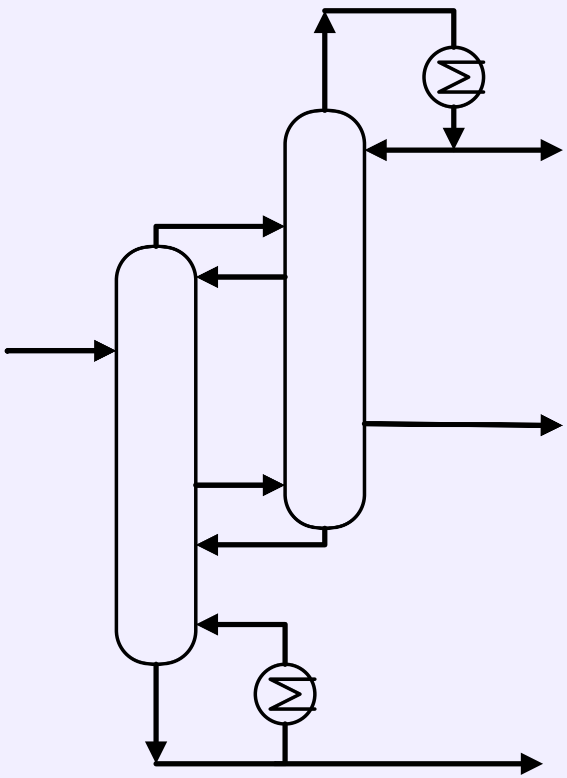
Indirect sequence

Separation of three-component mixtures

- Thermally coupled columns: energetic integration



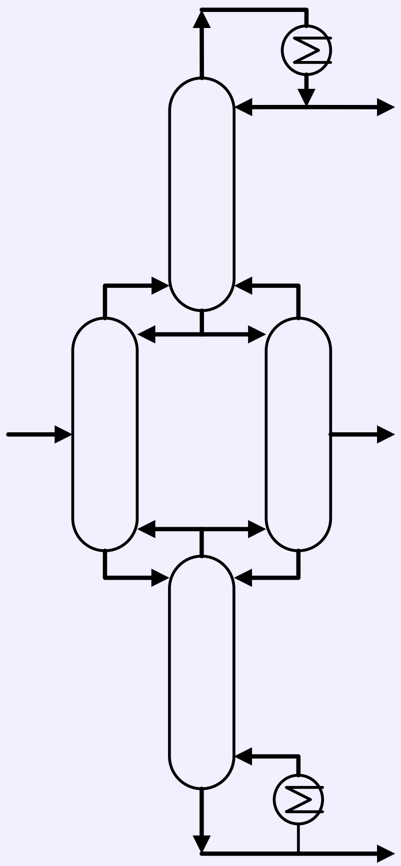
Classic Petlyuk sequence



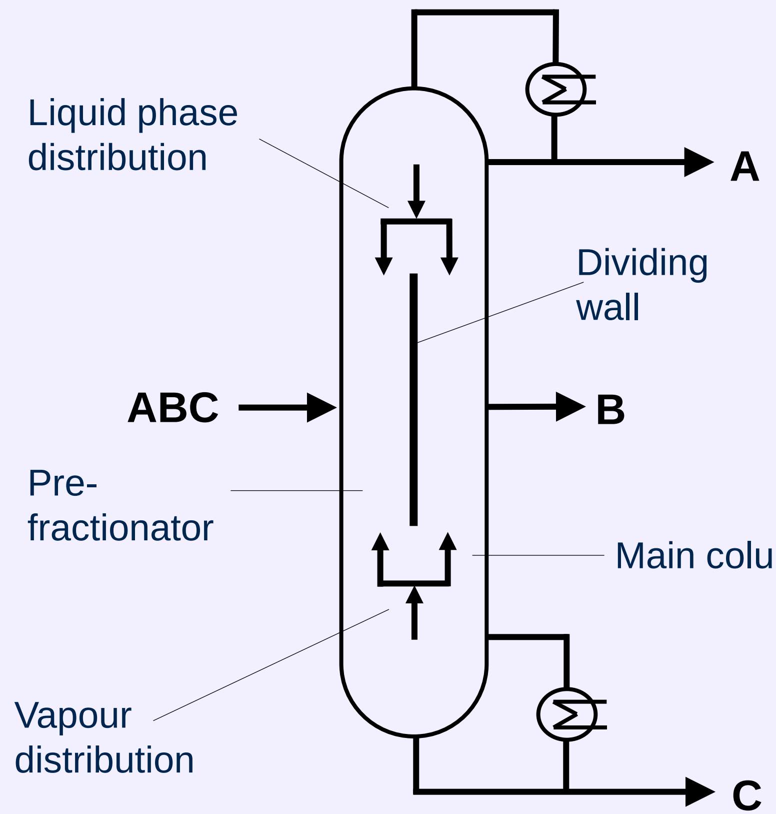
Modified Petlyuk structure for vapour flow control

Separation of three-component mixtures

- Thermally coupled columns: energetic integration
- Integration of the Petlyuk configuration in one DWC

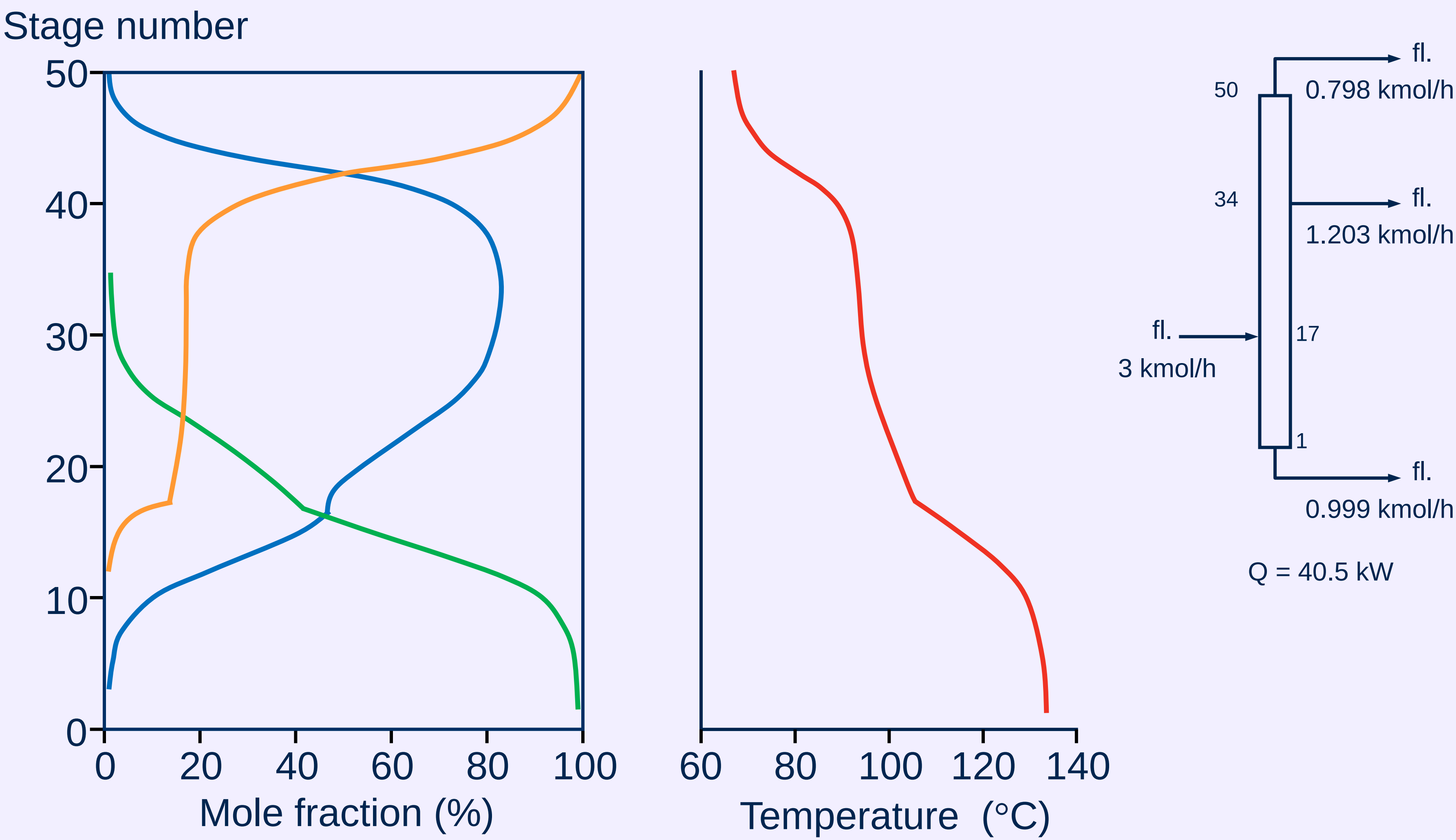


Four-column Petlyuk configuration



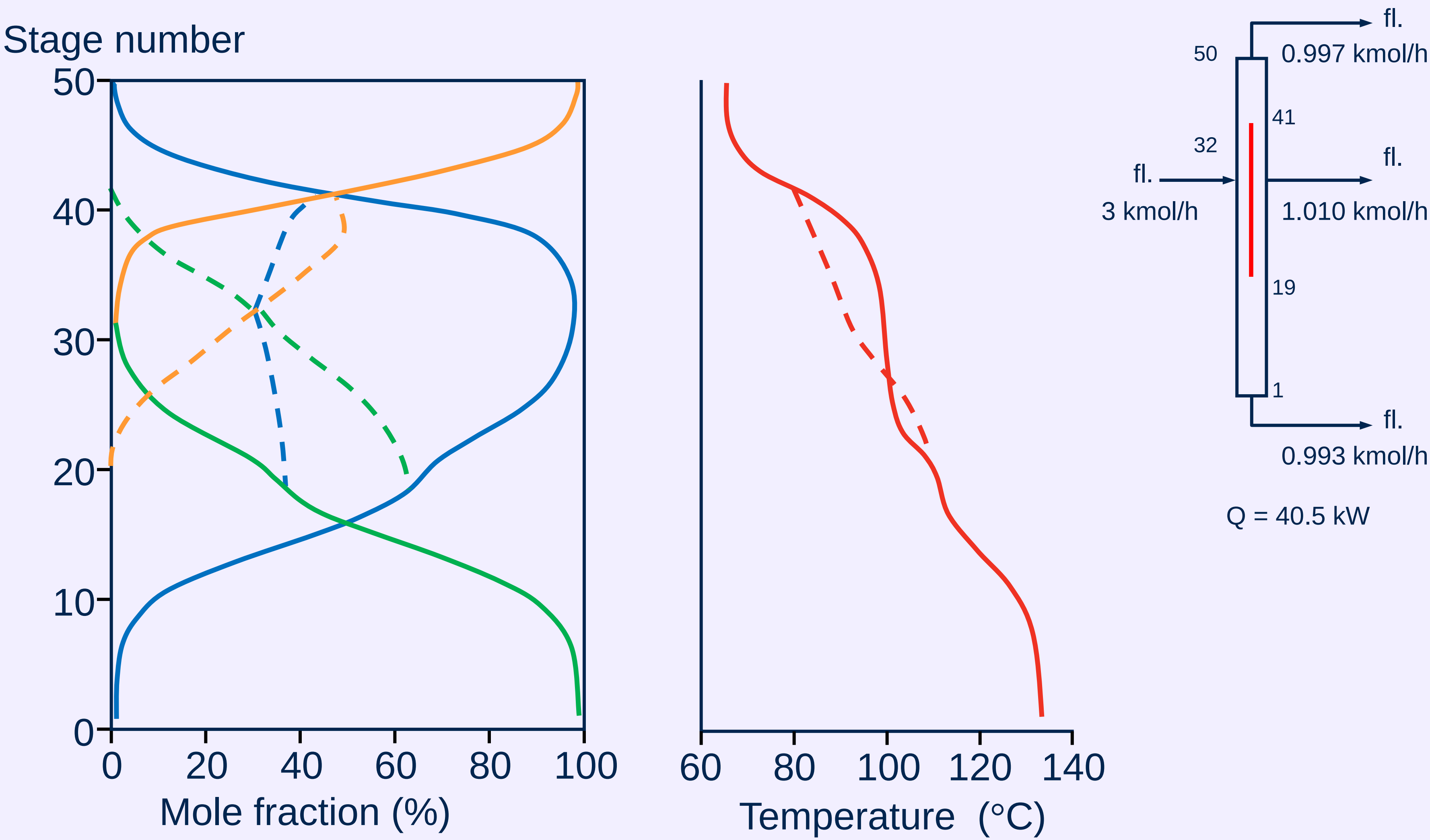
Dividing wall column

Separation of a C6/C7/C8 mixture in a column with a side draw



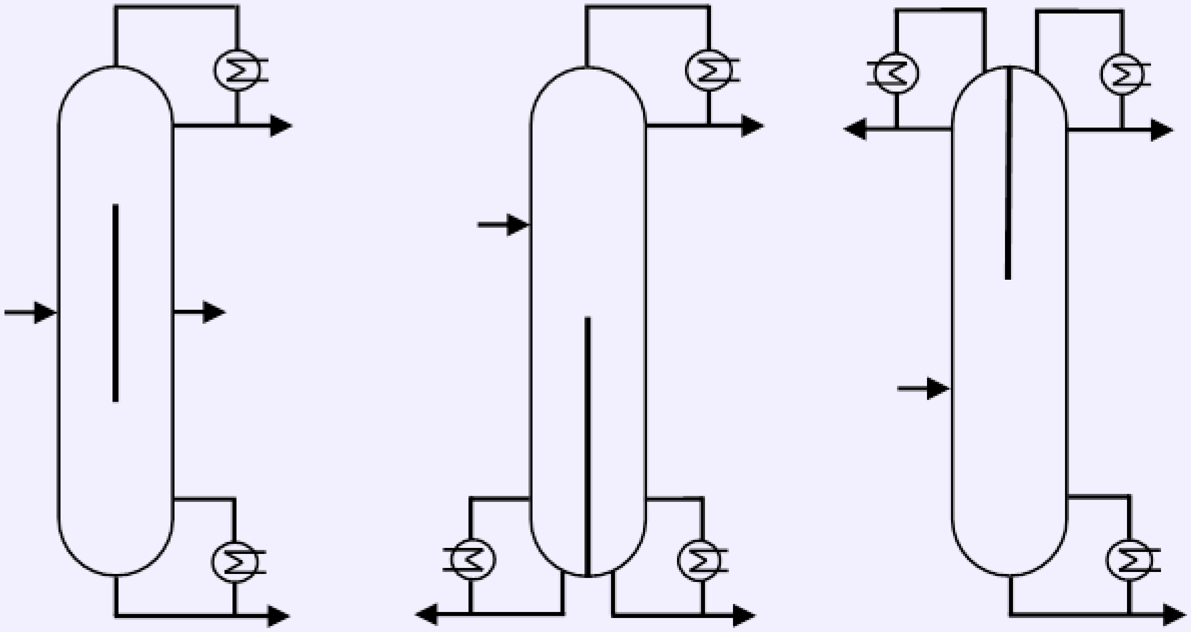
Grossmann et al., GVC/DECHEMA annual meeting (2006)

Separation of a C6/C7/C8 mixture in a DWC (single shell)



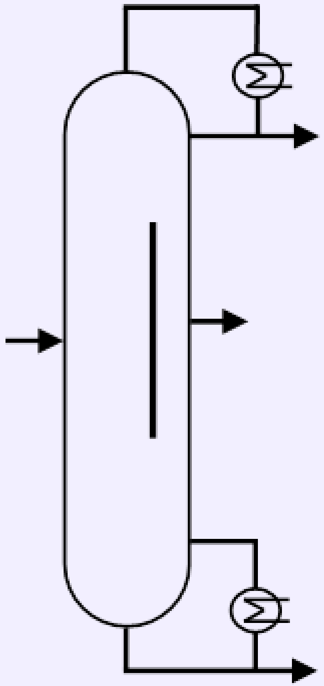
Grossmann et al., GVC/DECHEMA annual meeting (2006)

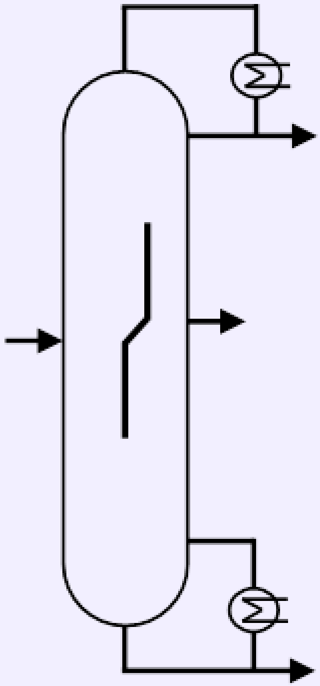
Basic types and wall position



- Classical configuration (left)
- Split shell column with common overhead and divided bottom section (middle)
- Split shell column with divided overhead and common bottom section (right)

Basic types and wall position





- Shifted wall (left) – e.g. when the amount of middle boiling component is low
- A DWC with diagonal wall sections (right) – e.g. for vapour feed

Welding

- Initially, dividing walls were welded to the shell

- The non-welded wall technology was developed and implemented by BASF SE and Julius Montz GmbH
- Non-welded walls result in much simpler column design, faster and more precise installation (*B.Kaibel et al*., 2006)
- Further benefits are fewer manholes and lower weight (less metal required)
- Faster, simpler and cheaper revamping
- First implementation of non-welded walls in mid 1990s
- Afterwards a considerable increase of DWCs delivered by Montz GmbH - around 85 deliveries in 2009 (*Dejanovic et al*., 2010)

Advantages of DWC technology

- Lower energy consumption as compared to common column configurations – savings up to 50% or even higher
- More compact equipment
- Lower equipment cost
- Reduced thermal load due to single evaporation
- Possibility to reach sharp separation of a ternary mixture within only one column
- Enhanced product yield and quality

Advantages of DWC technology

- According to literature, the revamping of conventional columns to DWCs is a relatively straightforward opportunity to reduce the operating costs (*Yildirim et al*., 2010).
- Reduction of one column can save up to 30% of the energy costs, and the revamping can pay back within one or two years (Parkinson, 2005)!

Favorable application areas

- Broad spectrum
  - From low-purity separation, e.g. in solvent recycling …
  - … up to high-purity separation, e.g. for electronic-grade products
- Frequently for cases, when the *desired middle-boiling product* component is to be separated from small amounts of low-boiling and high-boiling components

Limitations of DWC technology

- Operational pressure variation between column sections is impossible
- Higher temperature difference between reboiler and condenser
- Greater column height
- Generally more complex modelling, design and control

Modelling

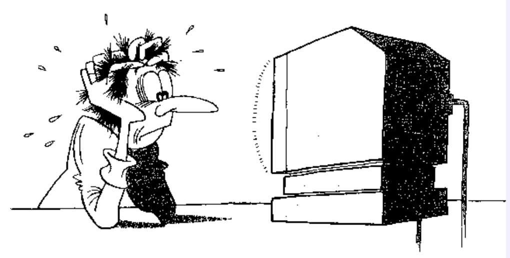
Expectations of Industry

- Modelling:
  - Predictivity independent of the system complexity
  - Covering more details about system interactions
  - Possibility to be extended to govern more complex processes, e.g. in reactive systems
- Simulation tools
  - User-friendly interface
  - High flexibility
  - Simple and robust initialisation

Present-day modelling practice

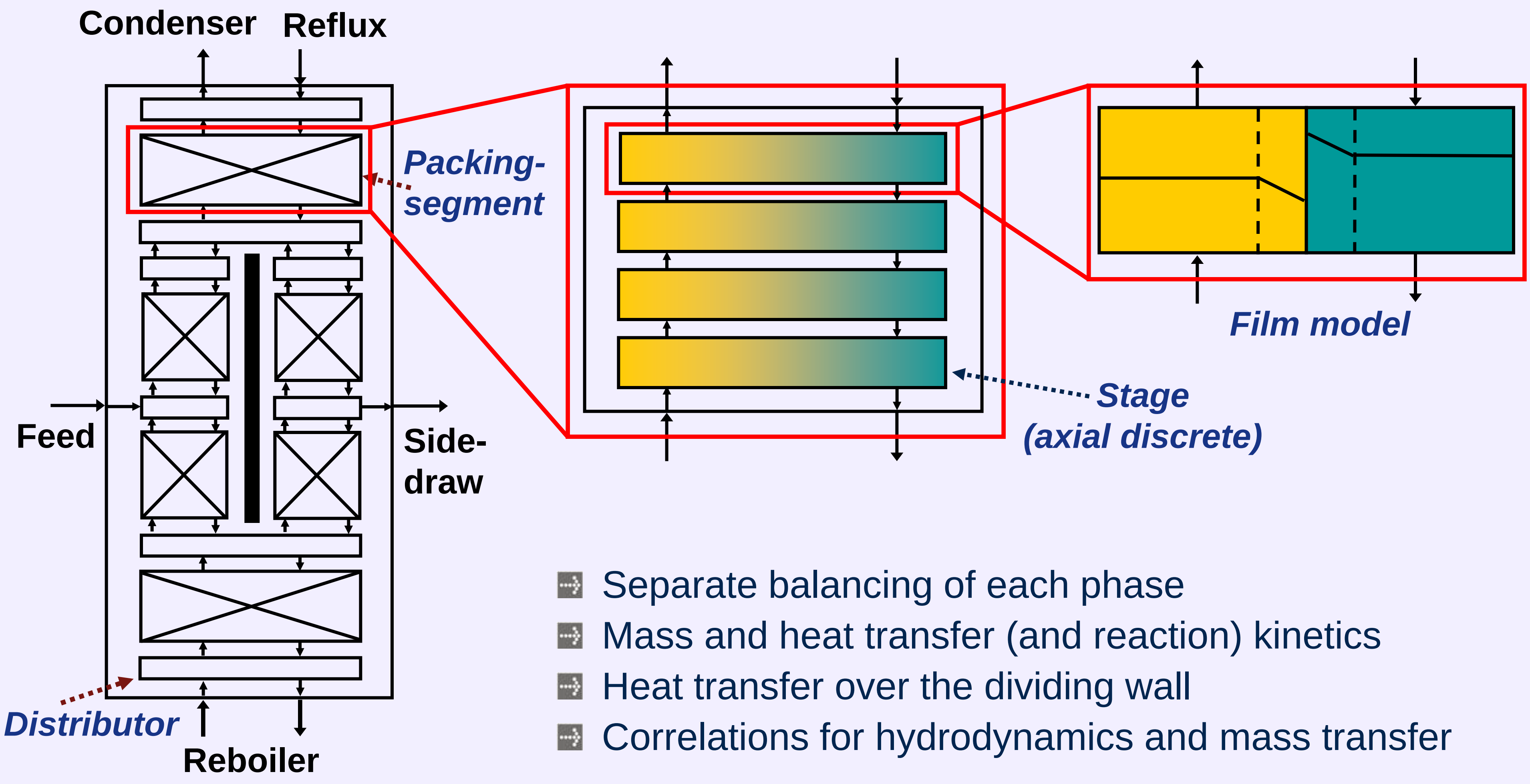
- Advantages:
  - Usage of well-known simulation tools (e.g. Aspen Plus™)
  - Results are often sufficient for non-reactive DWCs

- Disadvantages:
  - Convergence is often difficult
  - Problems for complex systems (e.g. multicomponent mixtures), as modelling depth is often inadequate



→ **Development of DWC models under consideration of existing know-how**

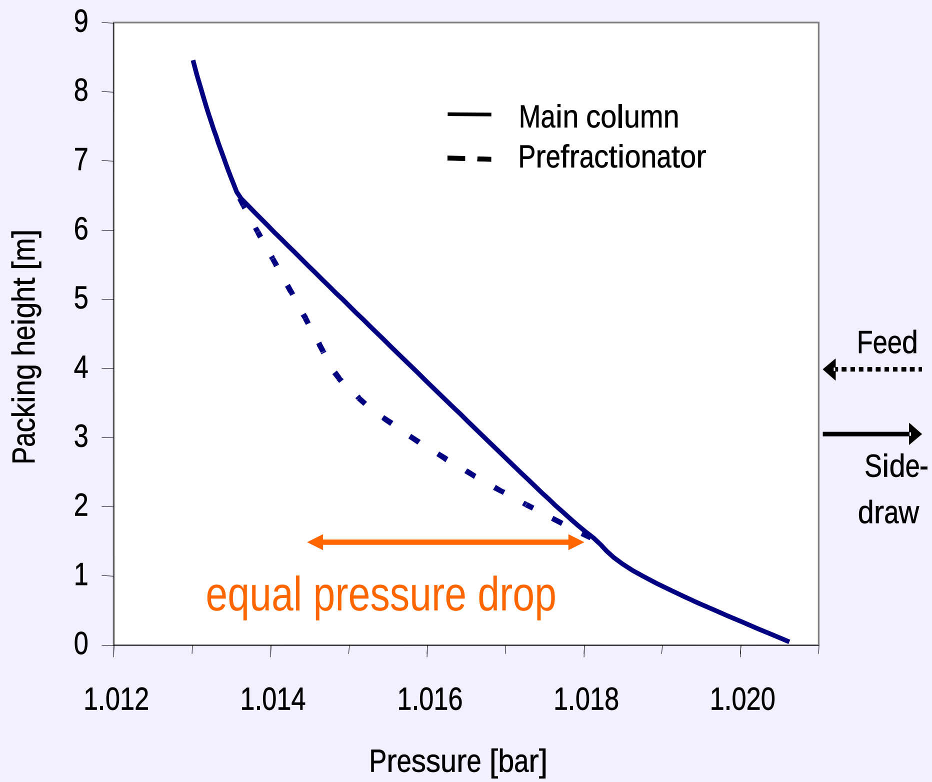
Rate-based modelling

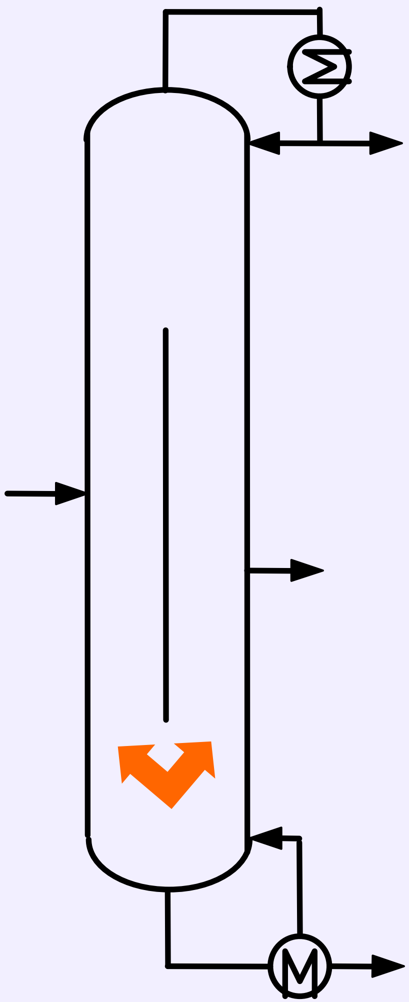


- Separate balancing of each phase
- Mass and heat transfer (and reaction) kinetics
- Heat transfer over the dividing wall
- Correlations for hydrodynamics and mass transfer

Rate-based modelling

- Peculiarities of the DWC:
  - Self-adjusting vapor distribution
  - Heat transfer through dividing wall





Rate-based modelling

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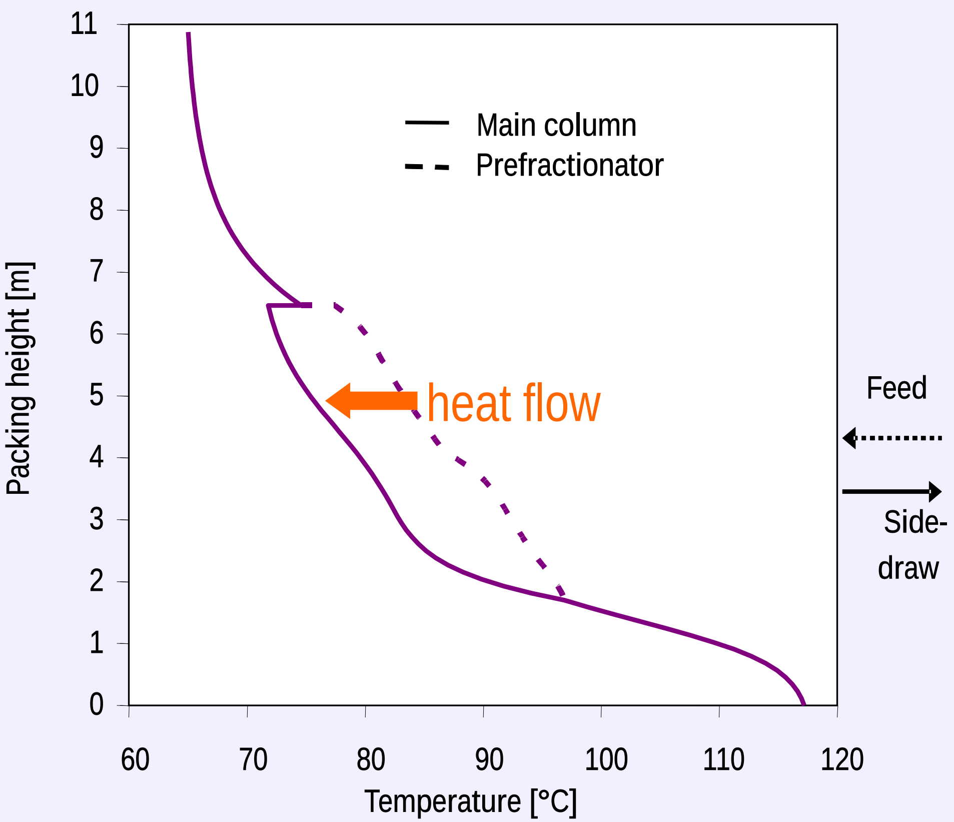
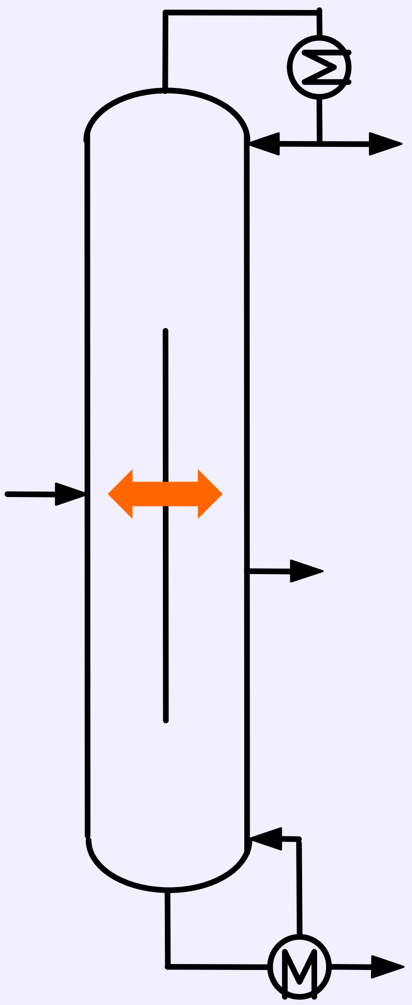




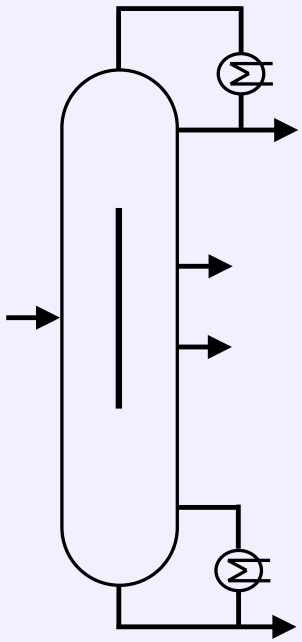
Control issues

- Concern that the benefits of the DWC technology are obtained at the cost of lacking controllability!
- Rather limited literature
- Additional degree of freedom due to liquid splitting – can be controlled!
- Both three-point and four-point control structures
- Different methods (*Yildirim et al*., 2011)
  - Controlling product purities
  - Controlling temperatures instead of purities
  - Controlling of the prefractionator sub-system
  - Some more advanced techniques
- According to the literature, DWCs are generally well controllable!

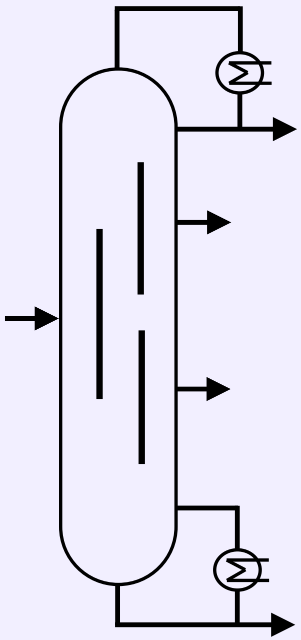
Some inspiring configurations
(four-component mixtures)

Possible DWC configurations for four-component mixtures

Kaibel column



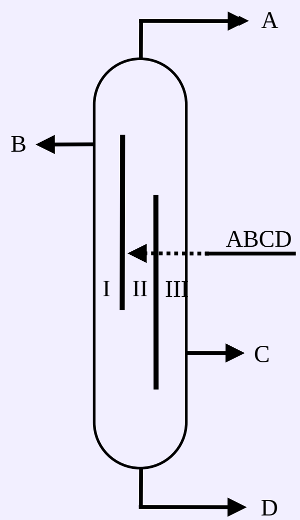
Sargent arrangement

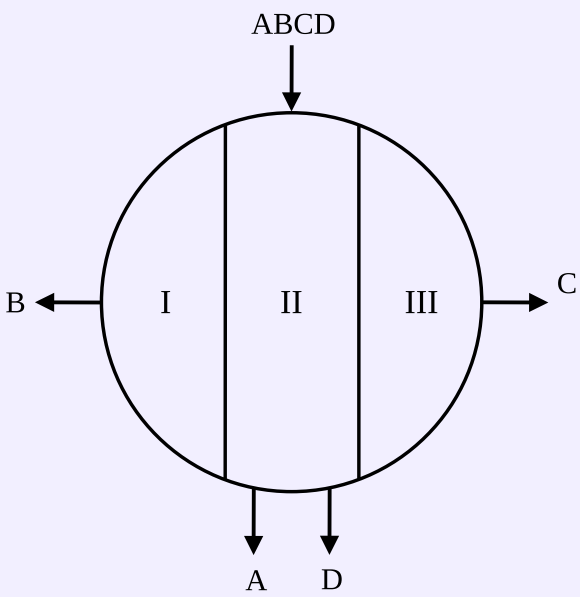


- Left configuration is thermally inefficient (*B.Kaibel et al*., 2006)
- Improvement by application of additional dividing walls (right)

Possible DWC configurations for four-component mixtures

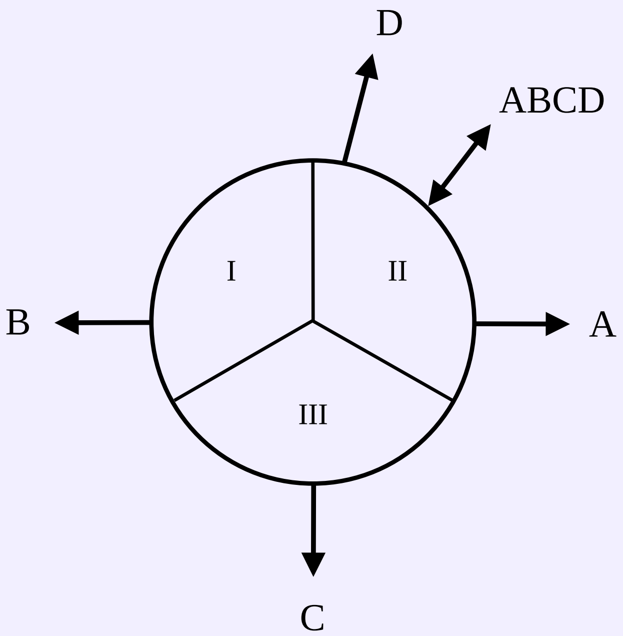
Agrawal arrangement





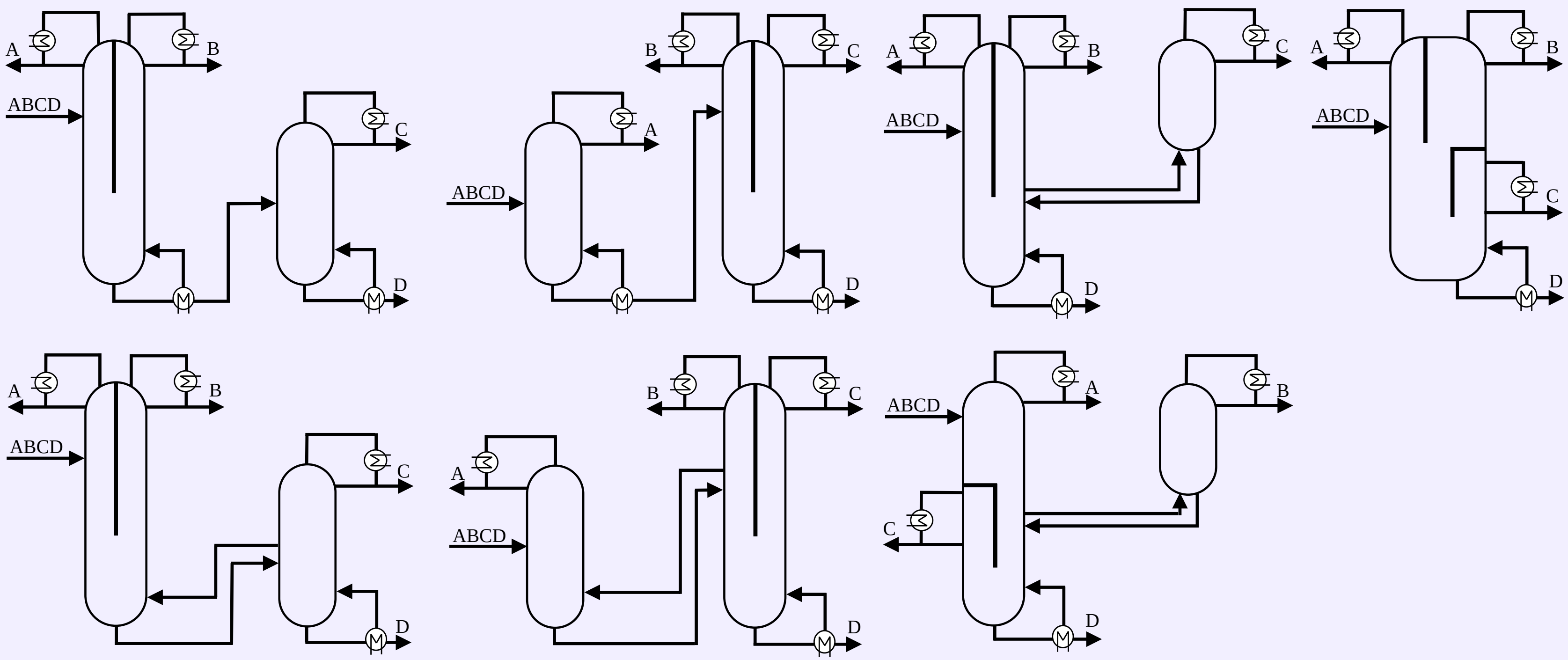
- Feed entering the middle partition of the DWC (*Agrawal*, 2001)

Possible DWC configurations for four-component mixtures



- Conceivable arrangement with three dividing walls

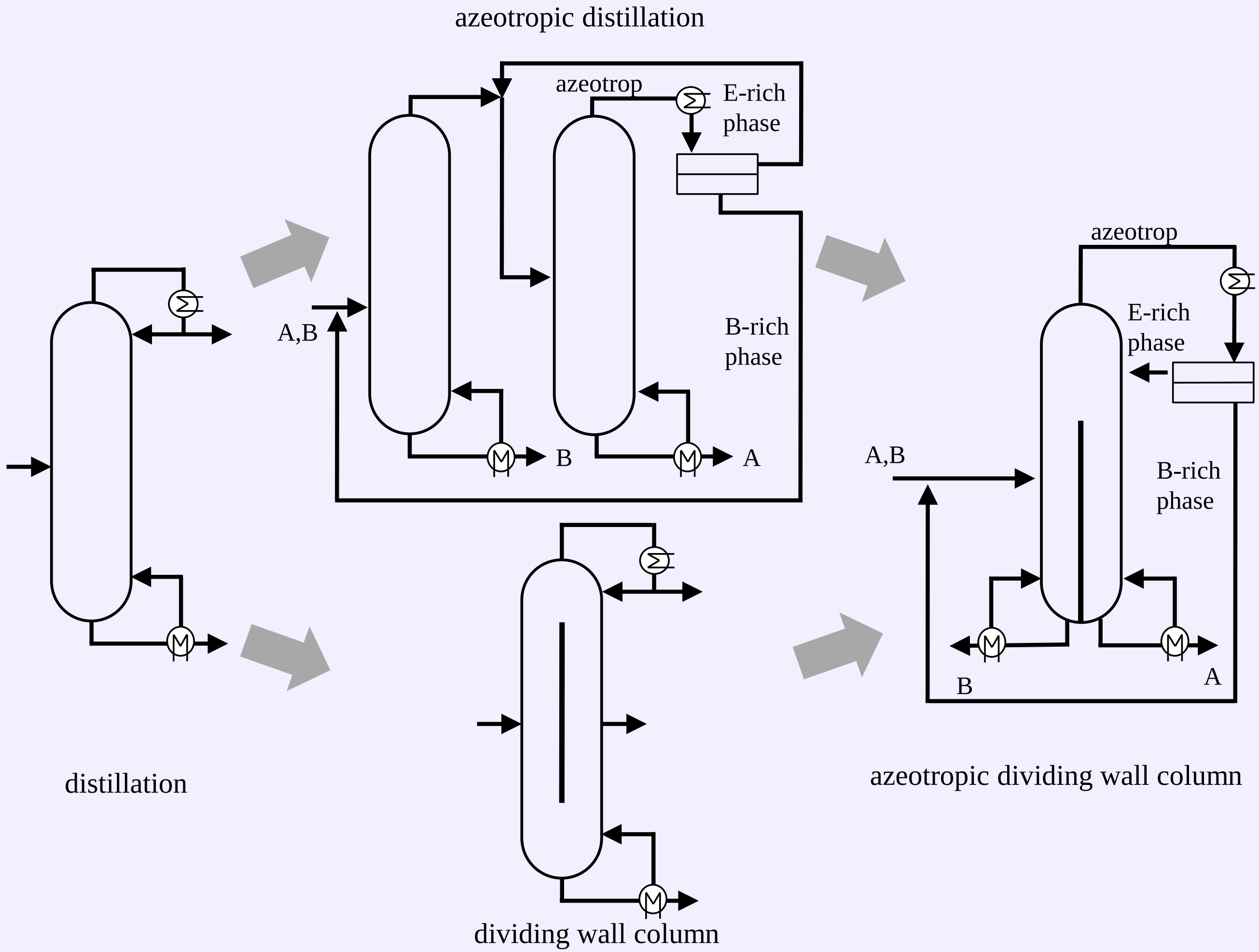
Possible DWC configurations for four-component mixtures



- A procedure allowing a quick synthesis of possible alternatives by *Rong* (2010)

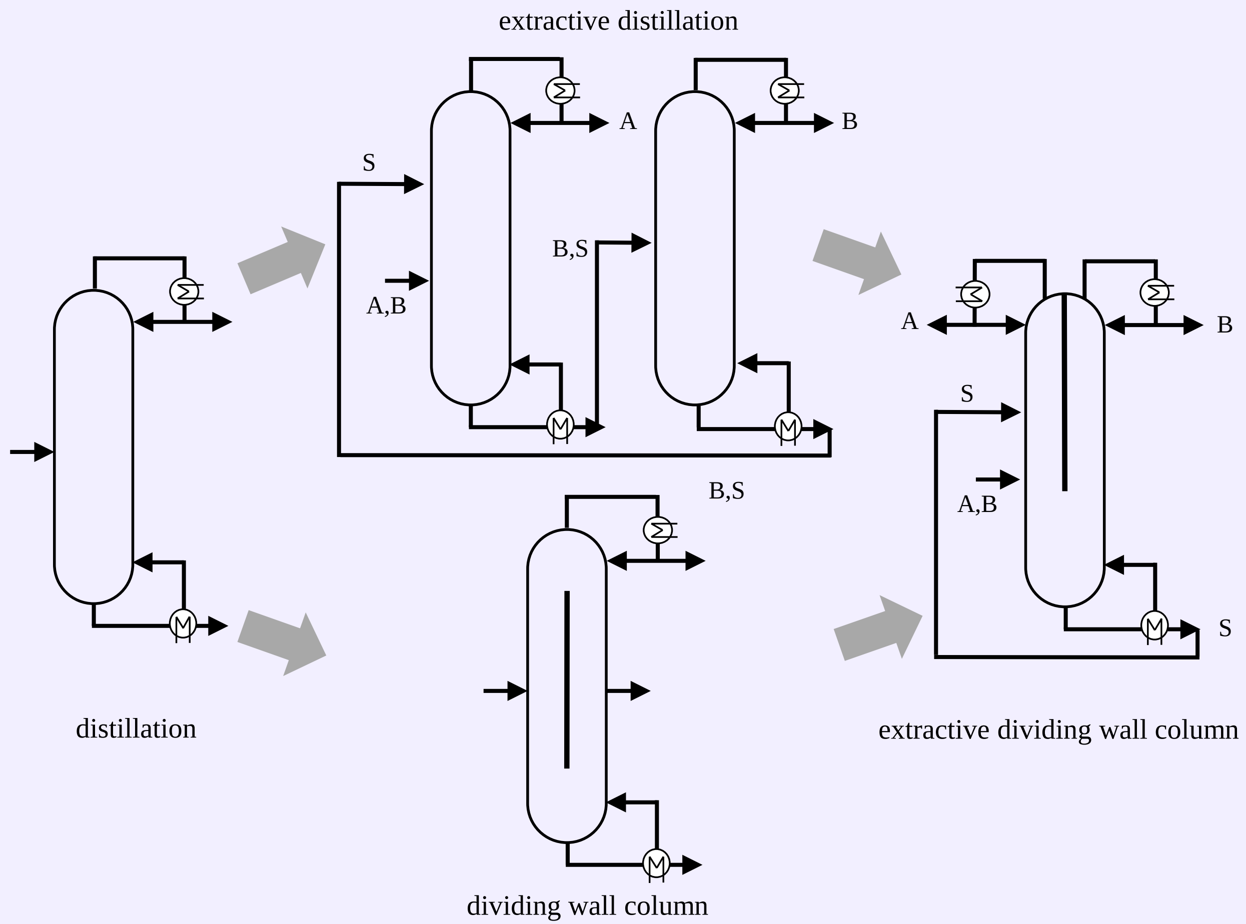
Azeotropic, extractive and reactive DWC

The path to an azeotropic dividing wall column (A-DWC)



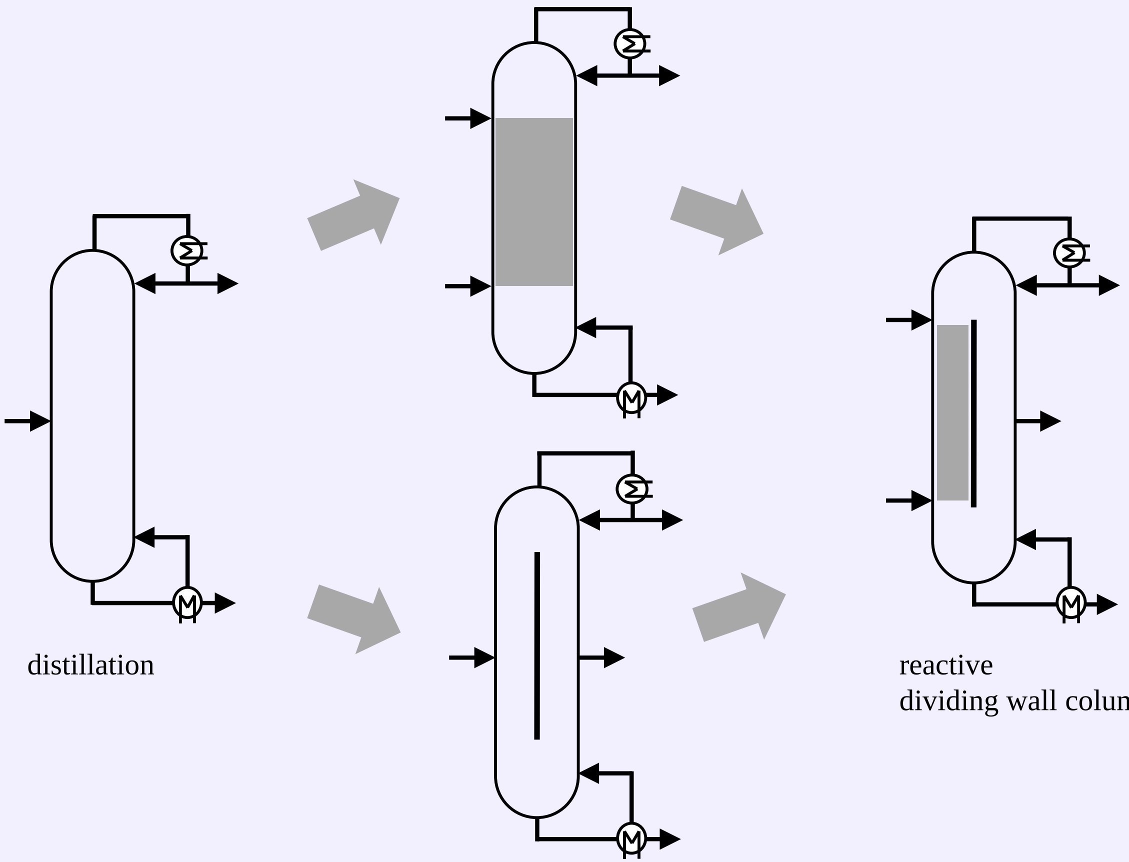
- Only few publications containing theoretical analysis; an industrial application mentioned by *B.Kaibel et al.*, 2006, without giving any details

The path to an extractive dividing wall column (E-DWC)



- Just few publications; however a couple of industrial application in Germany (by Uhde and BASF)

The path to a reactive dividing wall column (R-DWC)



- Still a niche application, future depends on reactive distillation development

Concluding remarks

Common barriers for PI from industrial point of view

- Reliability of conventional technology
- Risk due to lack of precedent
- Expensive new pilot plant facilities
- Concerns about safety and control
- Lacking knowledge about how and where to intensify
- Lack of validated PI units
- Missing criteria to evaluate PI
- Often more complex modelling

→ **In case of DWCs – largely overcome!!**

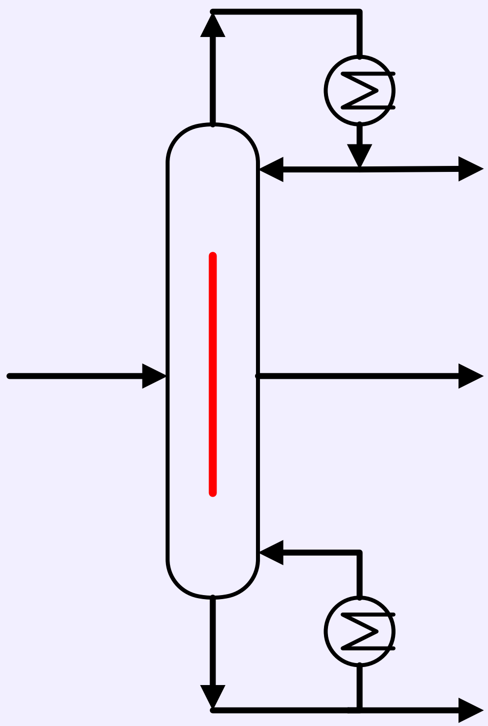
Summary

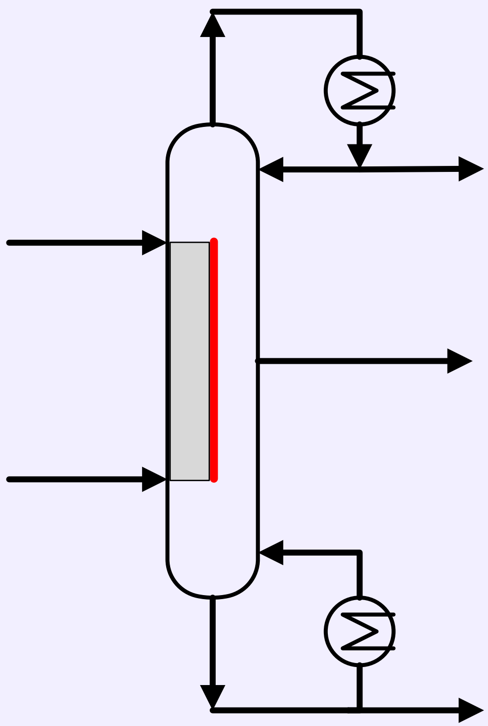
- Compared to conventional distillation units, DWCs represent advantageous alternative regarding both energy and hardware aspects
- The application of the DWC technology is expanding, but mostly by one chemical company only; this is accompanied by high activity of academia
- The design, operation and control of DWCs require adequate simulation tools; these are largely available
- High variability of the DWC technology (more than three components, azeotropic, extractive, reactive distillation)
- It is highly probable that the DWC will become a standard technology in the near future for a broad application spectrum – around 350 implementations is expected by 2015

→ **You are welcome to contribute to this trend!**

Further information sources

- *I.Dejanovic, Lj.Matijasevic, Z.Olujic, Chem. Eng. Process. 49 (2010) 559-580*
- *O. Yildirim, A.A.Kiss, E.Y.Kenig, Separ. Purif. Technol. 80 (2011) 403-417*





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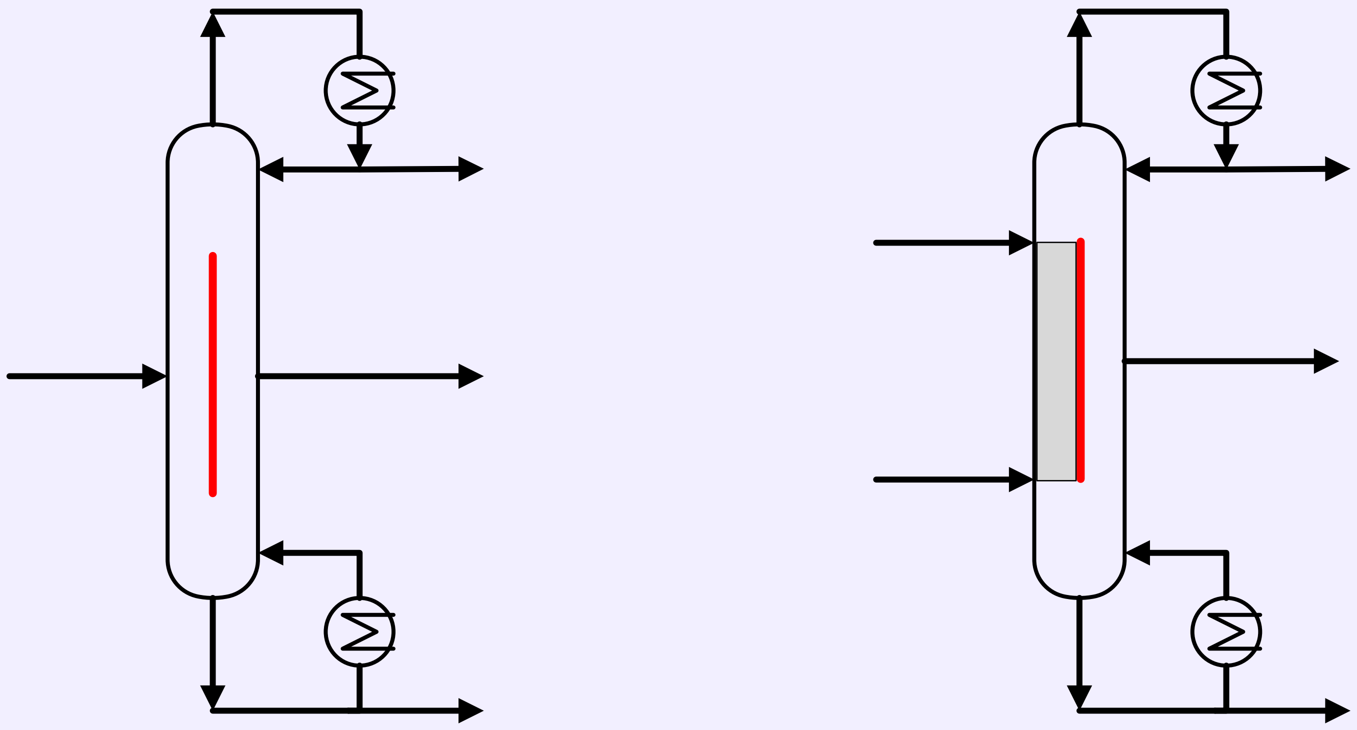
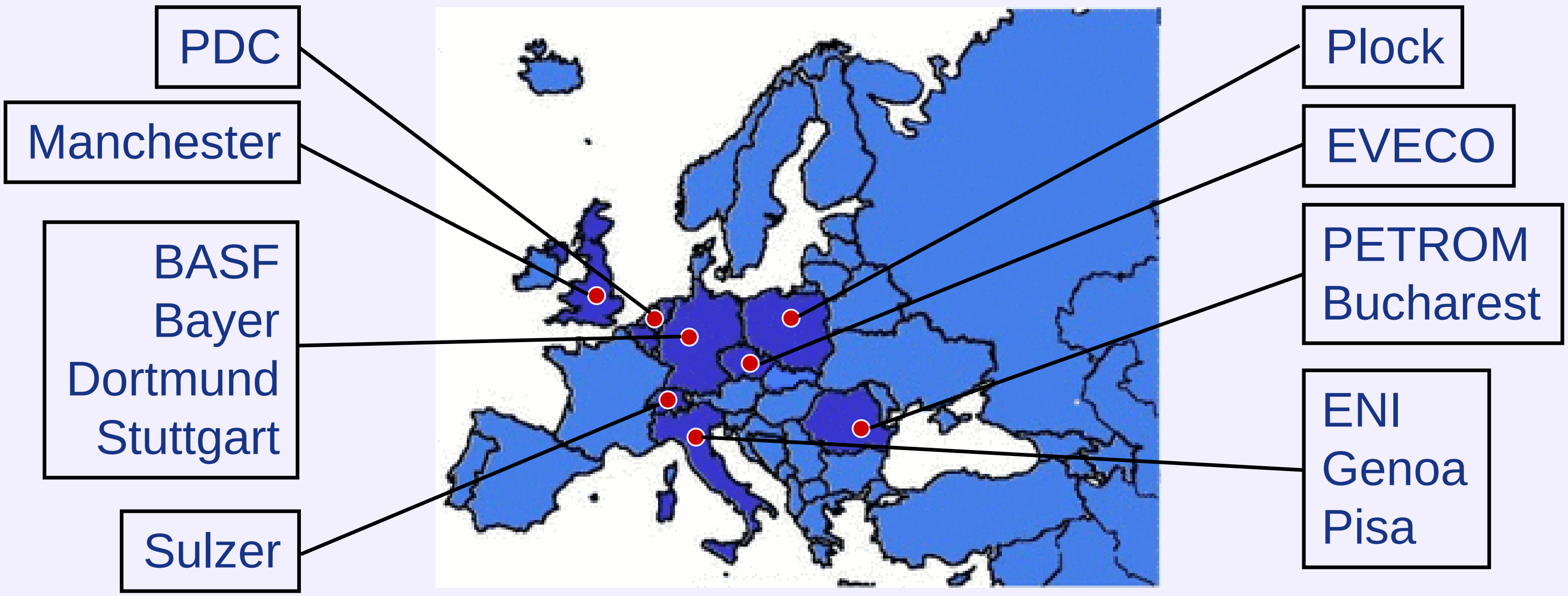


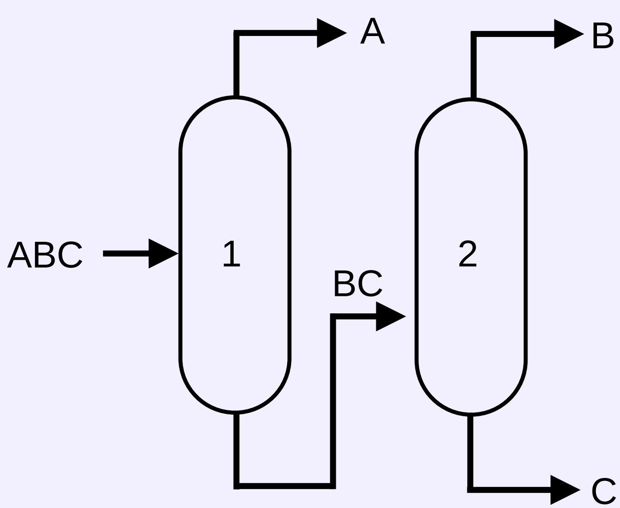
Toward validation of reactive DWC

- Runtime: February 2004 - January 2007
- 14 Partners from 8 European Countries
- Financial support by the European Commission



Explanation to the DWC integration principle

Conventional column sequence to separate a ternary mixture



Problem: High energy demand

Energy-integrated column (Petlyuk configuration)