Energy efficient distillation

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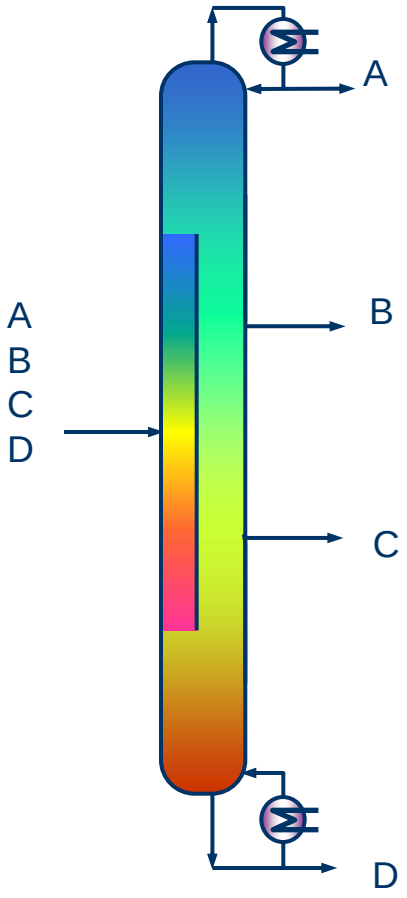
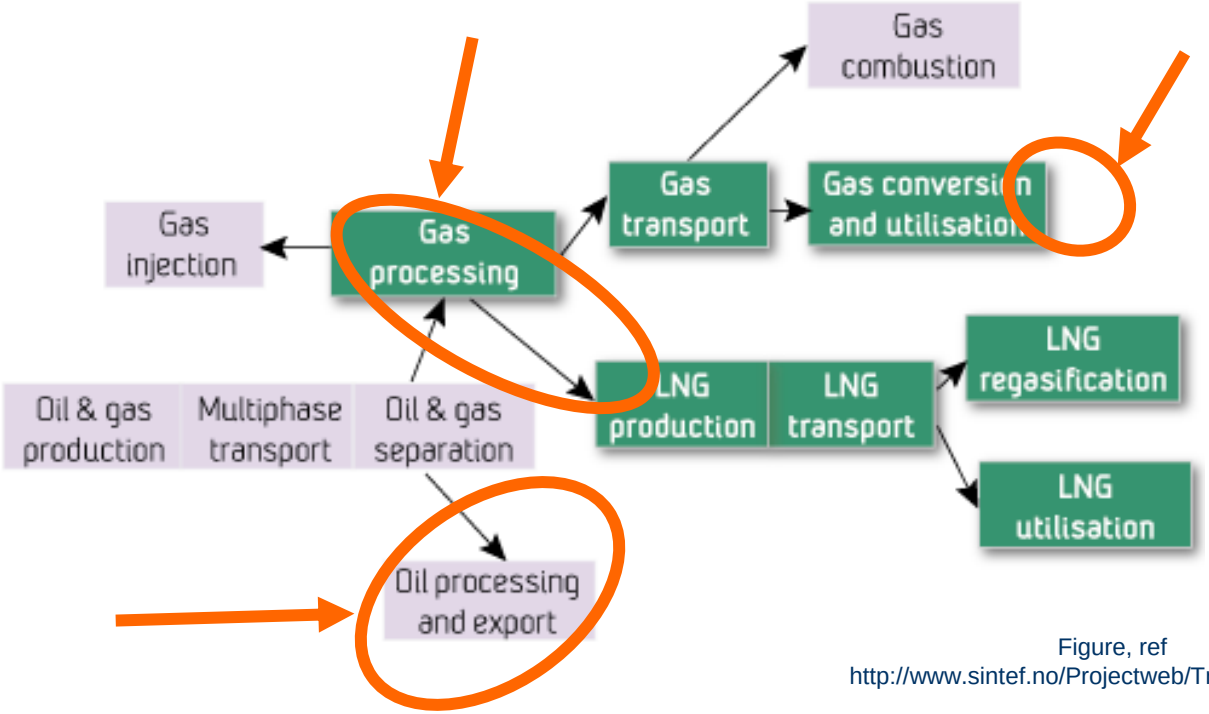
21 - 22 October 2009



Distillation in the gas value chain

- Distillation plays an important role in splitting raw production streams into more useful product streams with specified compositions



Figure, ref
http://www.sintef.no/Projectweb/Trondheim_GTS/

Distillation consumes energy

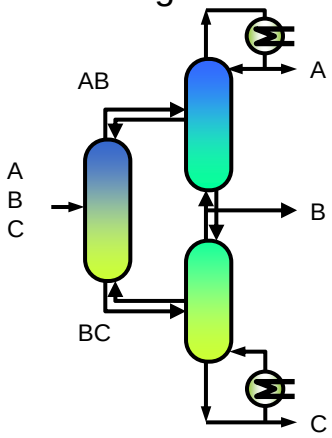
- 2-5% of the world industry heat consumption
- There is a potential for more energy efficient solutions
- Picture: Fractionation columns at the Snøhvit LNG-plant in Hammerfest

Foto: I.Halvorsen 21.09.2005

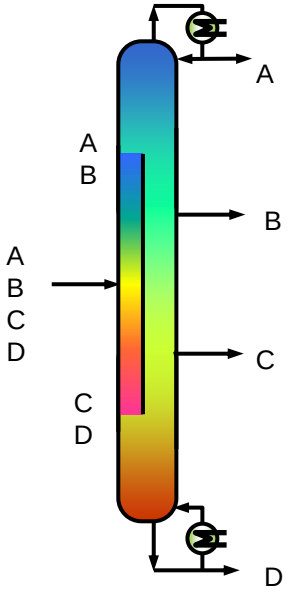
BEEDIST (Basic Energy Efficient Distillation Technology)

- Founded by the Norwegian Research Council through the GASSMAKS program
- SINTEF/NTNU 2008-2012
- Objectives
  - Study new integrated distillation arrangements
  - For reduction of capital cost and energy consumption (+ CO2-emission related to the energy).
  - 20-40% savings in reach.
  - Evaluate application in natural gas processing and conversion.
  - Design and operation
  - Develop laboratory
  - 2 PhD + post doc

3-product Petlyuk arrangement



4-product Kaibel-column with a dividing wall

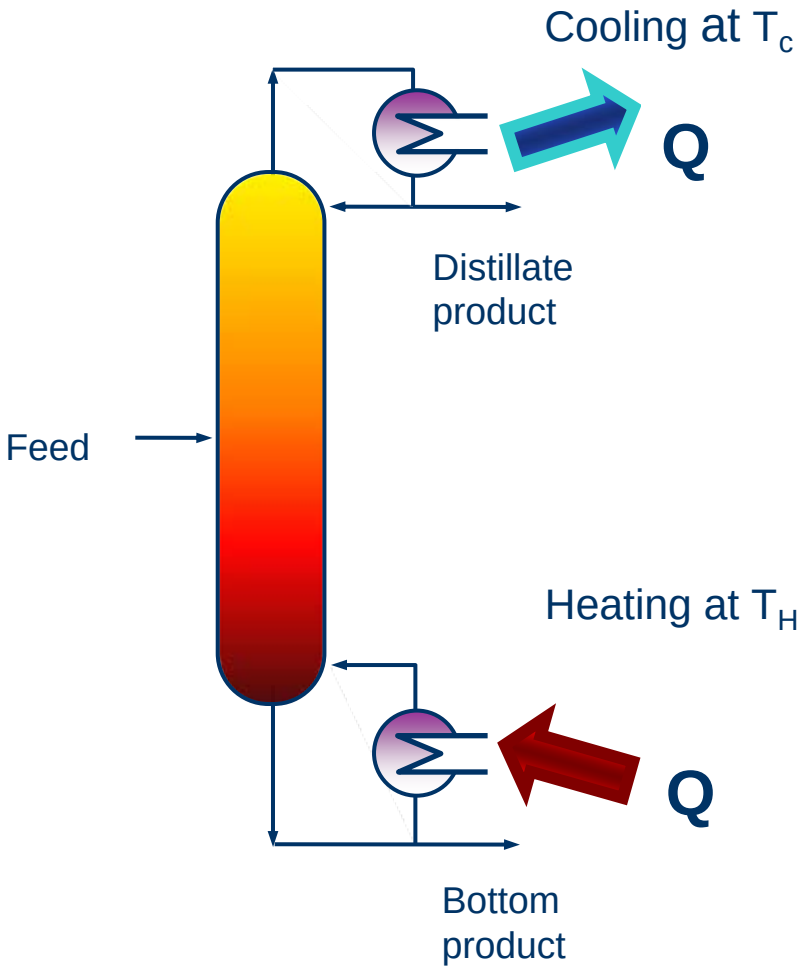


NTNU lab

Teoretical minimum energy

An ideal reversible process requires:

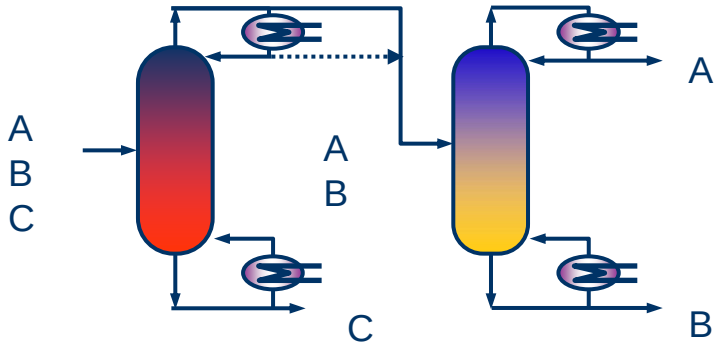
$$Q_{\min} = \frac{-\Delta S T_C}{1 - \frac{T_C}{T_H}}$$



Where entropy of mixing is

$$\Delta S = -\sum_i R x_i ln(x_i)$$

Increasing purity require energy- Mixing gives irreversible loss



A-composition

Can we find a minimum energy route to pure A?

Remixing at end of column 1

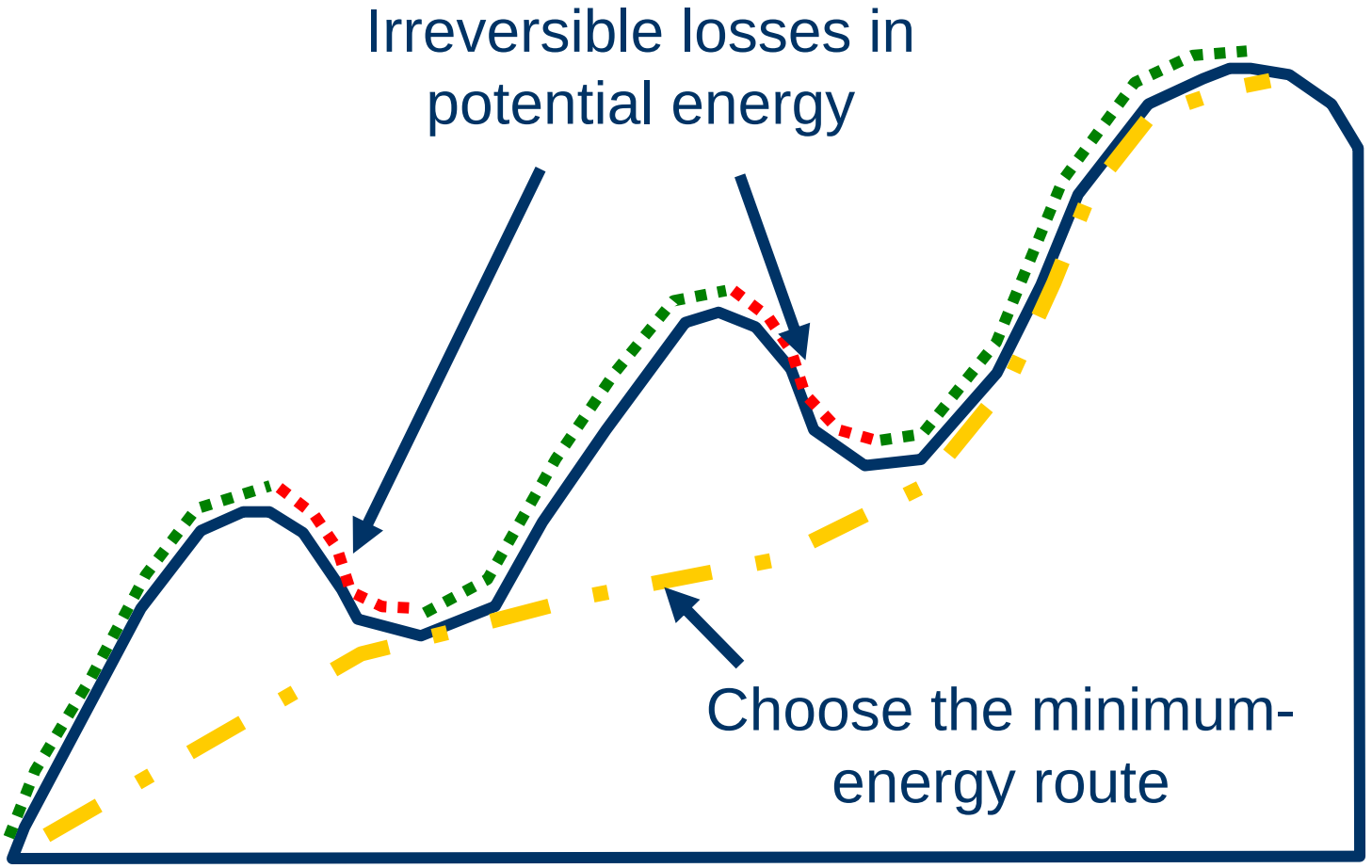
Position along path from feed to A outlet

Feed C1

Feed C2

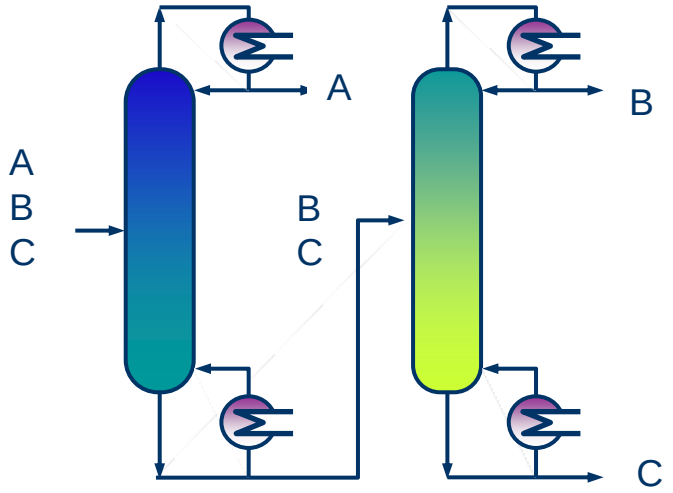
A-product

Minimum energy path to the mountain top

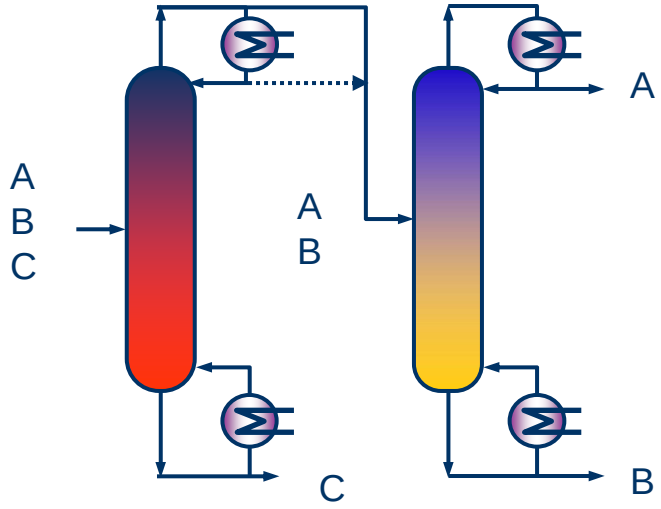


Conventional alternatives for 3-product separation: Sequence of binary columns

Direct Split: DS

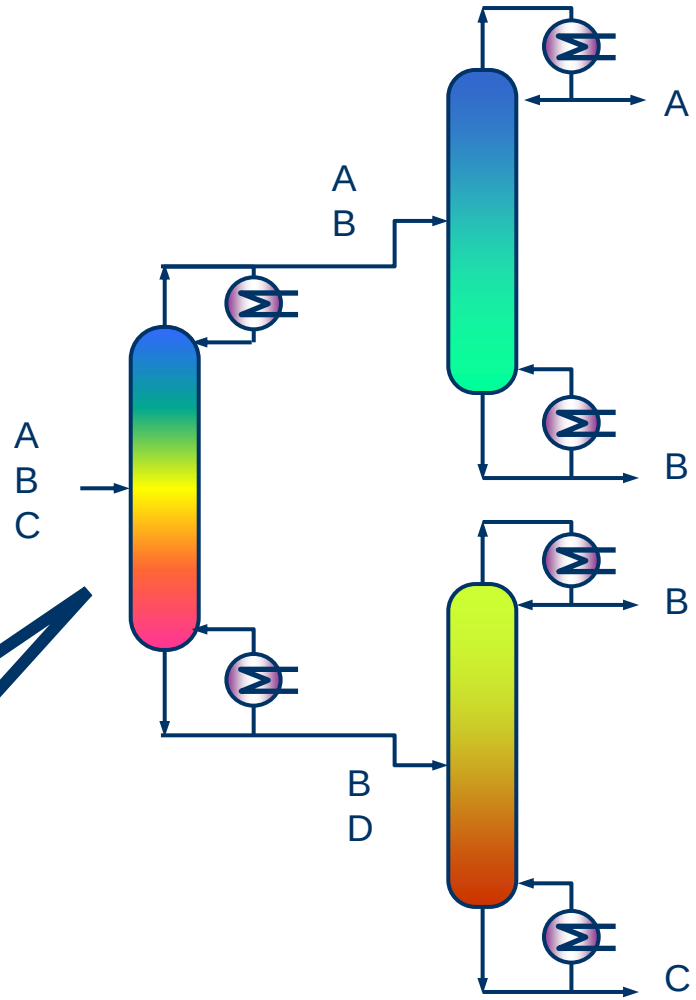


Indirect split: IS



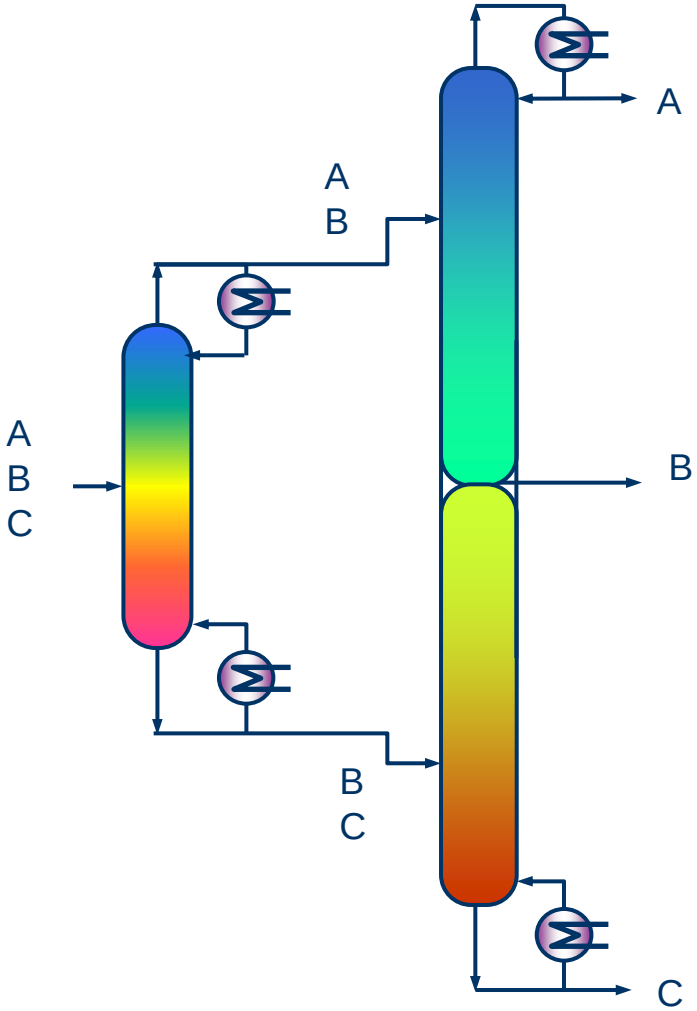
Alternatives for 3-product separation...

Prefractionator arrangement



The prefractionator does the simple A/C split

Conventional Prefractionator arrangement with a single main column

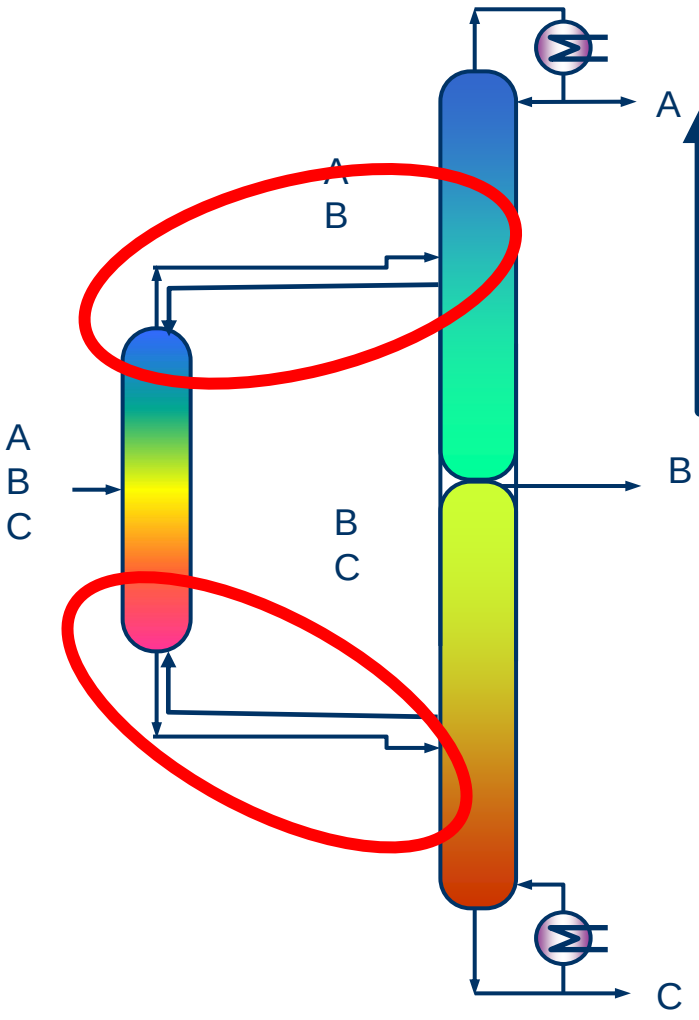


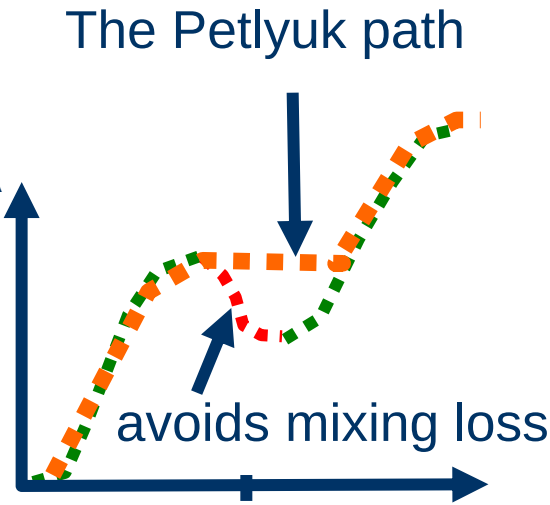
Apply full thermal coupling

The Petlyuk column

removes mixing loss at the interconnections

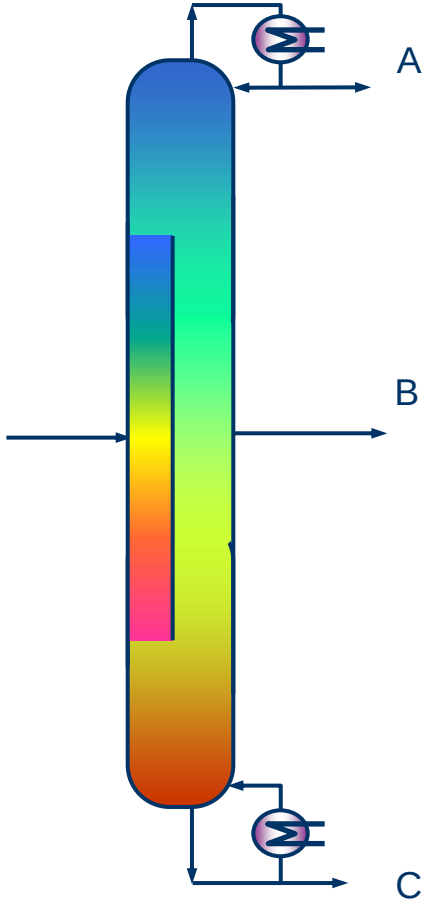
Saves 20-30% energy



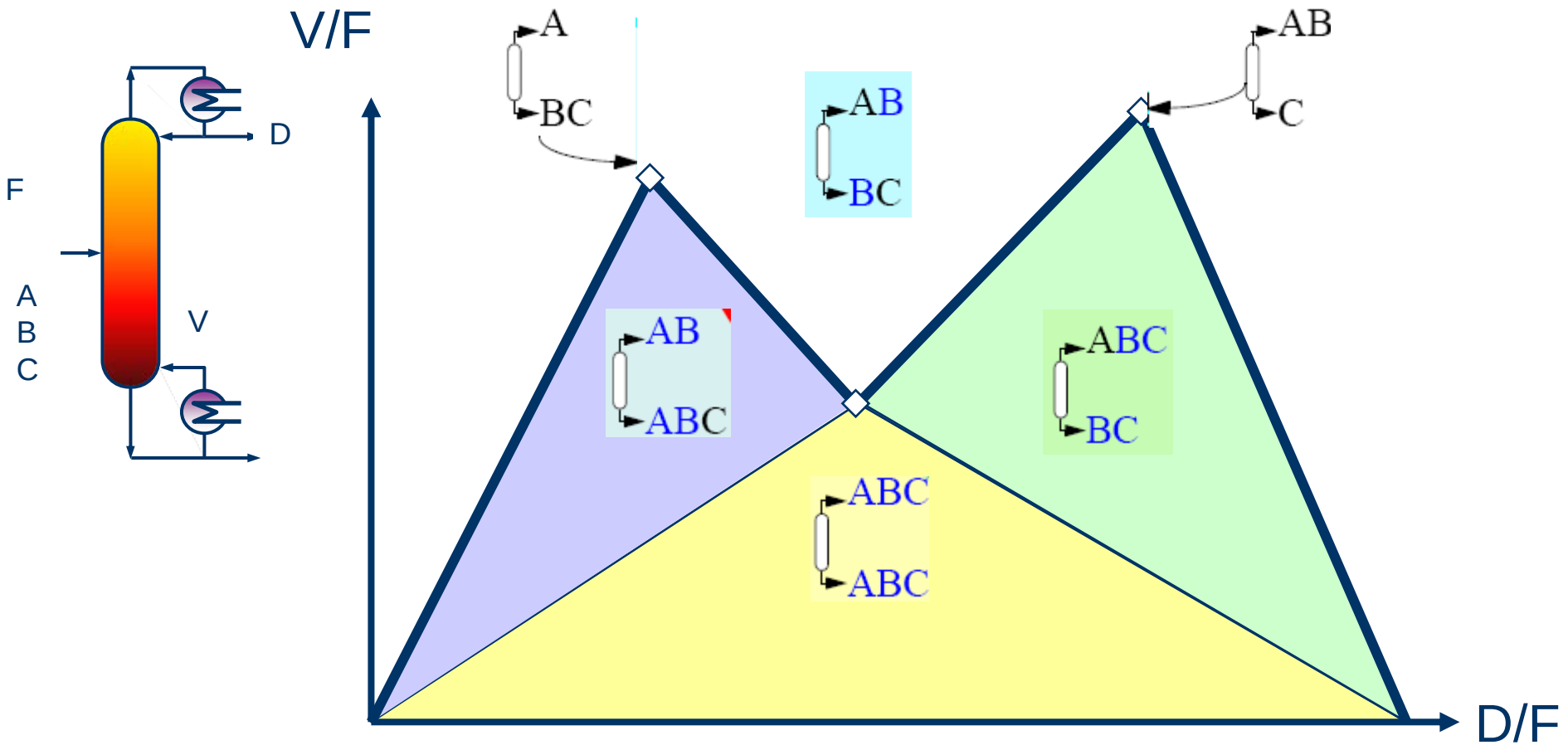


The dividing wall column (DWC)

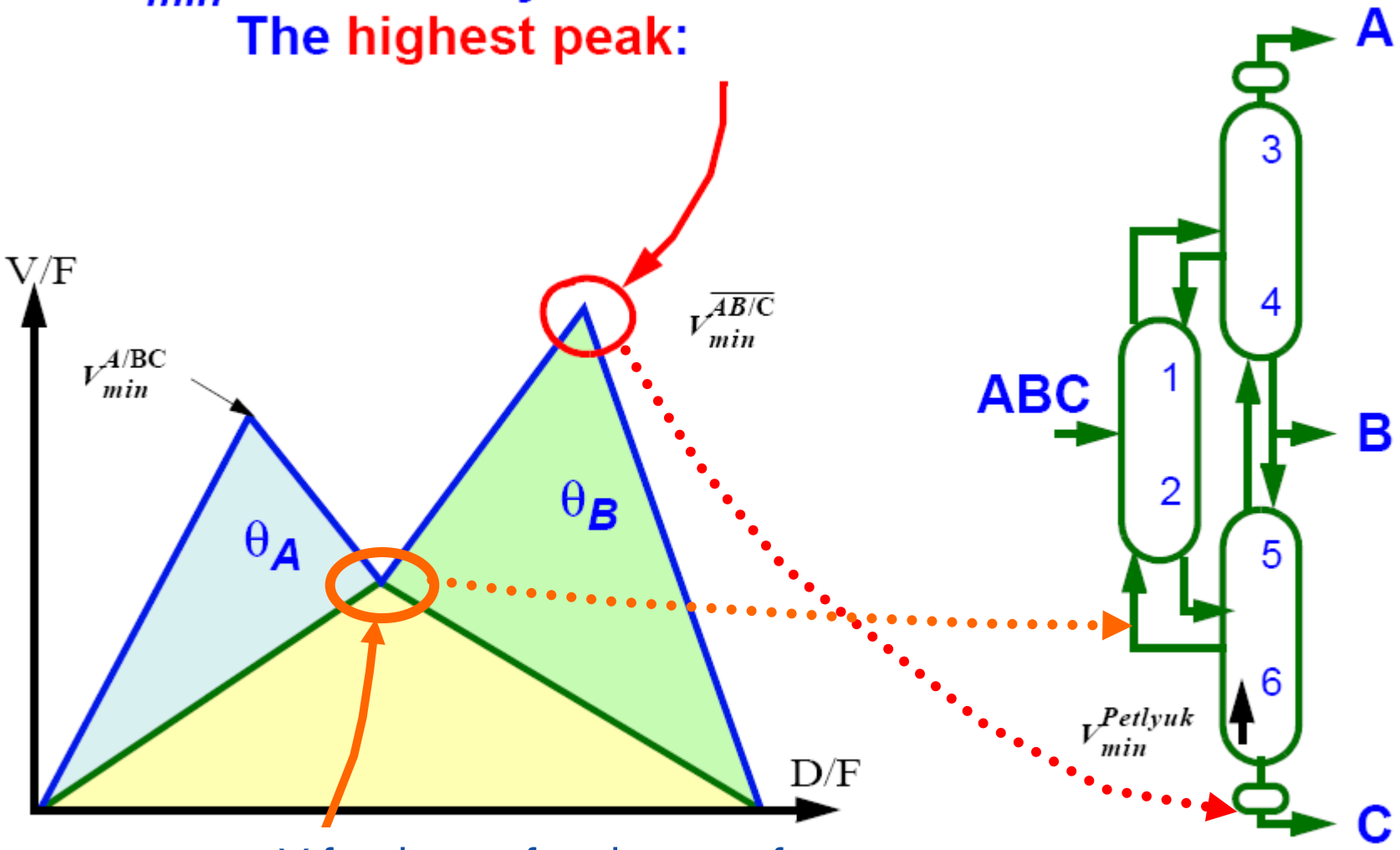
- The Petlyuk arrangement in a single shell
- Separates a single feed into three separate products in one column
- Just a single reboiler and condenser
- Saves 20-30% in both energy and capital



The V_{min}-diagram – for simple energy assessment

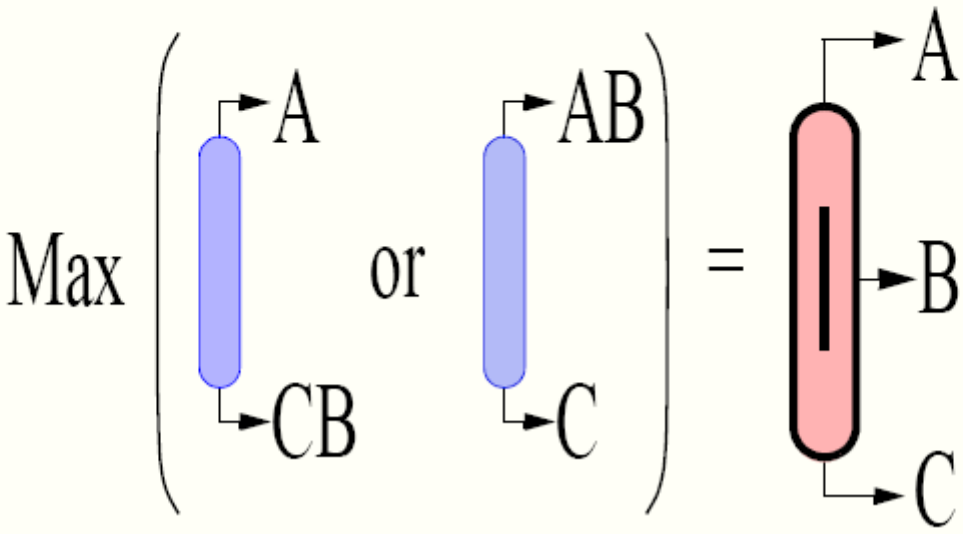


V_{min} for the Petlyuk column: The highest peak:



V for the prefractionator from the preferred A/C-split

Petlyuk column: V_{min} = the most difficult binary split



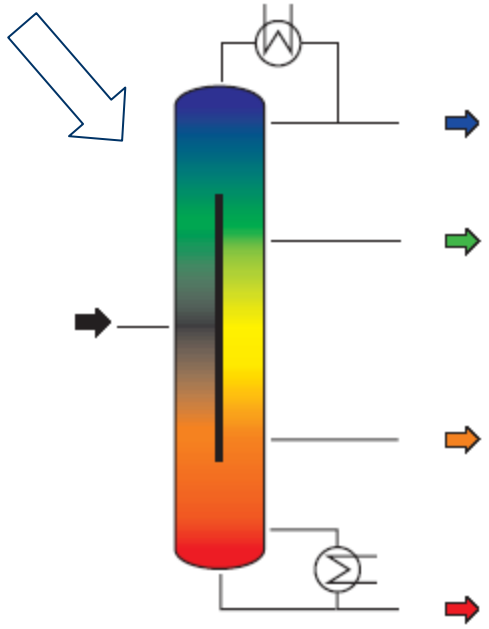
Industrial DWC/Petlyuk applications

German-speaking community dominates

- BASF: > 70 DWCs in operation. Increasing. **G. Kaibel pioner**
- Monz – main vendor for BASF
- Krupp-Uhde
- Sulzer
- Rashig
- Linde

Others

- MW Kellogg (UK)
- UOP (USA)
- UK, Japan, Indonesia, South Africa

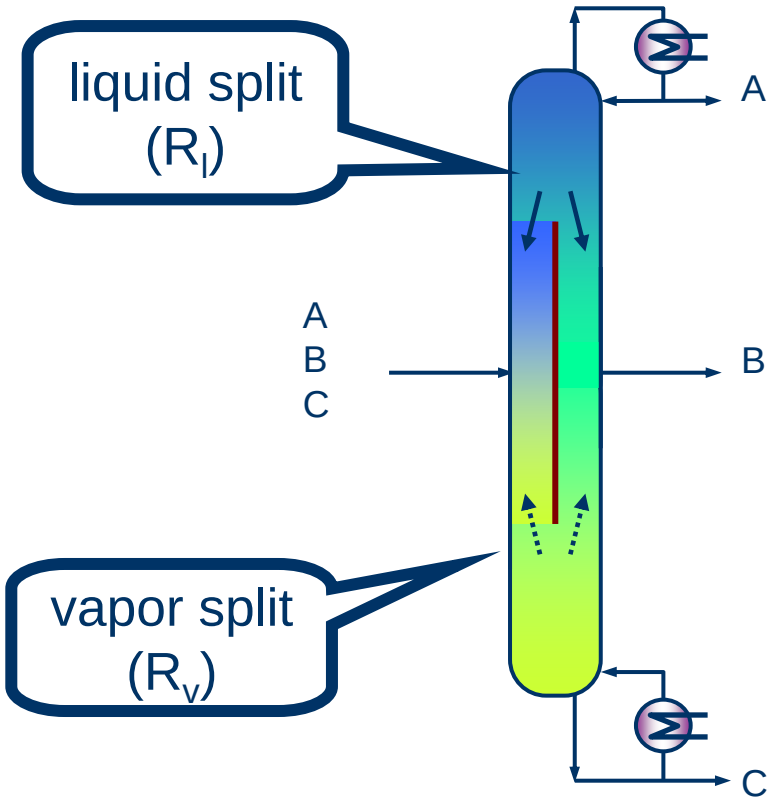


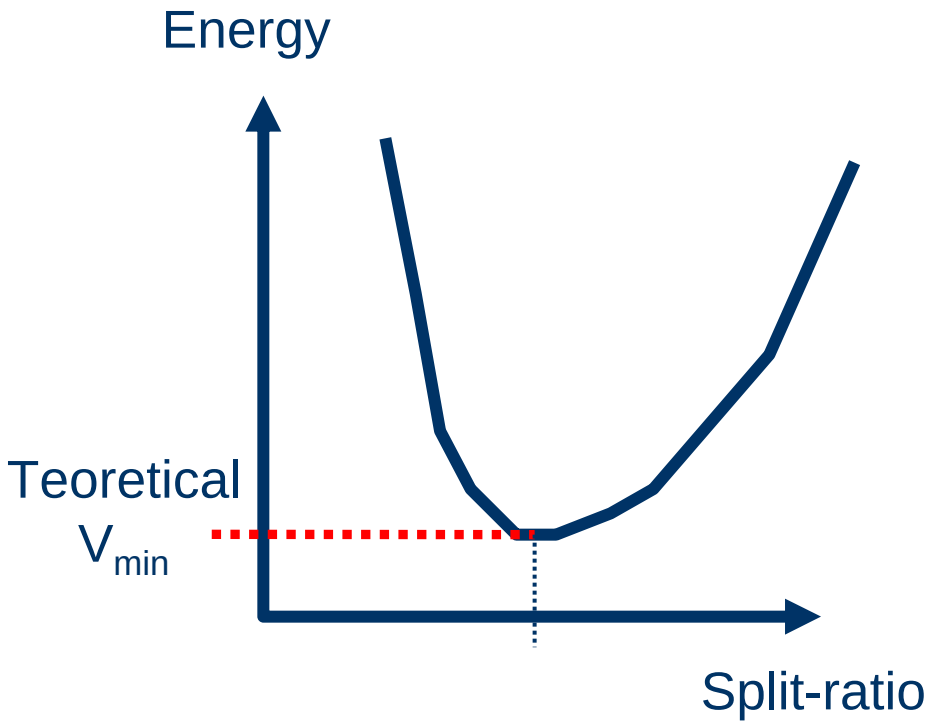
The Kaibel-column
4-product DWC!

Why consider a Petlyuk arrangement

- Large potential energy savings compared to conventional columns (20-30%)
  - Or – increase production and/or purity for given energy supply
- Capital cost savings due to more compact equipment => smaller footprint and removal of reboiler/condenser units
- Usage:
  - In theory: Anywhere (almost) where distillation is a suitable separation technology and more than 2 products are produced.
  - In practice: Some cases may be unsuitable due to required temperature/pressure range, height, or if liquid/vapor load in different sections are very different.
  - Practical variations can be made, e.g. side-strippers/rectifiers
  - Revamping of existing conventional columns may have significant potential

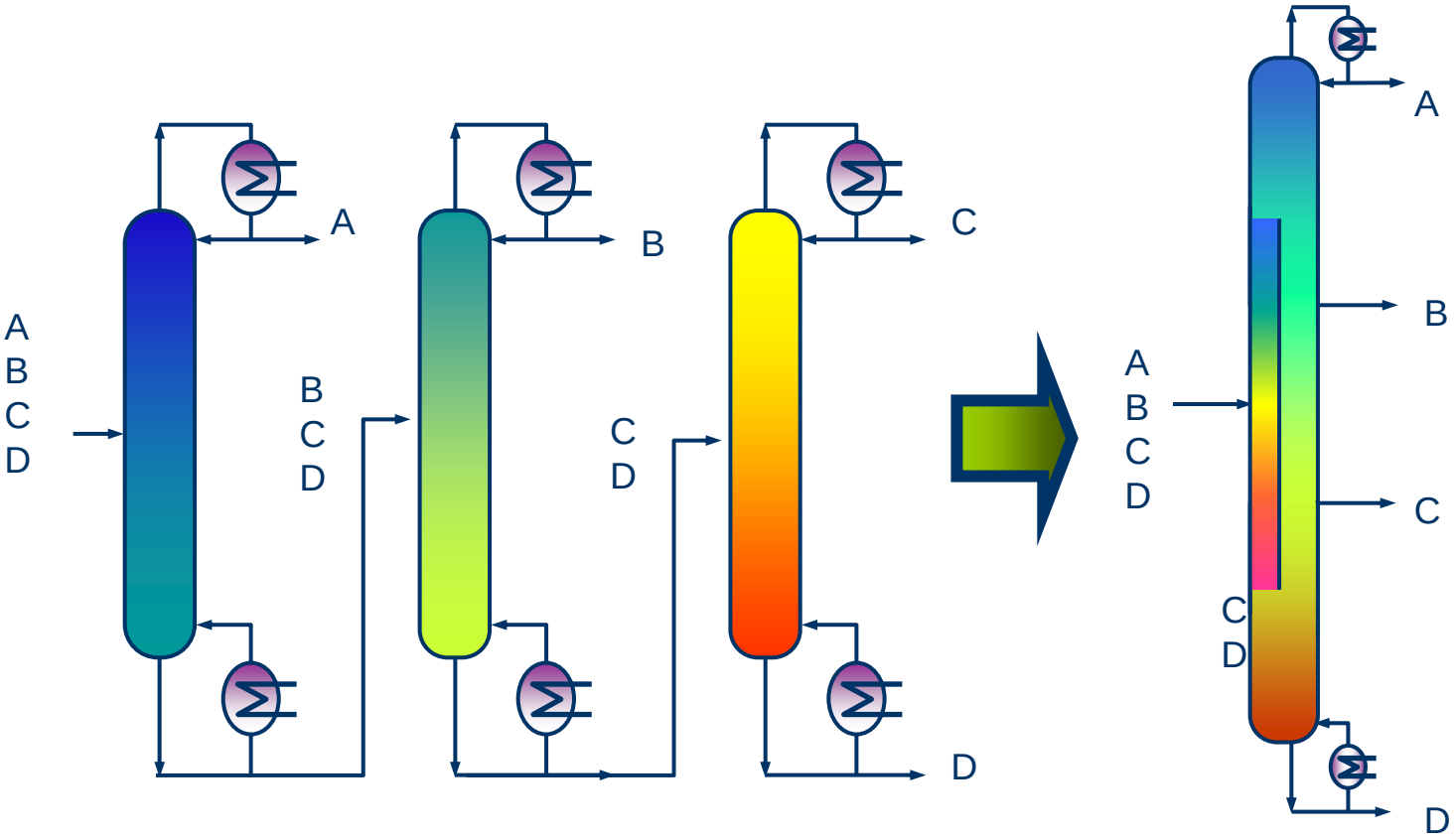
Critical for obtaining the teoretical savings in practice: How to control the splits





Tool: Self optimizing control

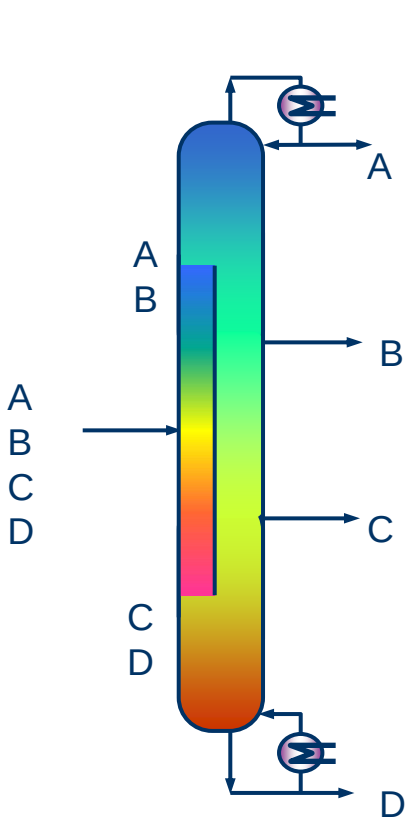
Extend to 4-product DWC: The Kaibel column – (1987)

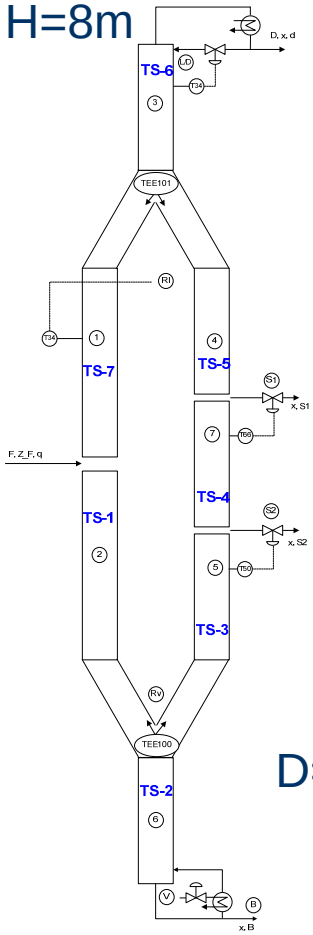


4 products in a single shell!

Saves 30-40 %

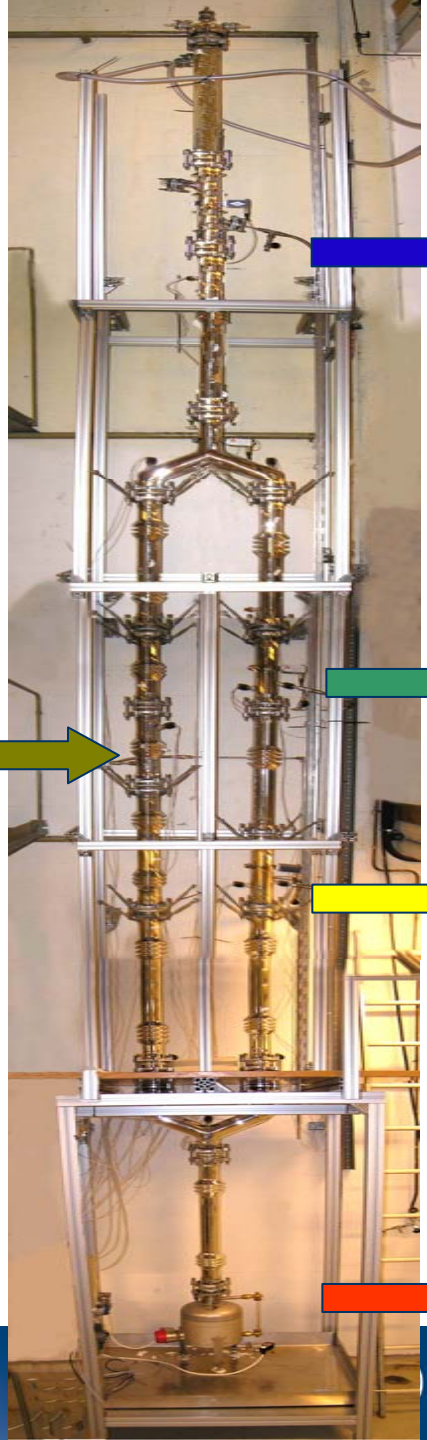
The Kaibel column at NTNU





Feed
(ABCD)

D=5/8cm



First really big 4-product DWC

Kaibel column

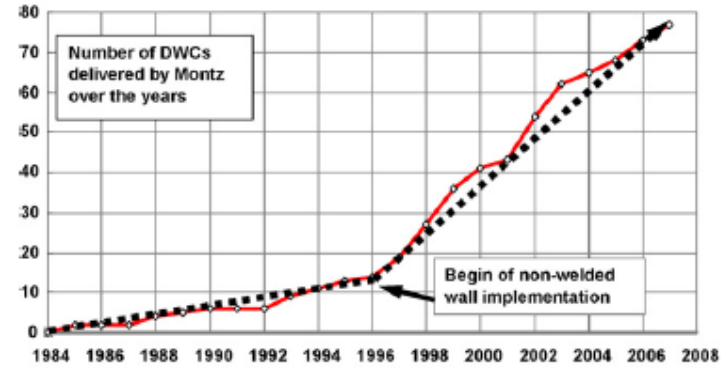


Fig. 2. The number of the dividing wall columns delivered by J. Montz over the years.

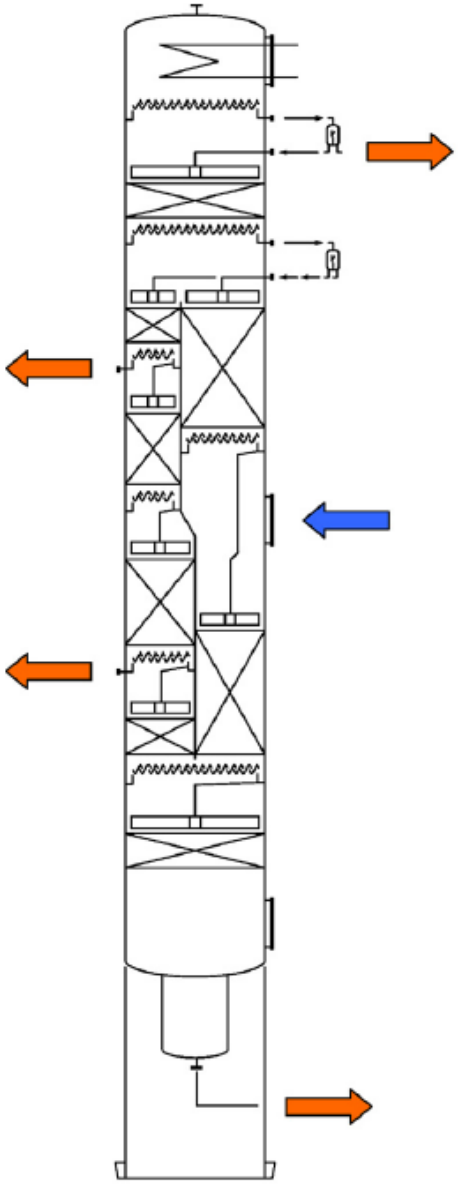
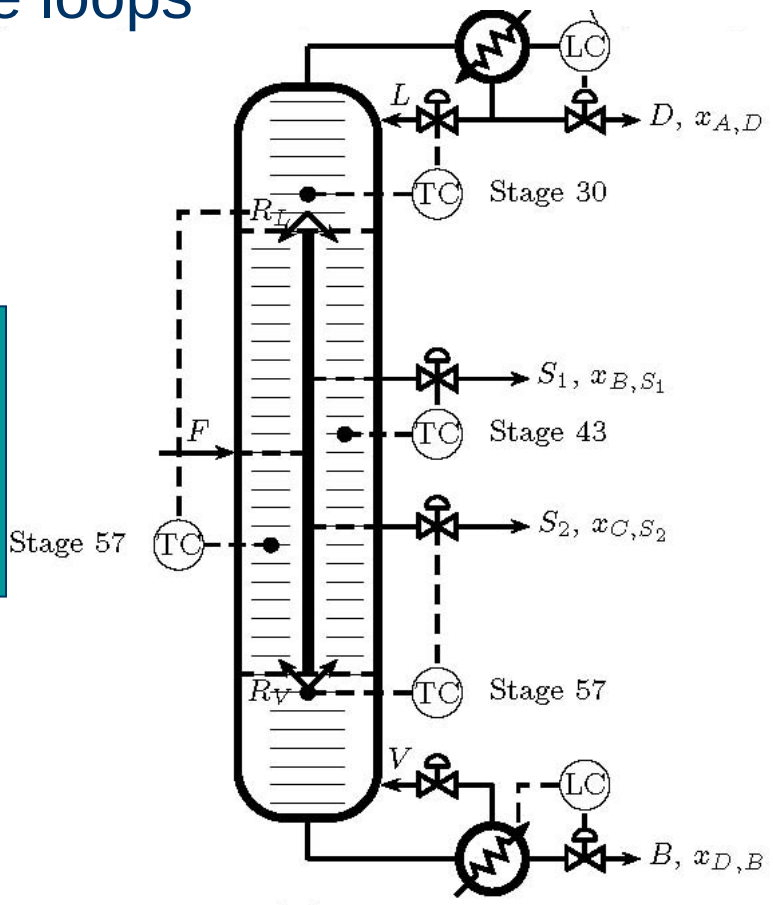


Fig. 3. A photograph of the shell and a drawing illustrating internal configuration of a DWC for separation of a four component feed into pure products.

Control study (Strandberg 2009)

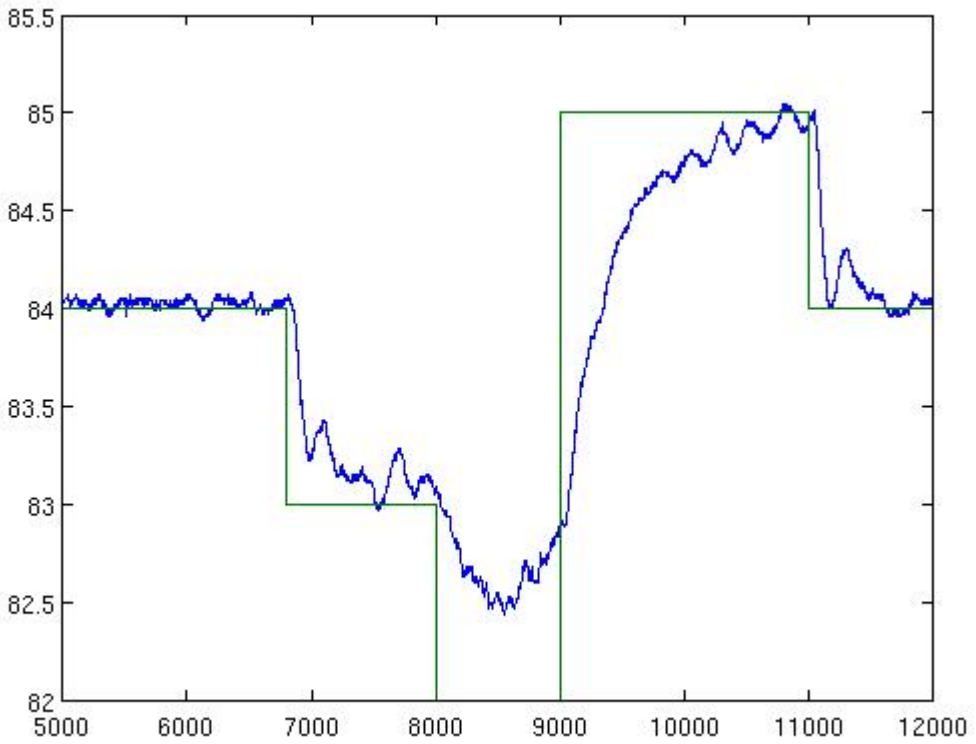
Stabilizing Control by 4 temperature loops

Need to adjust liquid split online in order to stabilize prefractionator



Step response test on pilot column

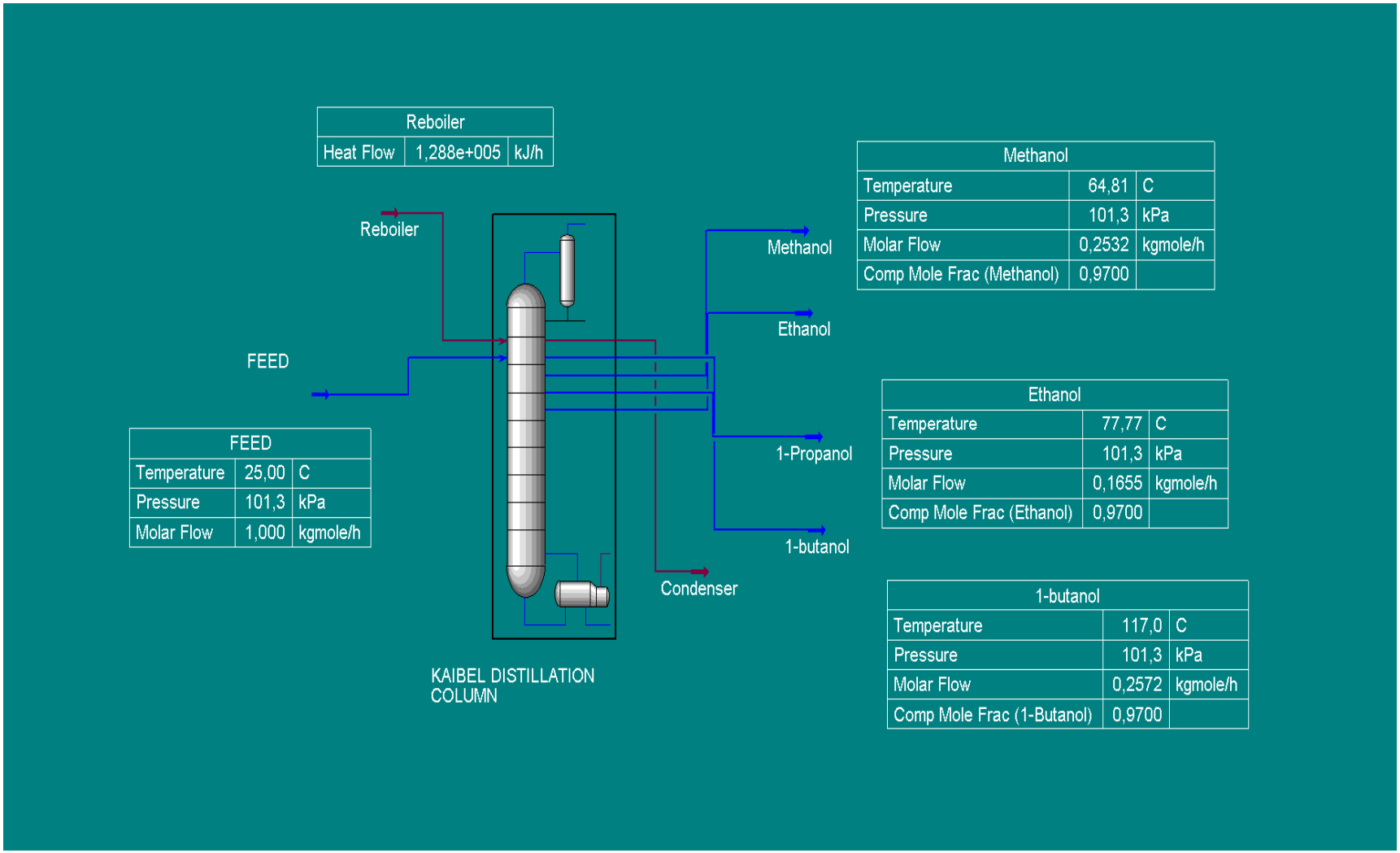
Prefractionator temperature below feed controlled by adjusting the liquid split



More results:

- Master thesis by Martin Kvernland 2009
- Matlab model exension includes heat loss and vapor bypass for stage inefficiency
- Implemented a 4x4 MPC with a reduceded linear state space model (reduced from original >200 to 15 states)
- The MPC controller in Matlab can be interfaced to Labview via OPC

UniSim Simulation for Kaibel Column



Toolbox for rigorous simulations

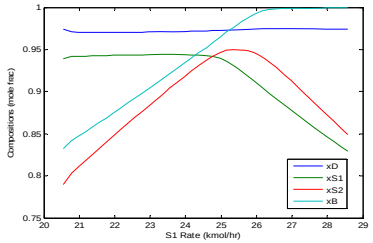
by Maryam Ghadrdan

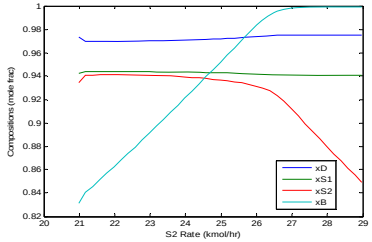
MATLAB
Advanced Optimization
& Execution Control

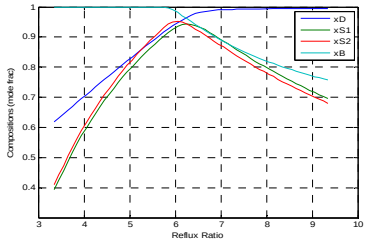
Execution control →

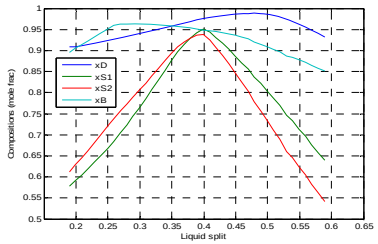
← Variables values

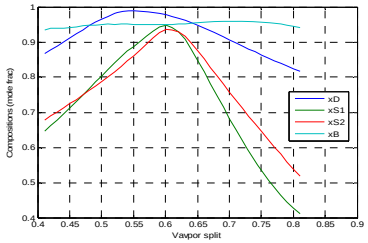
HYSYS/UNISIM
Rigorous Simulation





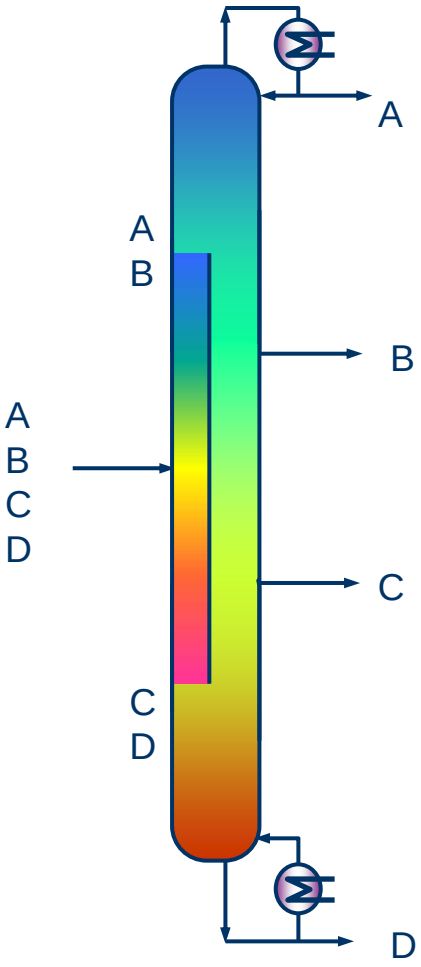




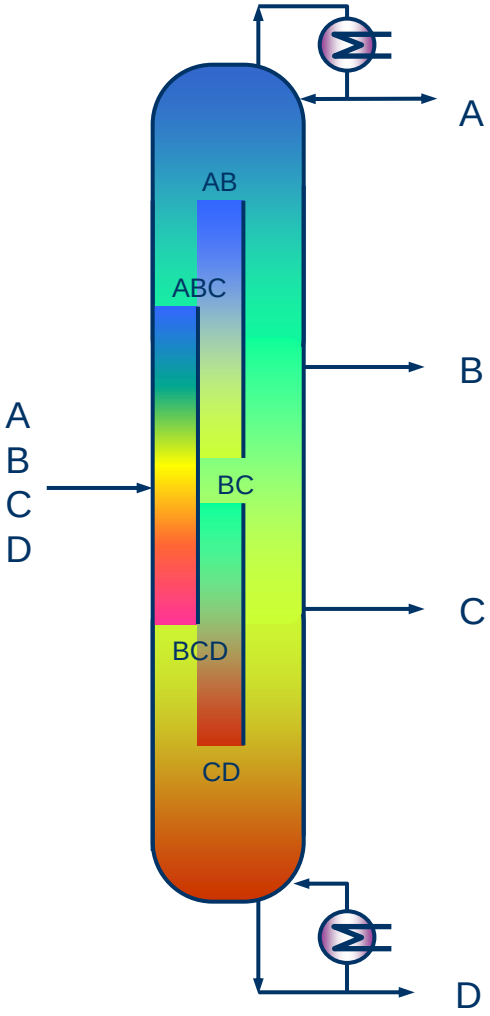


Further work

- Model development and refinement
  Both in Matlab and Unisim/Hysys
- Lab column experiments
- Control structure design
  (including selfoptimising control)
- Optimizing control / minimum energy control
- Optimal process design
- Extended Petlyuk arrangements
- Alternative structures like HIDiC, Heat integrated and other energy efficient arrangements



Extended 4-product Petlyuk DWC with multiple dividing walls

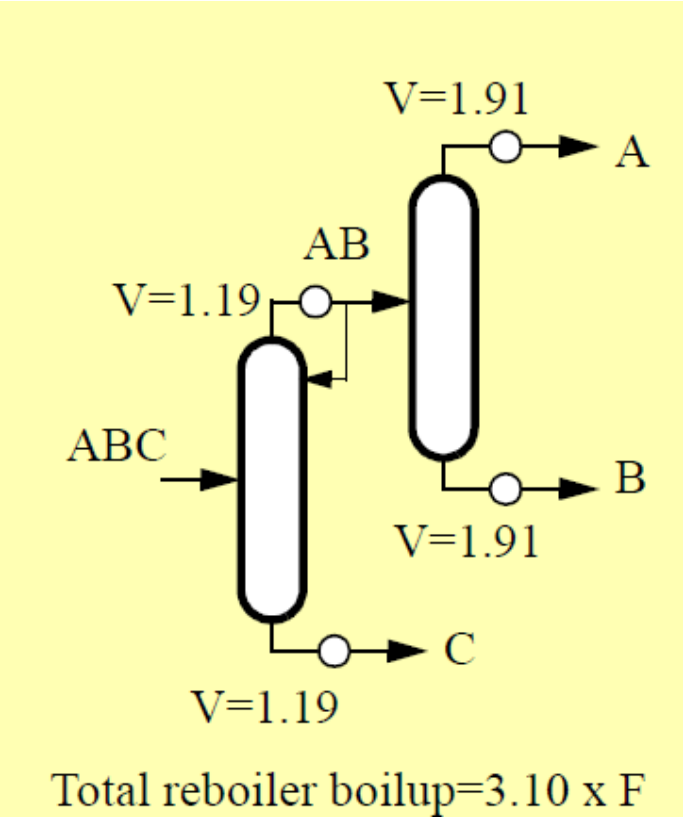


Teoretical savings up to 50%

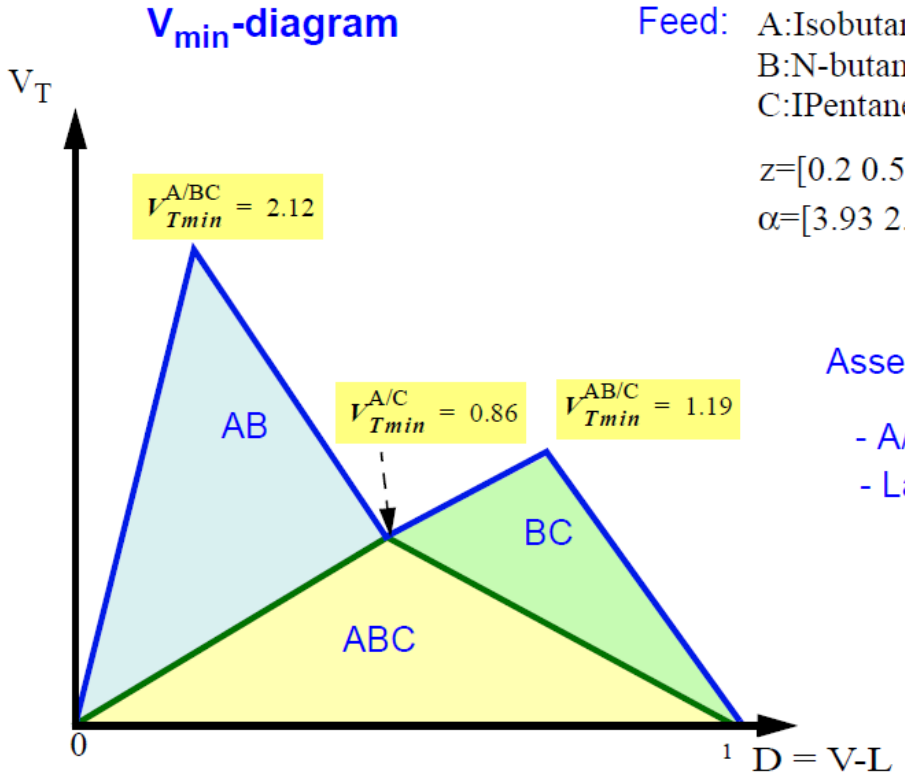
What about complexity in design and operation?

What about revamp?

- A Butane case (butane/C5+) and butane splitter (iC4/nC4):



Total reboiler boilup=3.10 x F



Feed: A:Isobutane
B:N-butane
C:IPentane and heavier

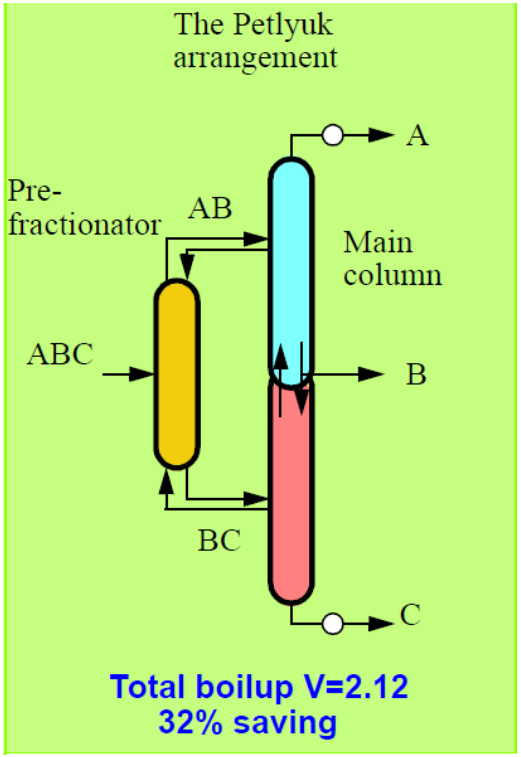
z=[0.2 0.5 0.3] q=1 F=1
α=[3.93 2.85 1]

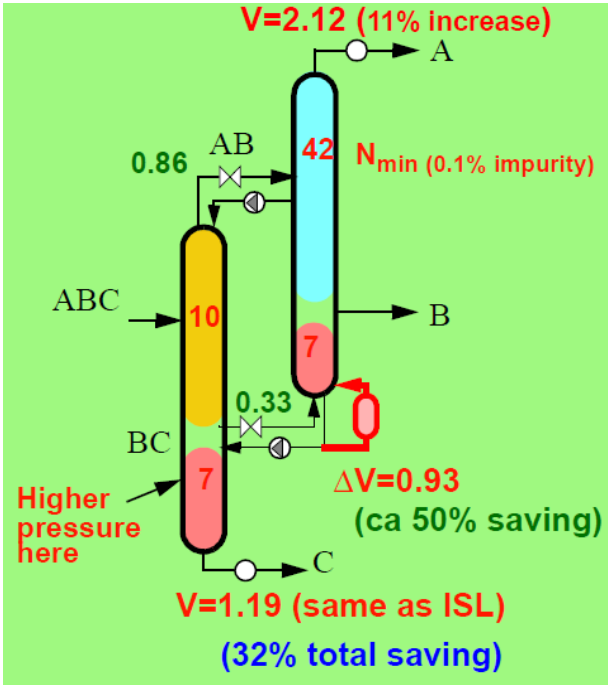
Assessment:

- A/B split dominates
- Large ΔV=0.93

Add direct coupling and save 32 %

Simple revamp of exisiting columns is equivalent to the full Petlyuk arrangement





Energy Efficient Distillation

- We can do it!