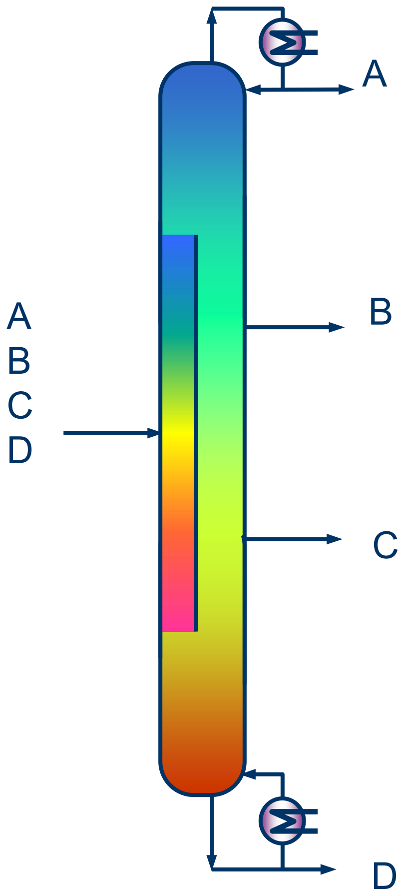
Energy efficient distillation

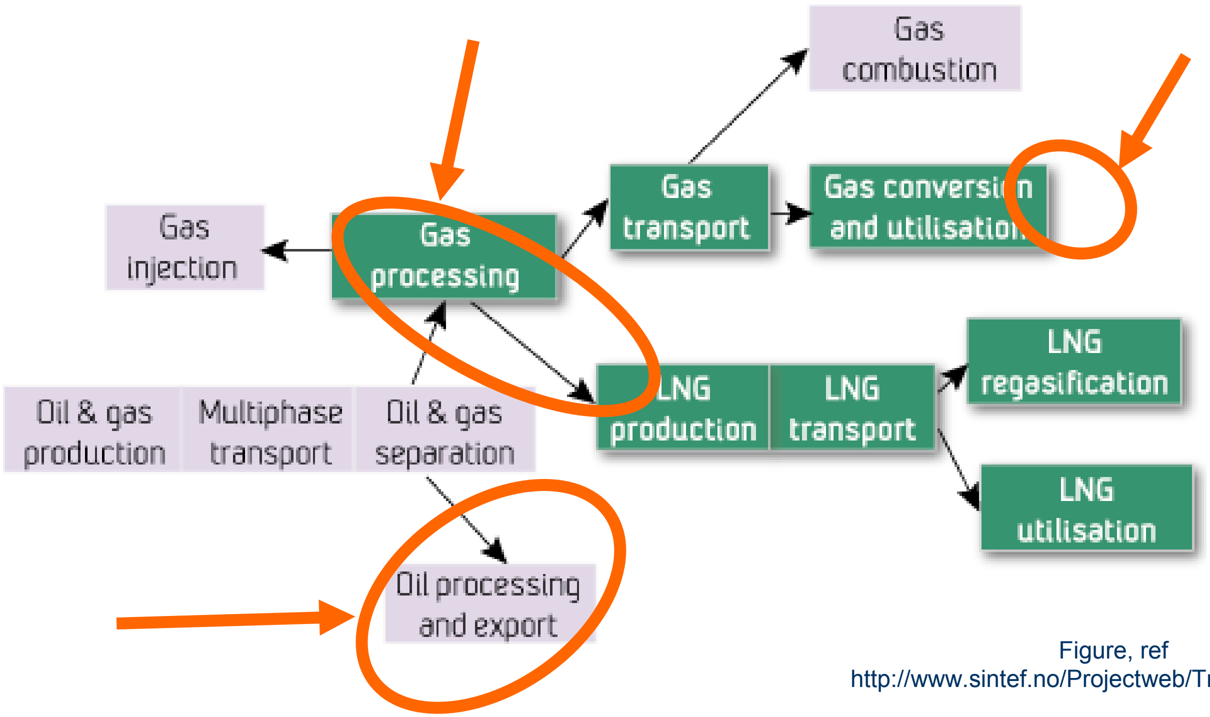


Ivar J. Halvorsen, Maryam Ghadrdan,
Deeptanshu Dwivedi, Mohammad Shamsuzzoha and
Sigurd Skogestad

1st Trondheim Gas Technology Conference,
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

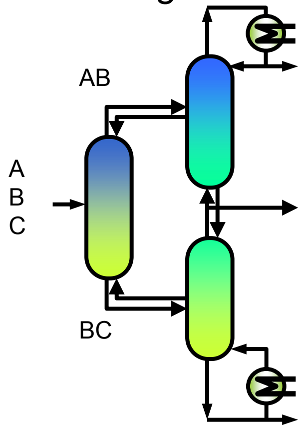
- 2-5% of the world industry heat consumption
- There is a potential for more energy efficient solutions
- Picture: Fractionation columns at the Snøhvit LNG-plant in Hammerfest

Foto: I.Halvorsen

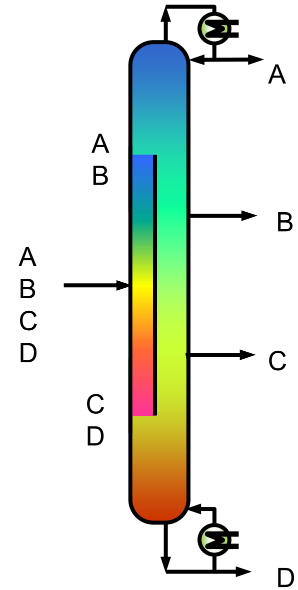
BEEDIST (Basic Energy Efficient Distillation Technology)

- 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

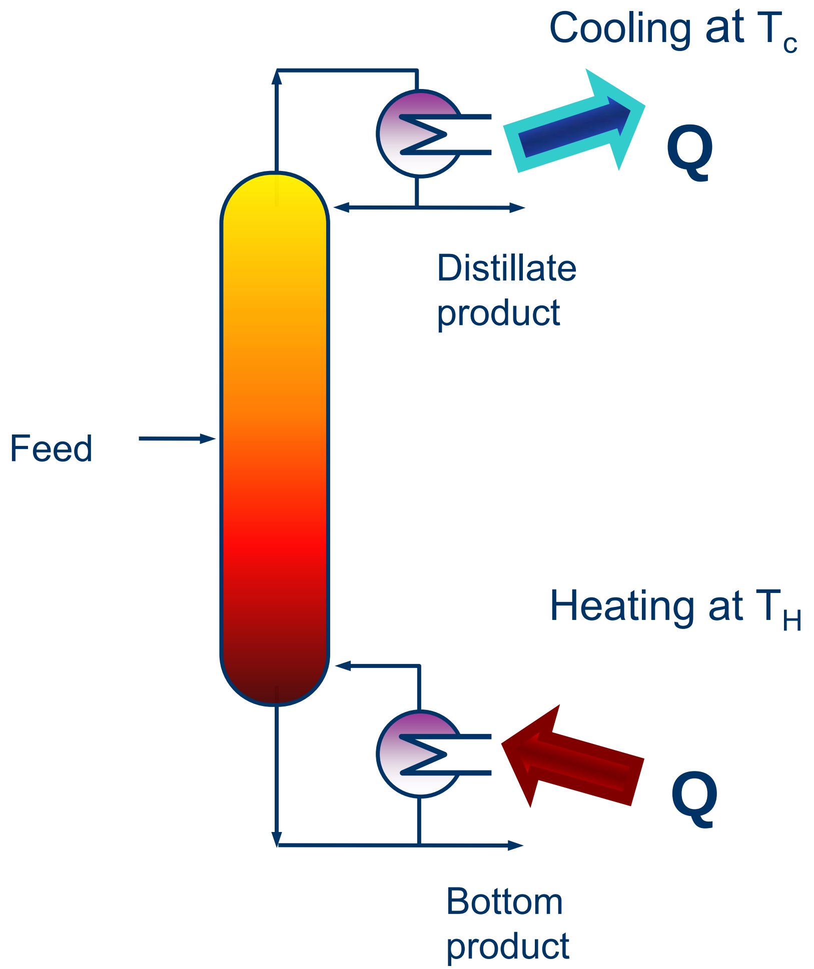
Teoretical minimum energy

An ideal reversible process requires:

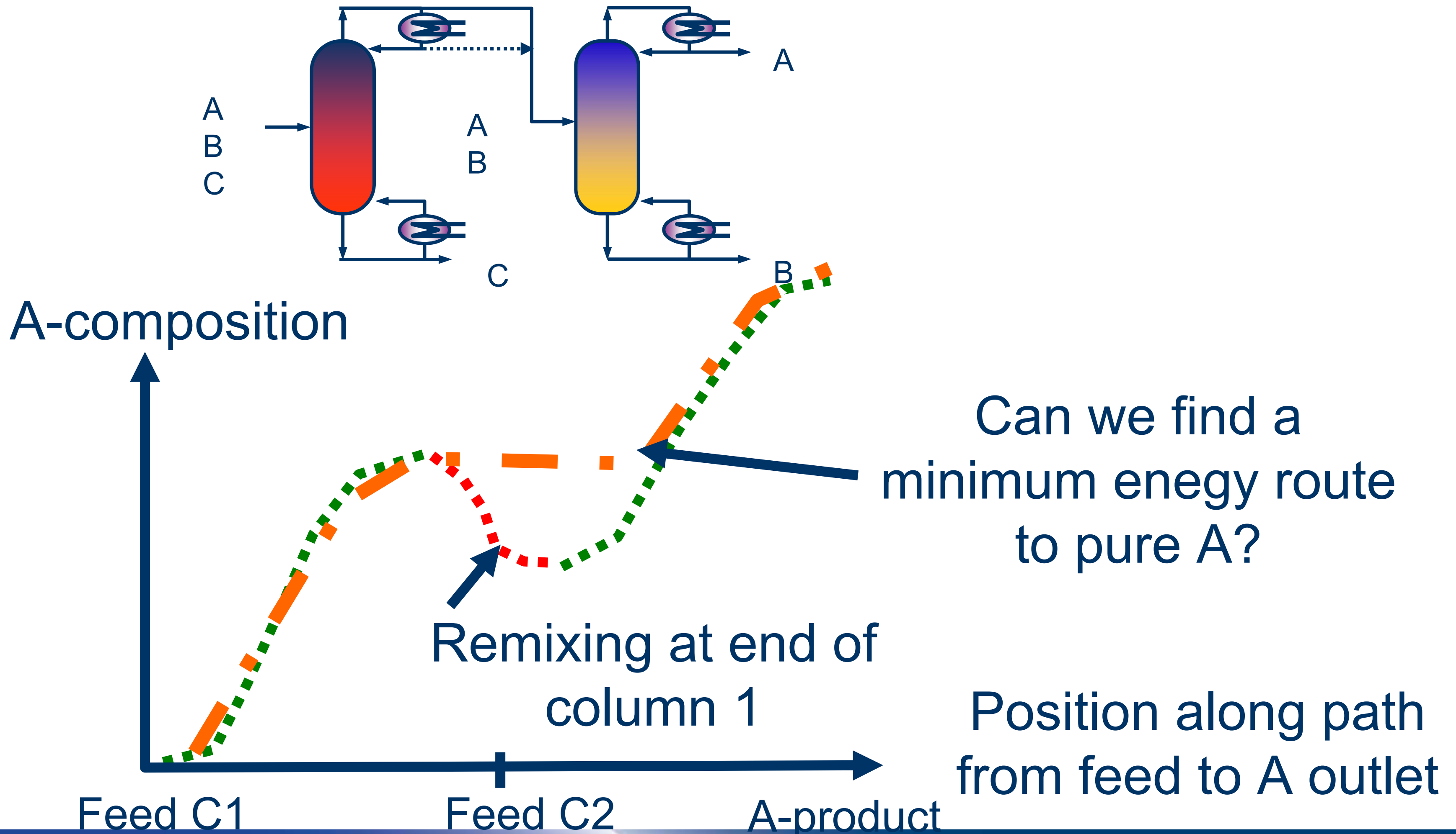
$$Q_{\min} = \frac{-\Delta S T_C}{1 - \frac{T_C}{T_H}}$$

Where entropy of mixing is

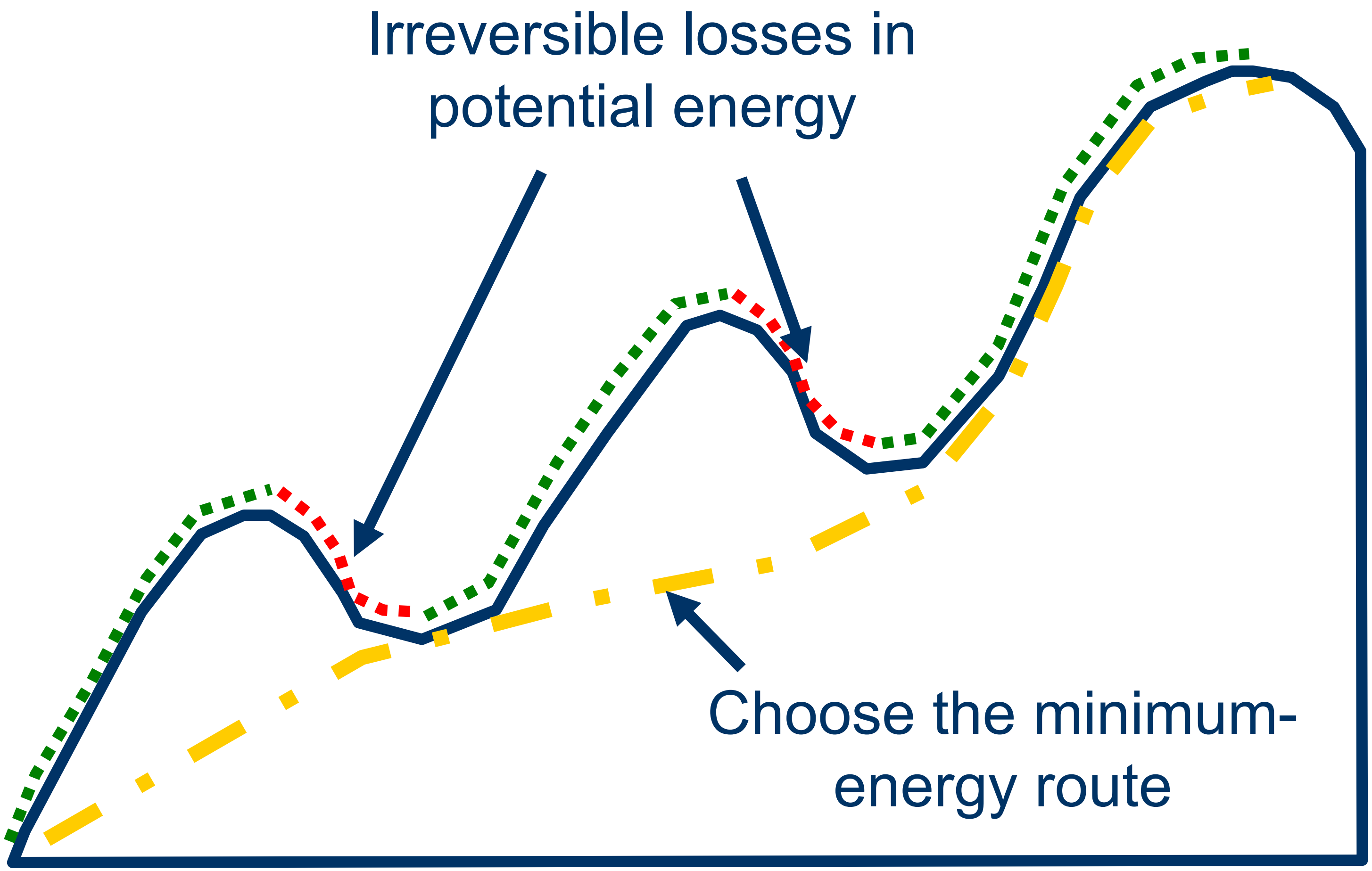
$$\Delta S = -\sum_i R x_i ln(x_i)$$



Increasing purity require energy- Mixing gives irreversible loss

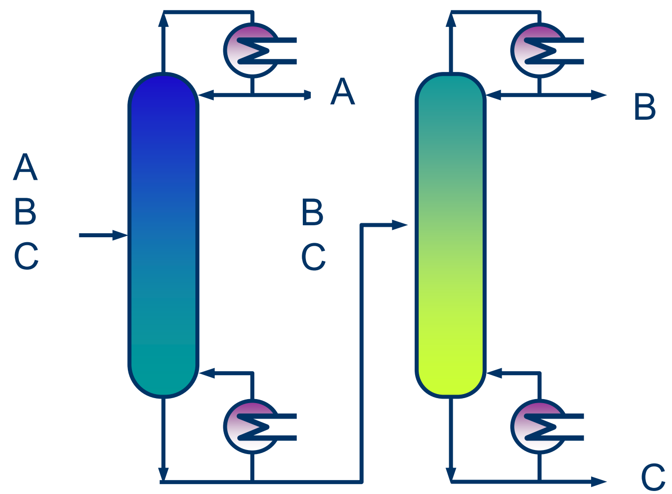


Minimum energy path to the mountain top

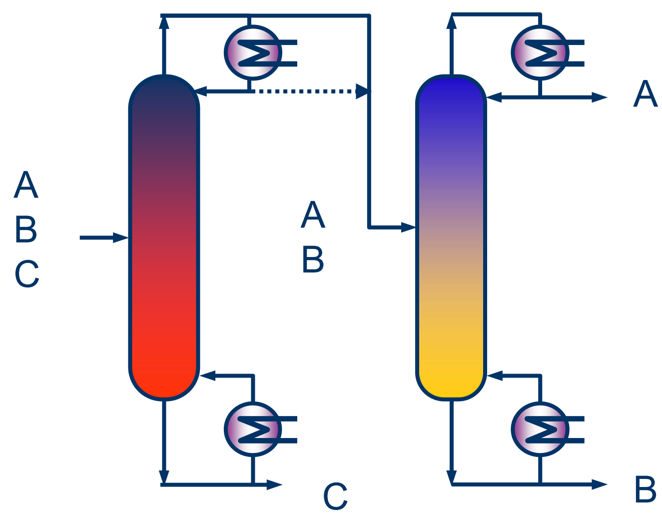


Conventional alternatives for 3-product separation: Sequence of binary columns

Direct Split: DS

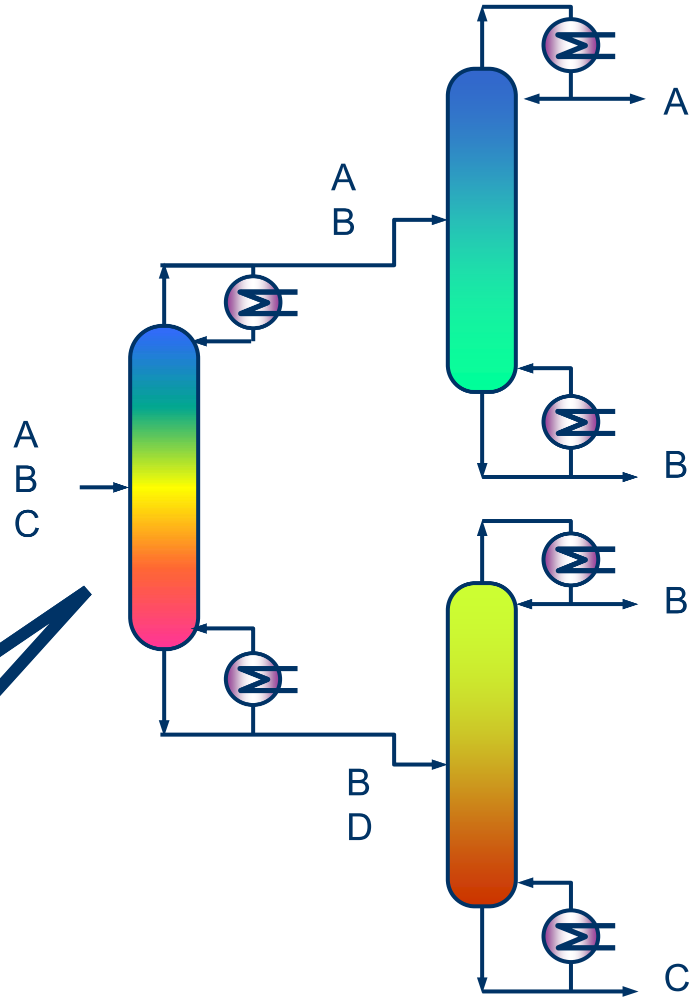


Indirect split: IS



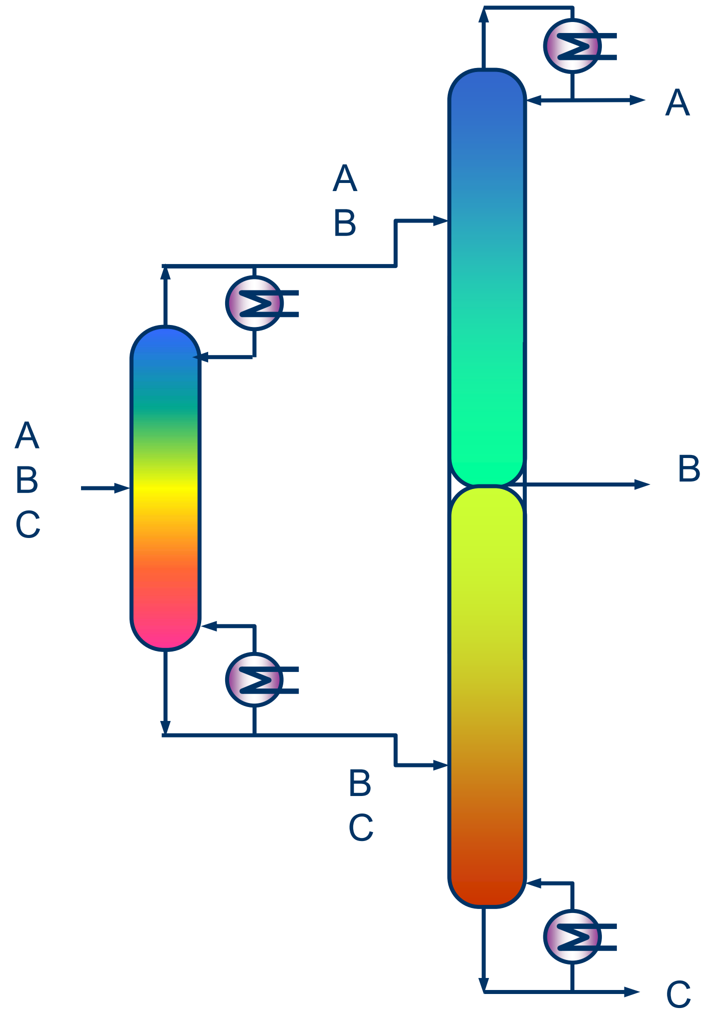
Alternatives for 3-product separation...

Prefractionator arrangement



The prefractionator does the simple A/C split

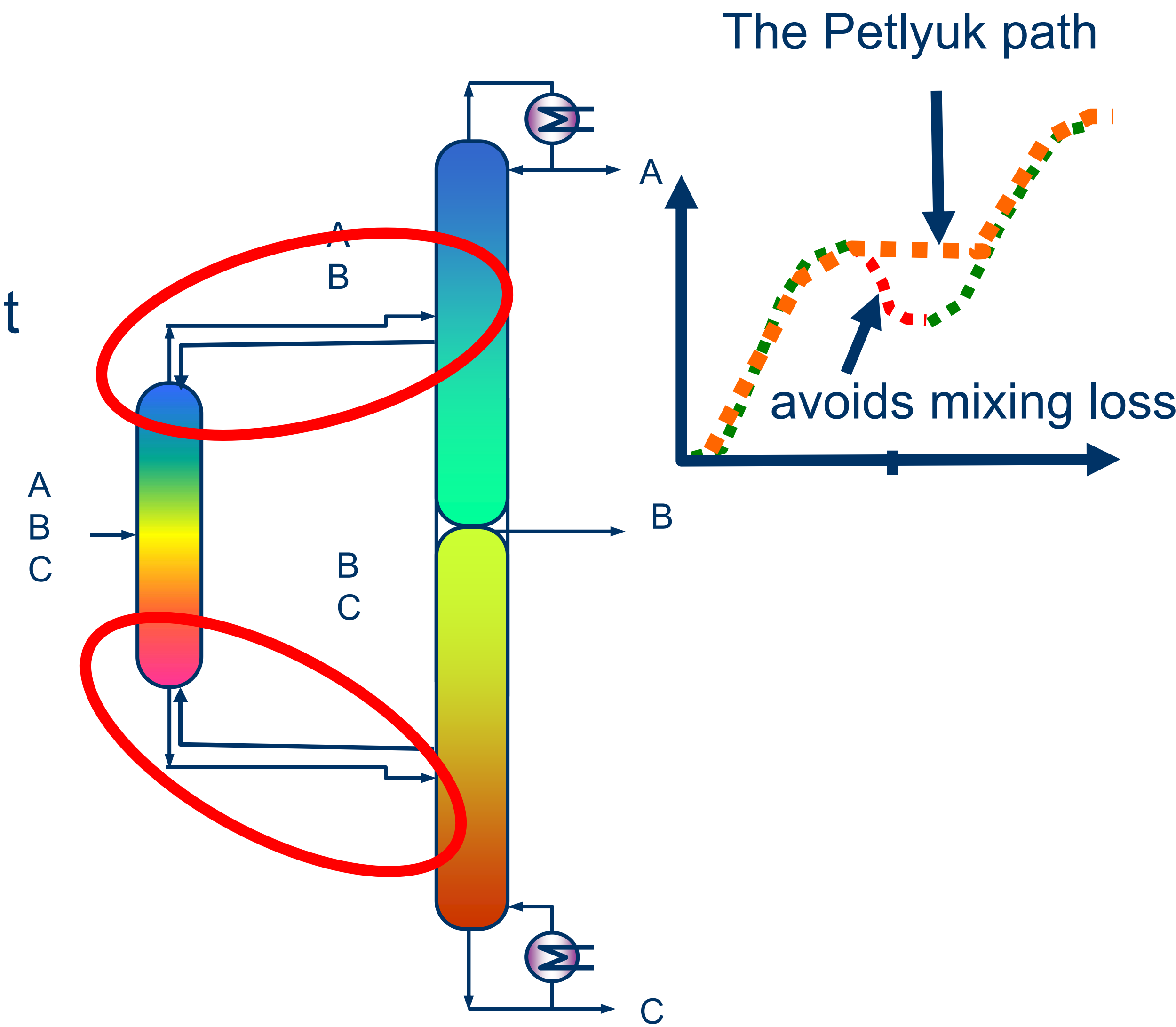
Conventional Prefractionator arrangement with a single main column



Apply full thermal coupling

The Petlyuk column

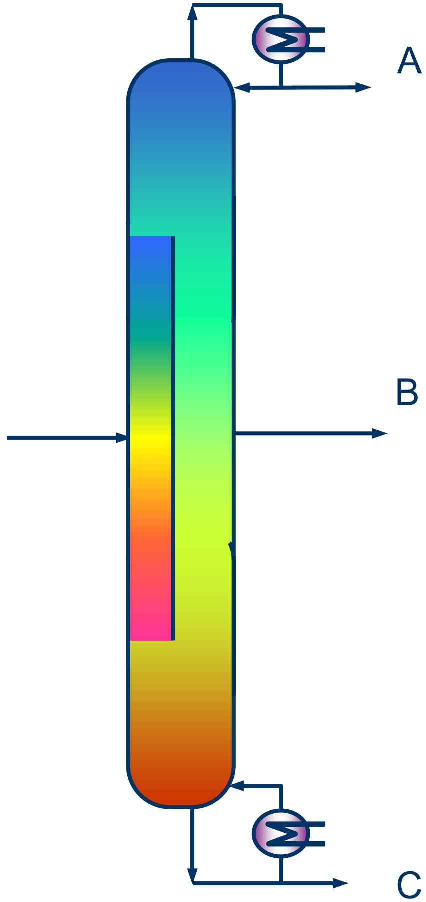
removes mixing loss at the interconnections



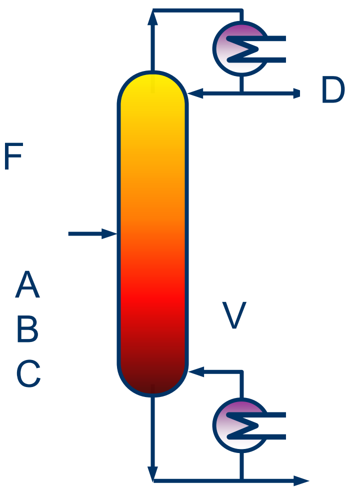
Saves 20-30% energy

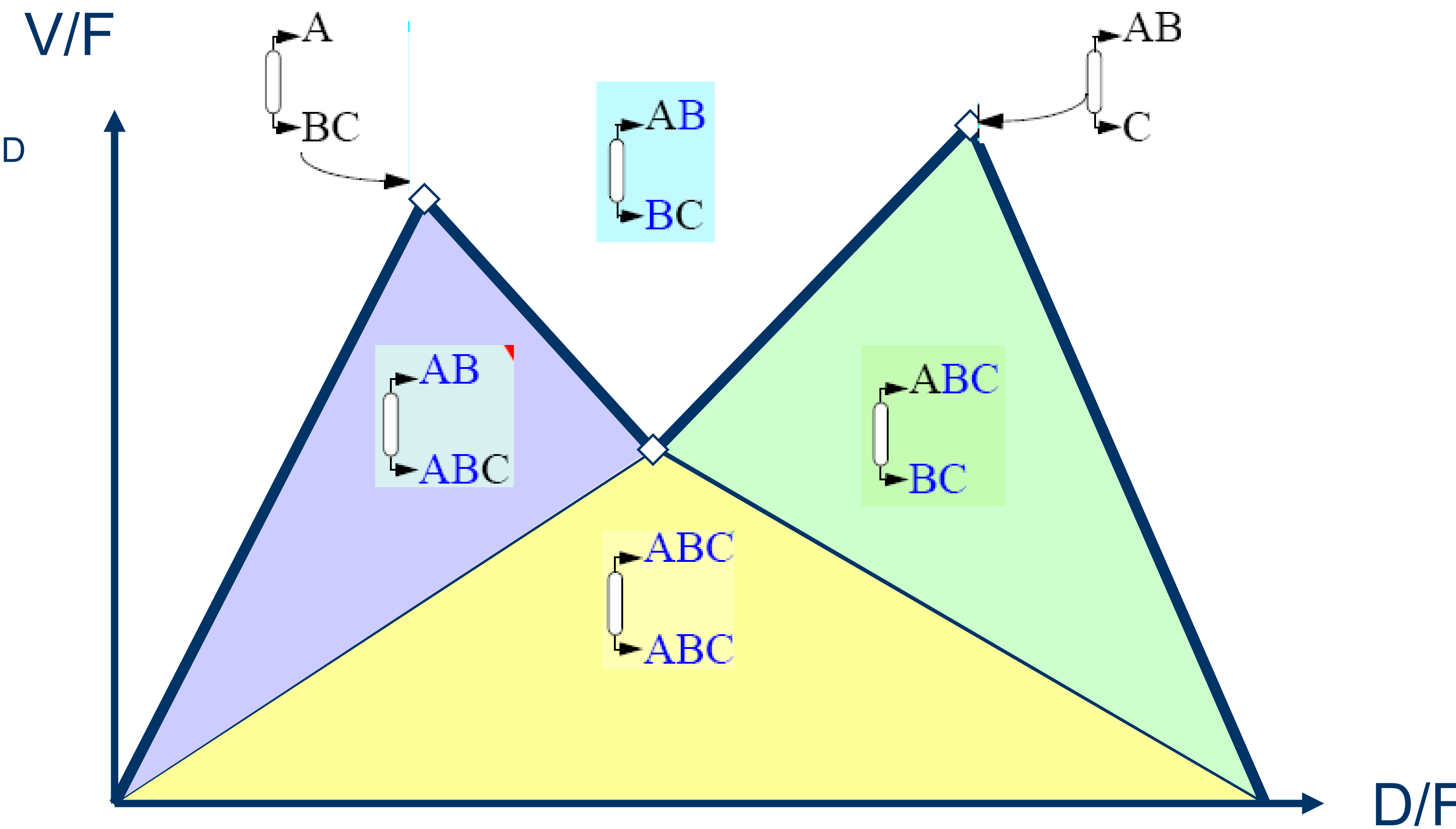
The dividing wall column (DWC)

- 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

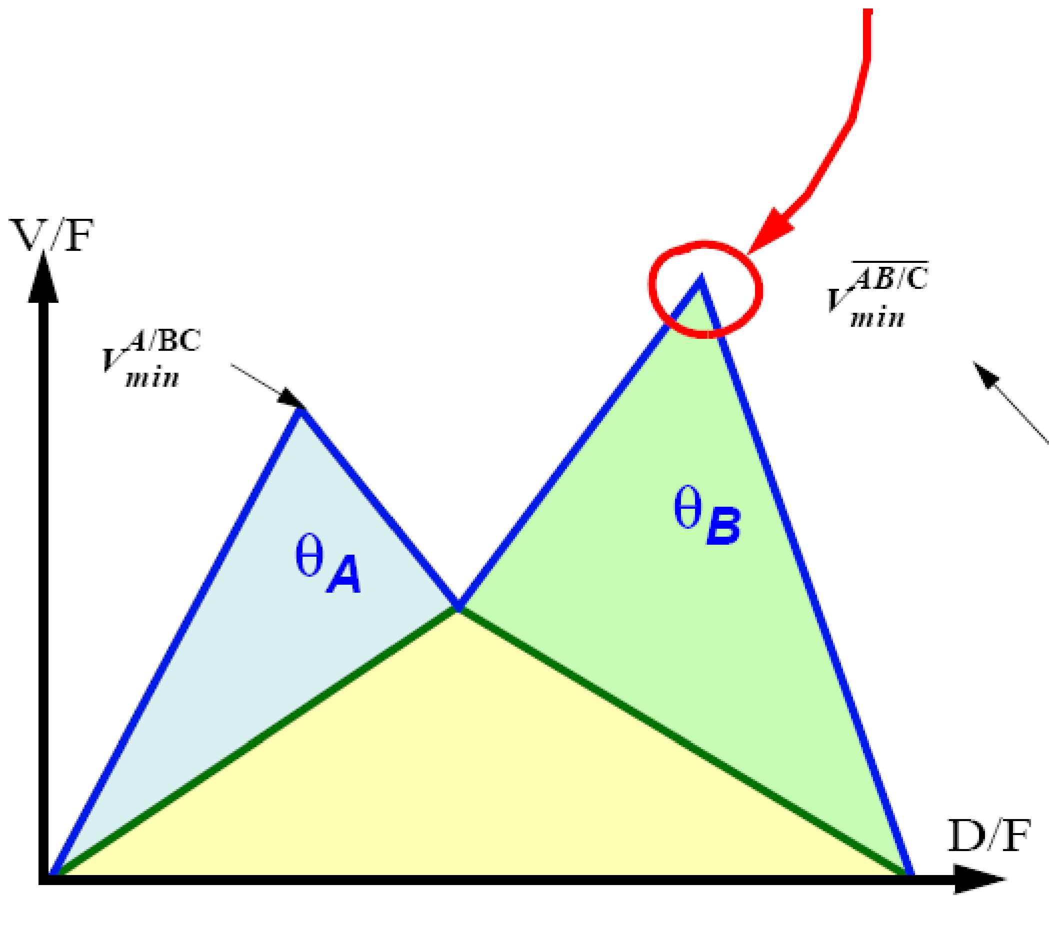


The V_{min}-diagram – for simple energy asessment

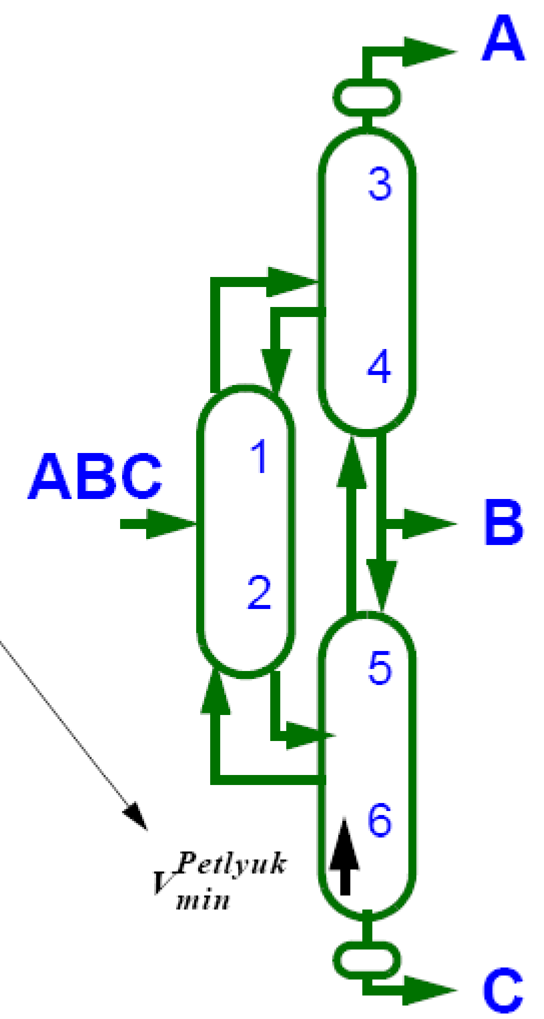




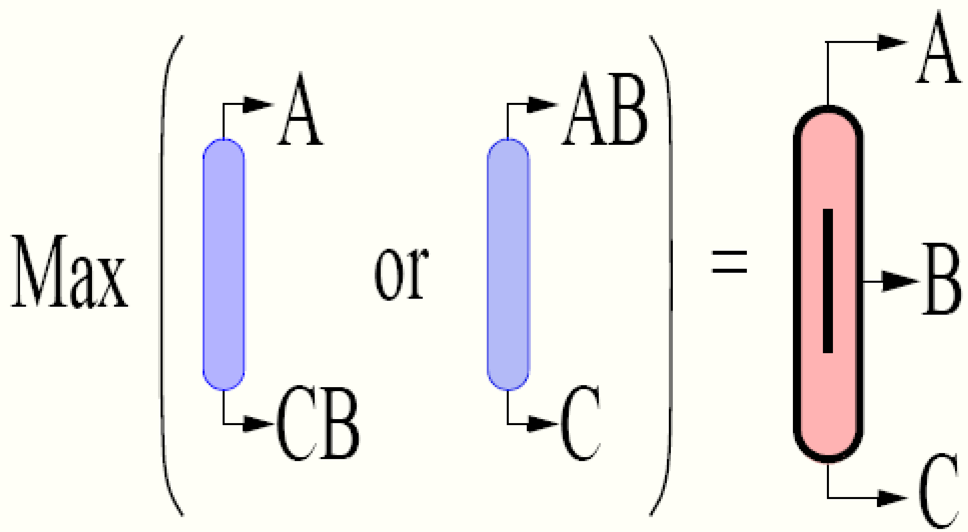
V_{min} for the Petlyuk column:
The highest peak:



V_{min}-diagram



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



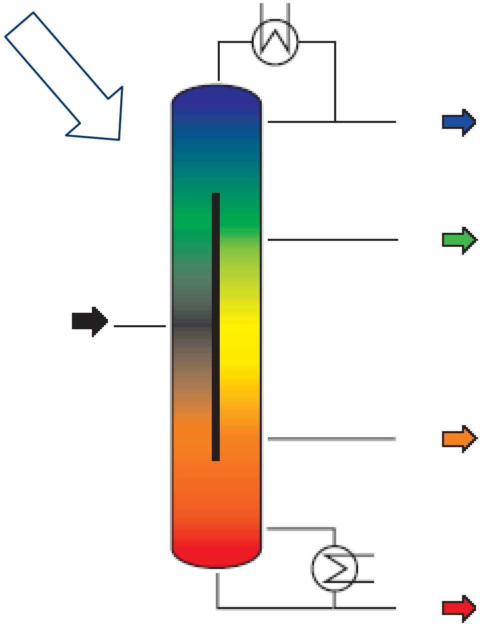
Industrial DWC/Petlyuk applications

German-speaking community dominates

- BASF: 40 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

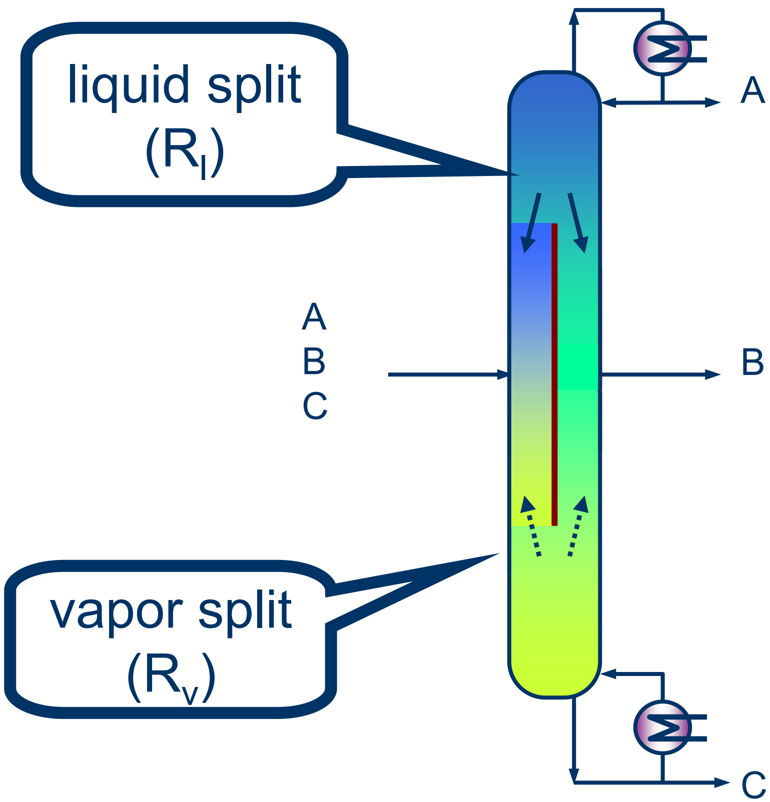


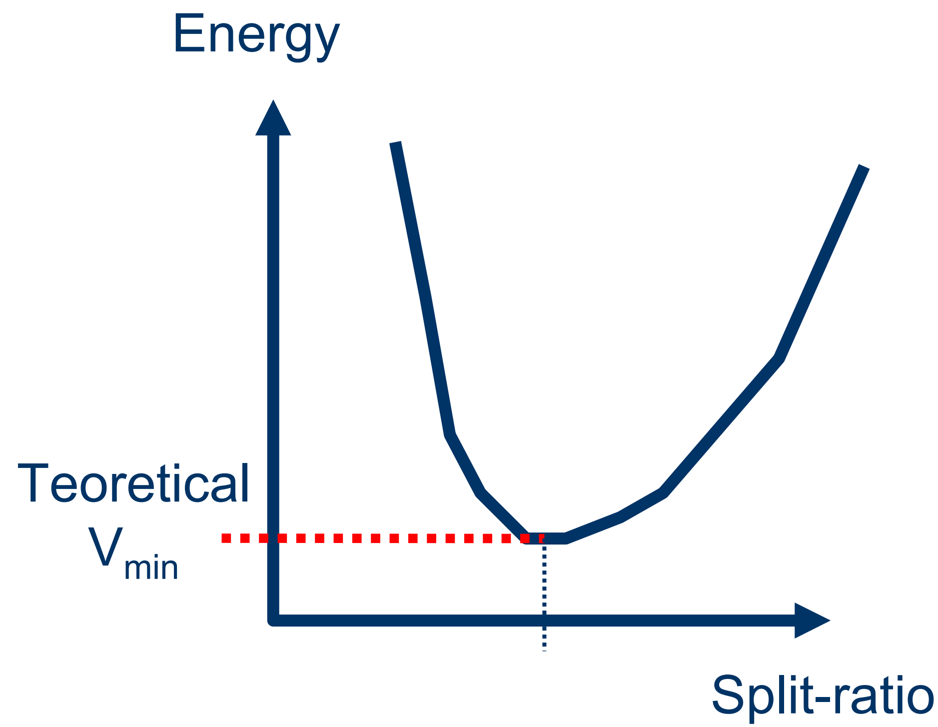
The Kaibel-column
4-product DWC!

Why consider a Petlyuk arrangement

- Large potential energy savings compared to conventional columns (20-30%)
  - Or – increase production 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

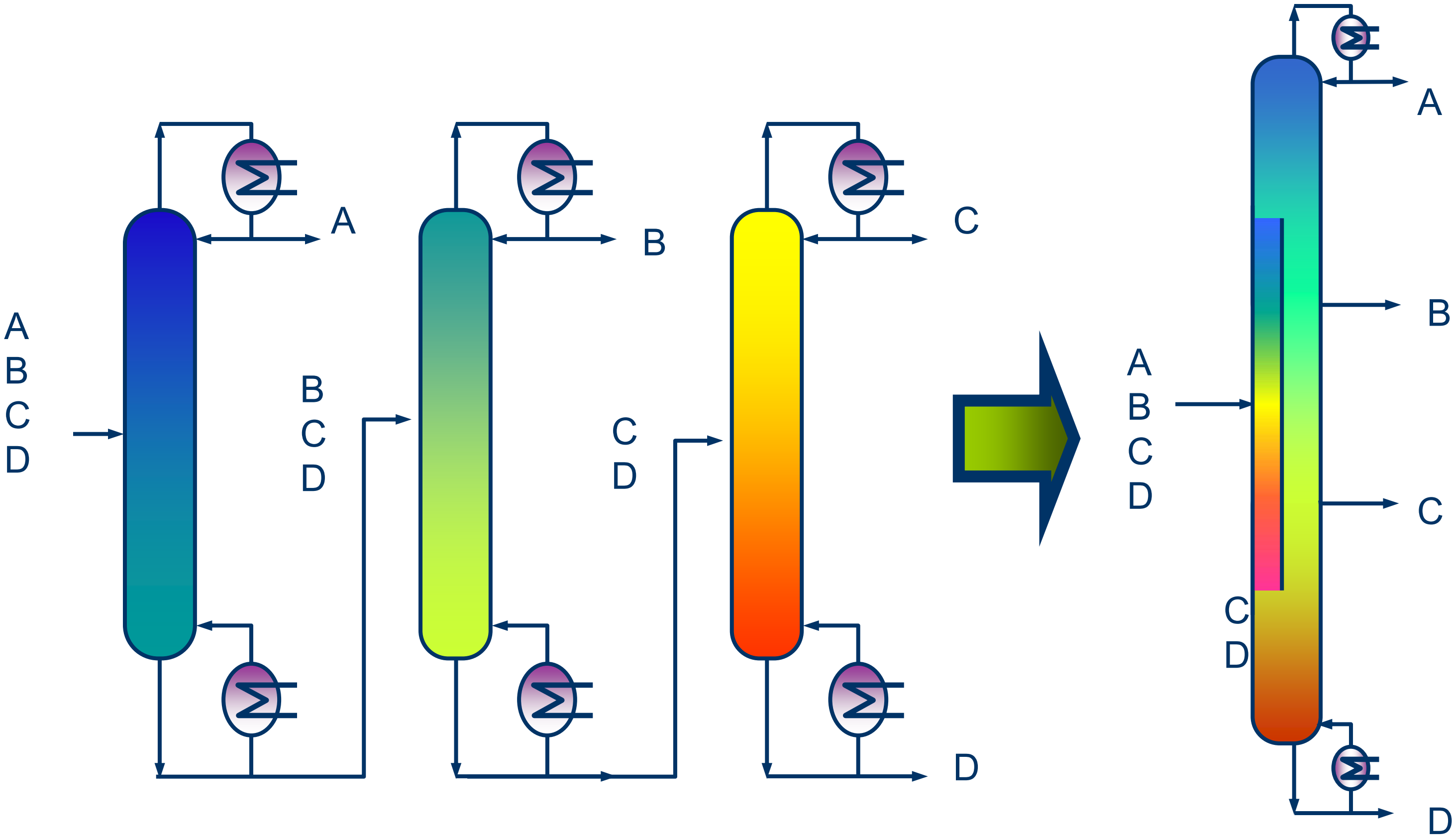
Critical for obtaining the teoretical savings in practice: How to control the splits





Tool: Self optimizing control

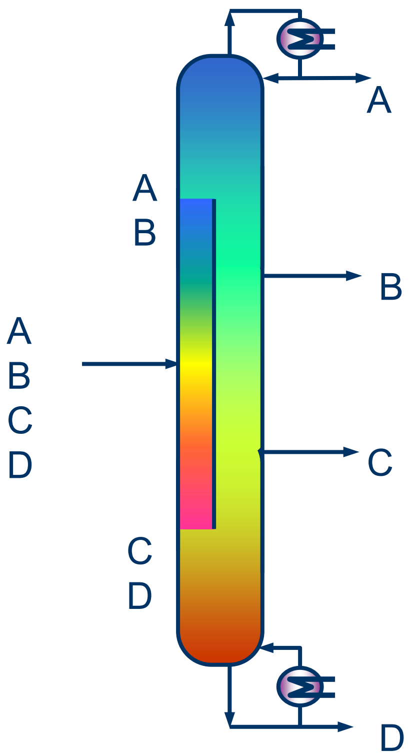
Extend to 4-product DWC: The Kaibel column – (1987)

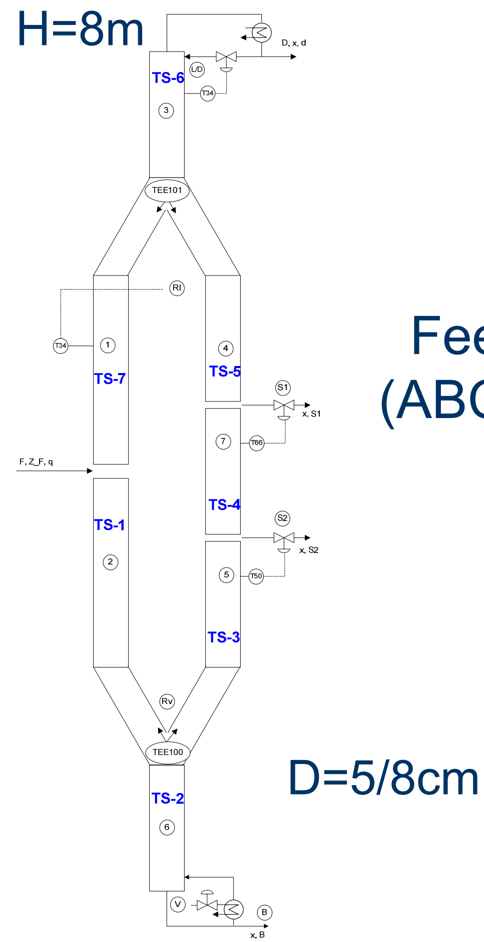


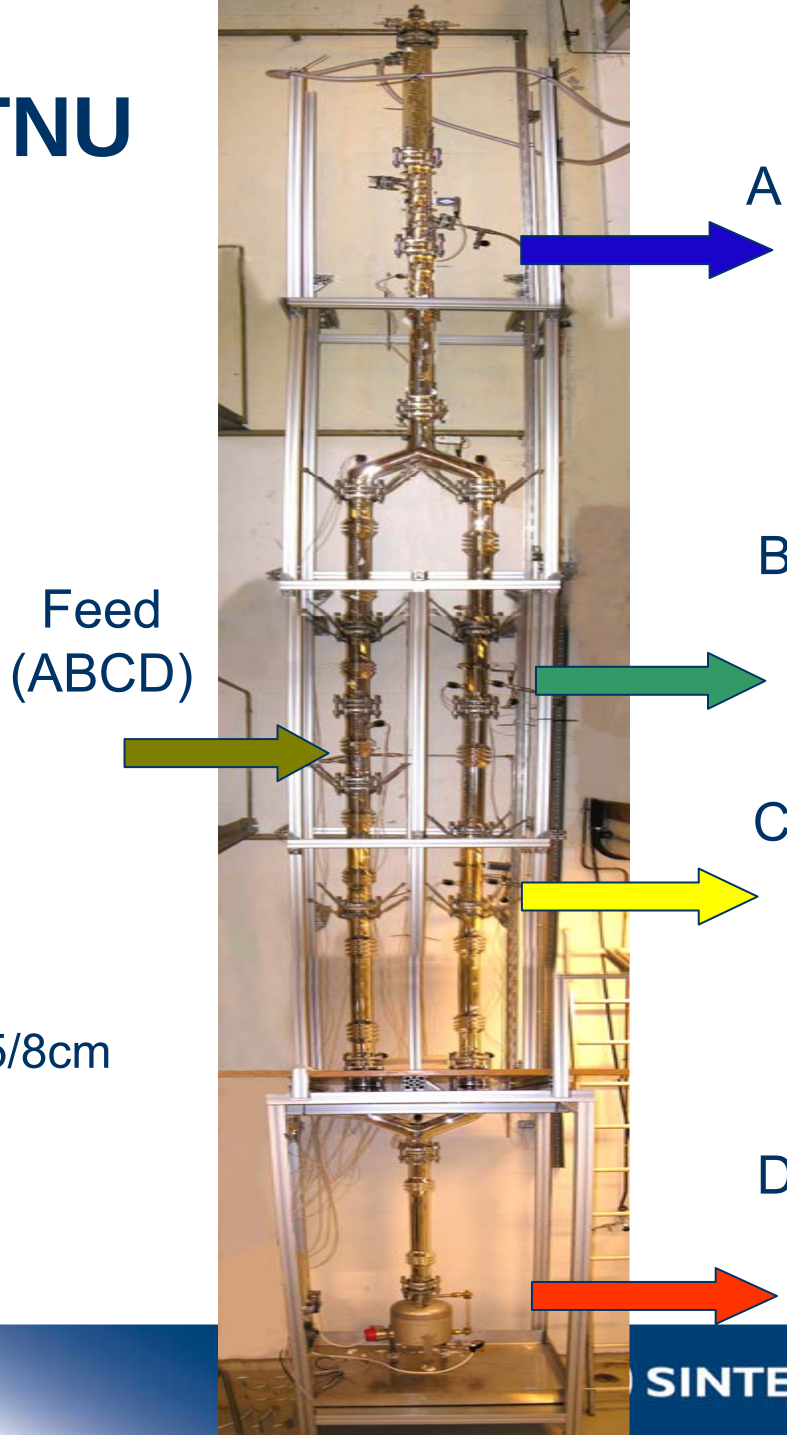
4 products in a single shell!

Saves 30-40 %

The Kaibel column at NTNU







First really big 4-product DWC

Kaibel column

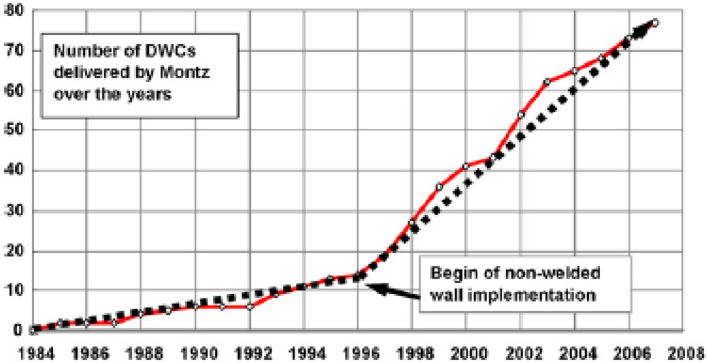


Fig. 2. The number of the dividing wall columns delivered by J. Montz over the years.

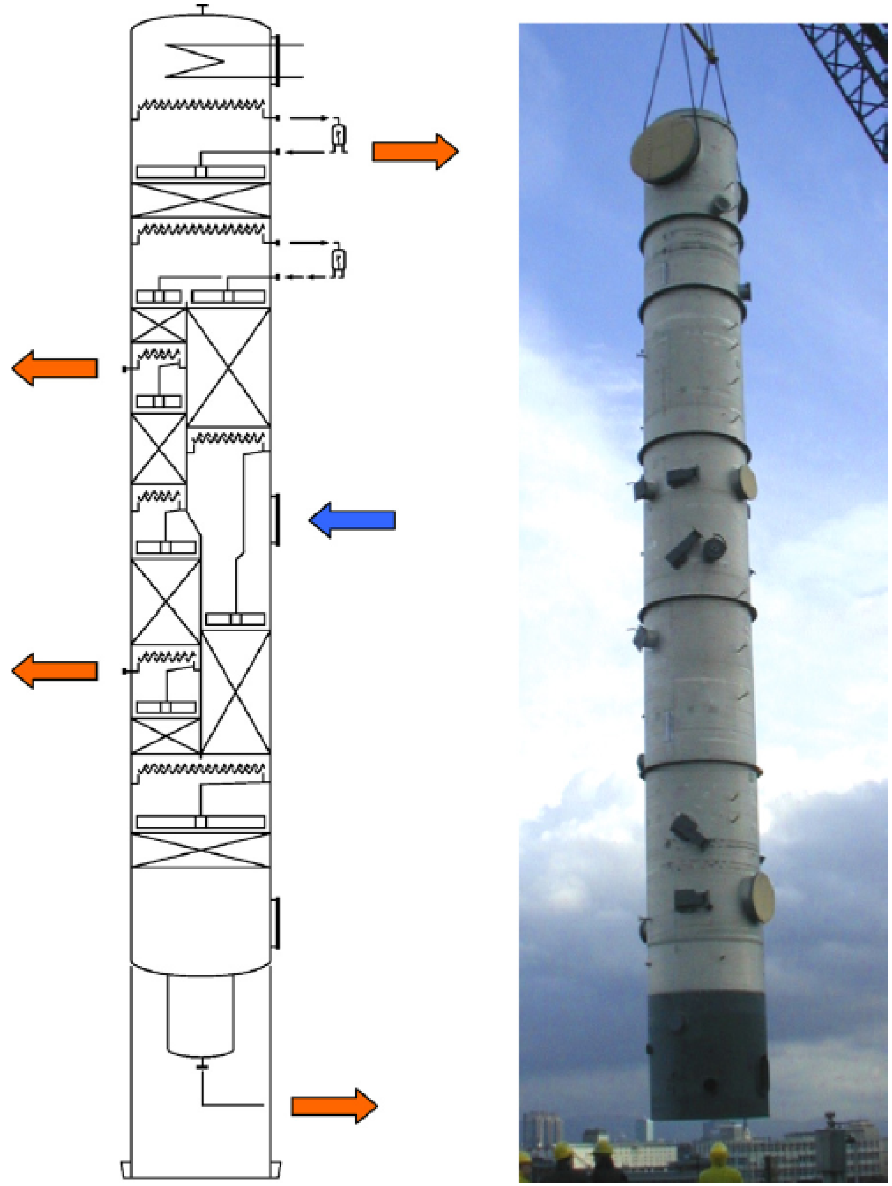
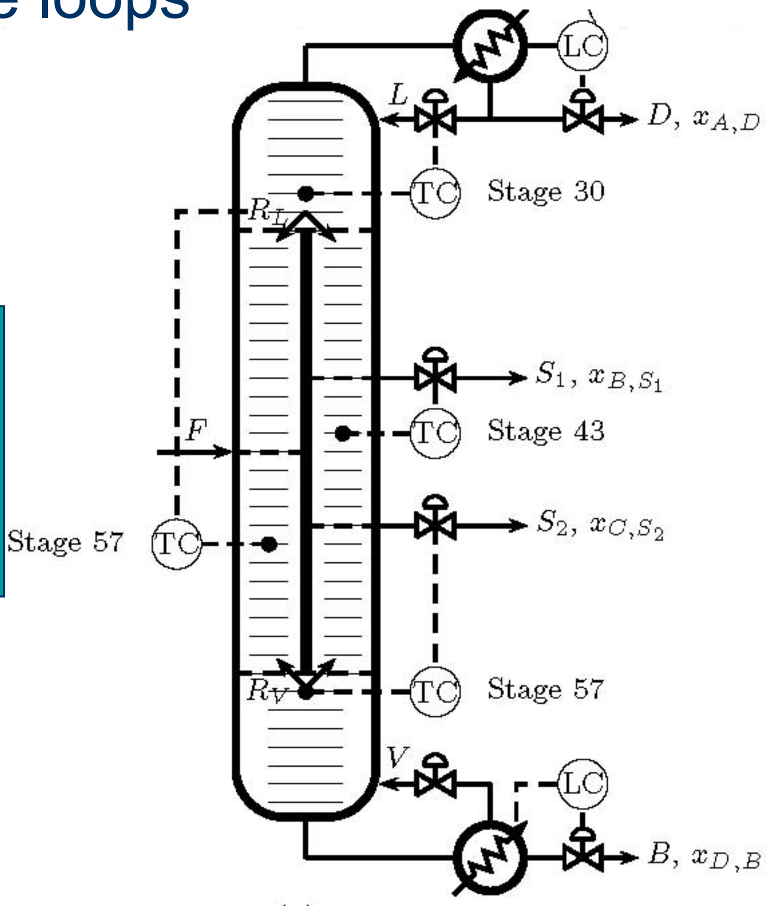


Fig. 3. A photograph of the shell and a drawing illustrating internal configuration of a DWC for separation of a four component feed into pure products.

Control study (Strandberg 2009)

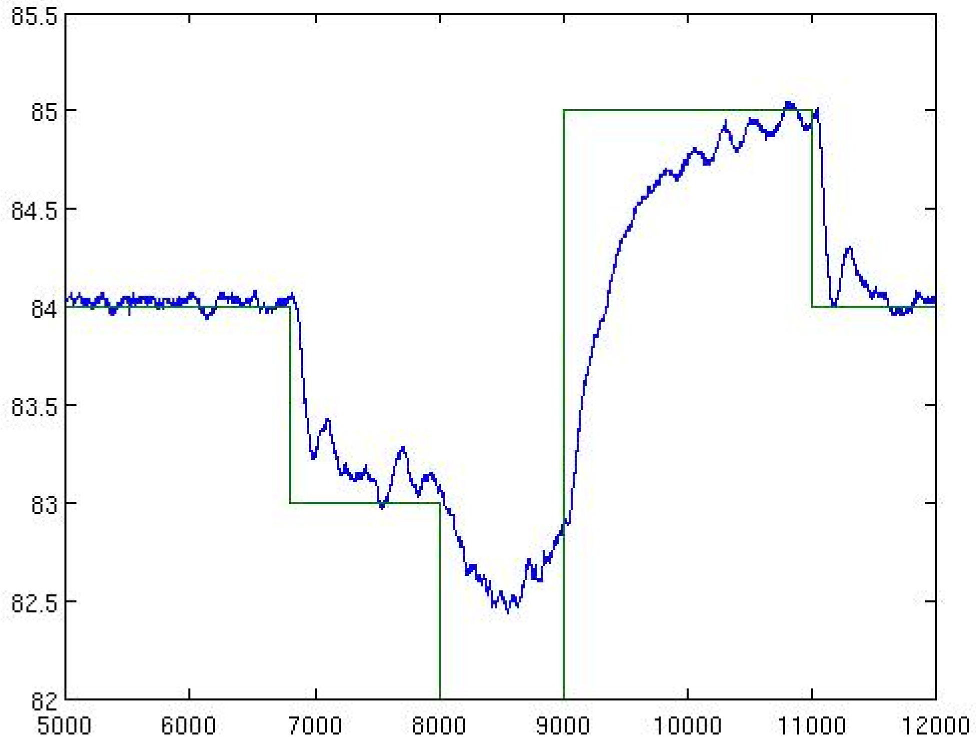
Stabilizing Control by 4 temperature loops

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

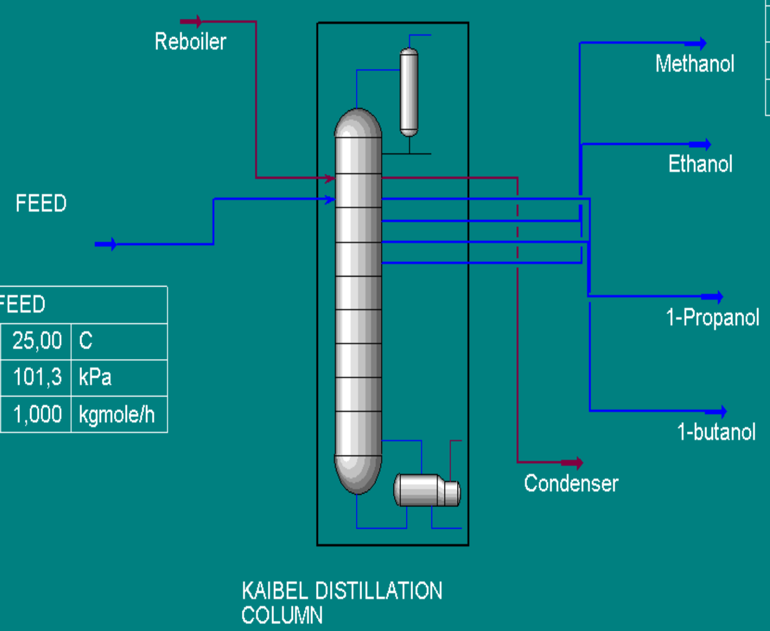


More results:

- 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

Reboiler		
Heat Flow	1,288e+005	kJ/h



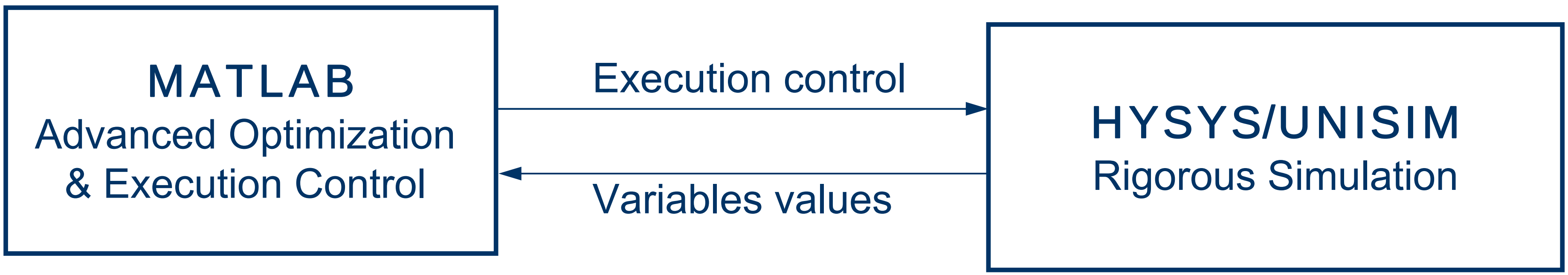
FEED		
Temperature	25,00	C
Pressure	101,3	kPa
Molar Flow	1,000	kgmole/h

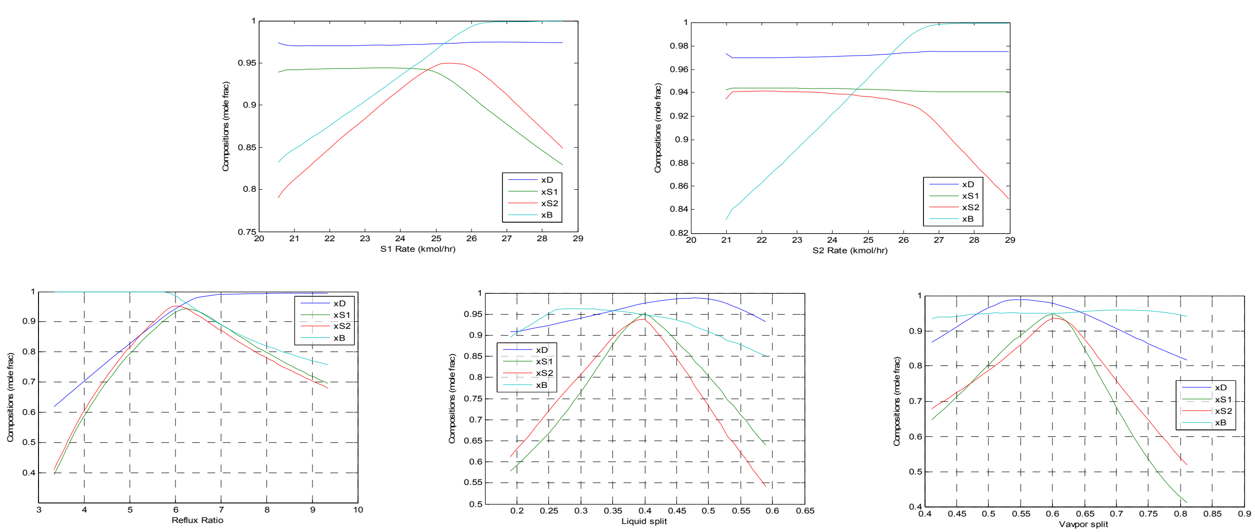
Methanol		
Temperature	64,81	C
Pressure	101,3	kPa
Molar Flow	0,2532	kgmole/h
Comp Mole Frac (Methanol)	0,9700	

Ethanol		
Temperature	77,77	C
Pressure	101,3	kPa
Molar Flow	0,1655	kgmole/h
Comp Mole Frac (Ethanol)	0,9700	

1-butanol		
Temperature	117,0	C
Pressure	101,3	kPa
Molar Flow	0,2572	kgmole/h
Comp Mole Frac (1-Butanol)	0,9700	

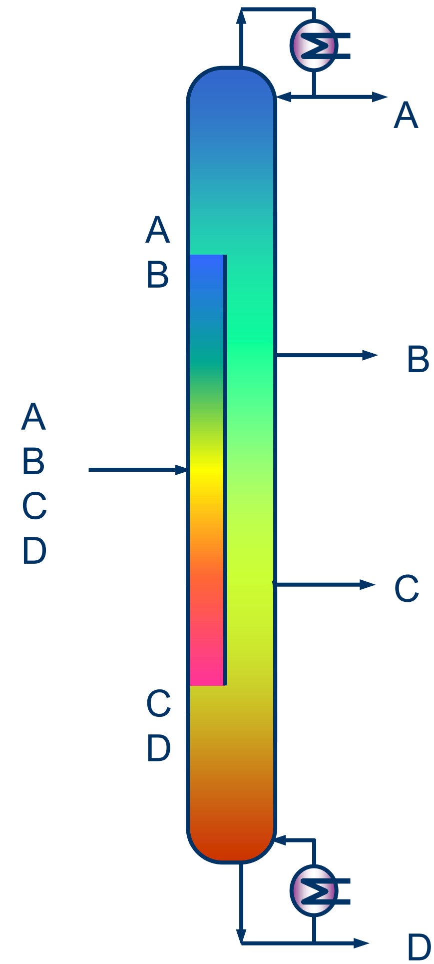
Toolbox for rigorous simulations
by Maryam Ghadrdan



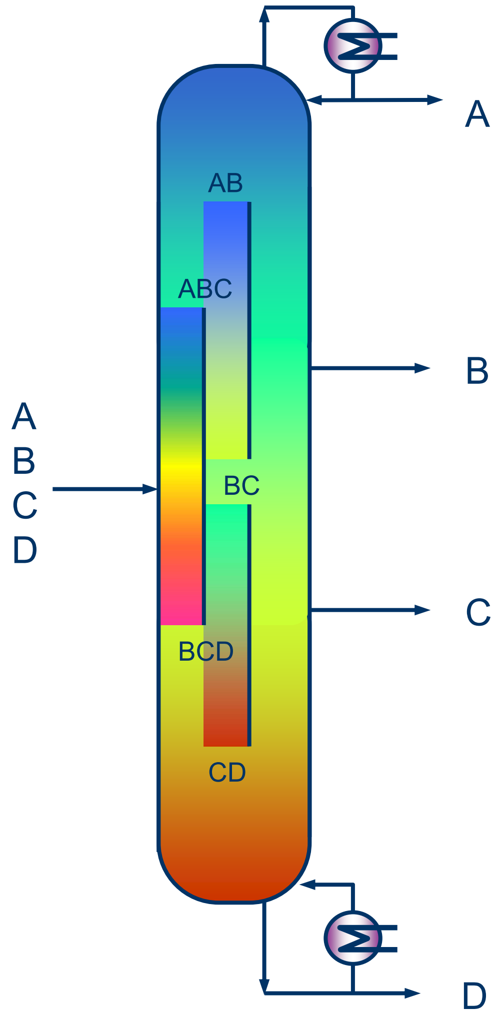


Further work

- 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

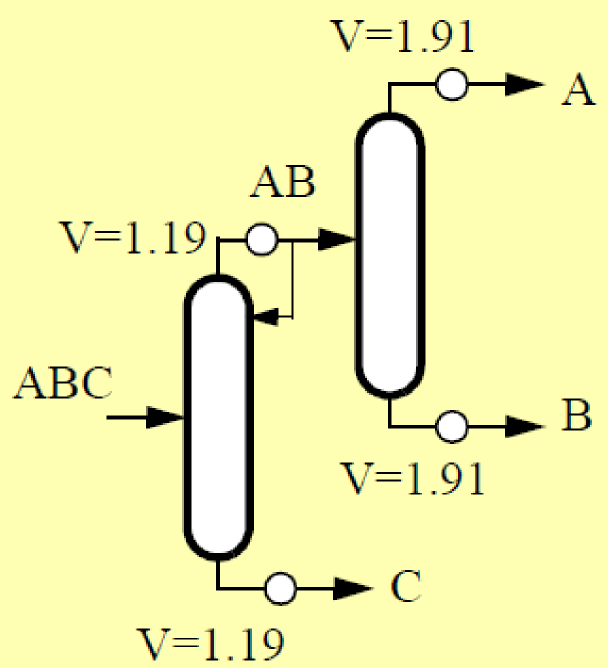


Teoretical savings up to 50%

What about complexity in design and operation?

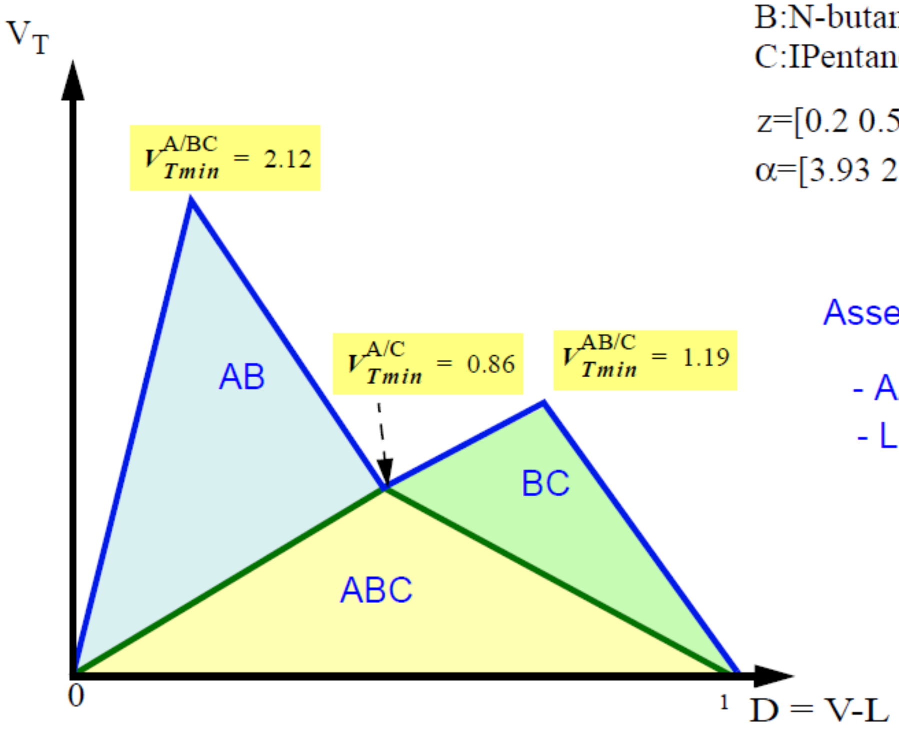
What about refit?

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



Total reboiler boilup=3.10 x F

V_{min}-diagram



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

z=[0.2 0.5 0.3] q=1 F=1

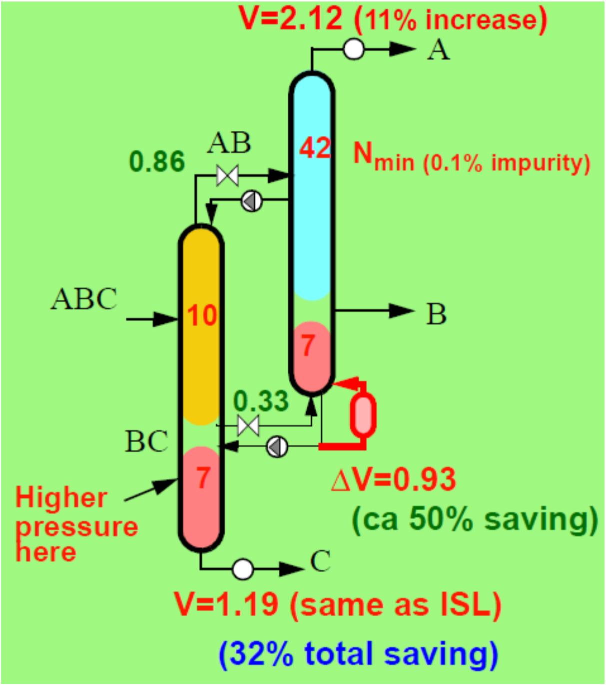
α=[3.93 2.85 1]

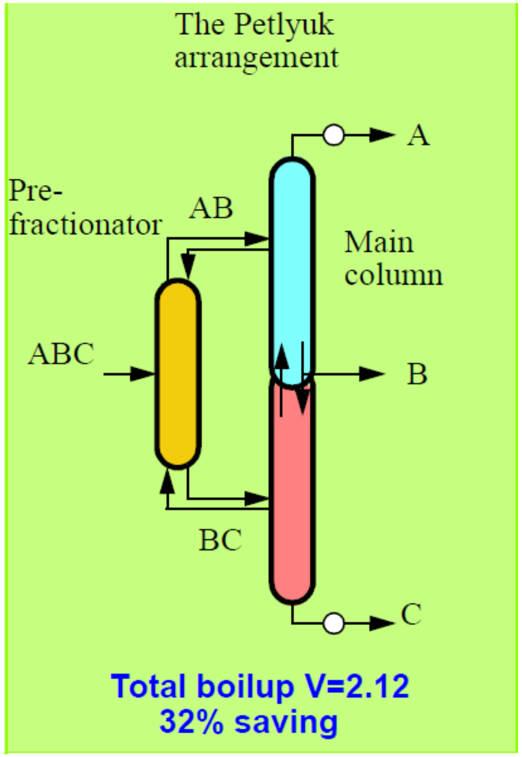
Assessment:

- A/B split dominates
- Large ΔV=0.93

Add direct coupling and save 32 %

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



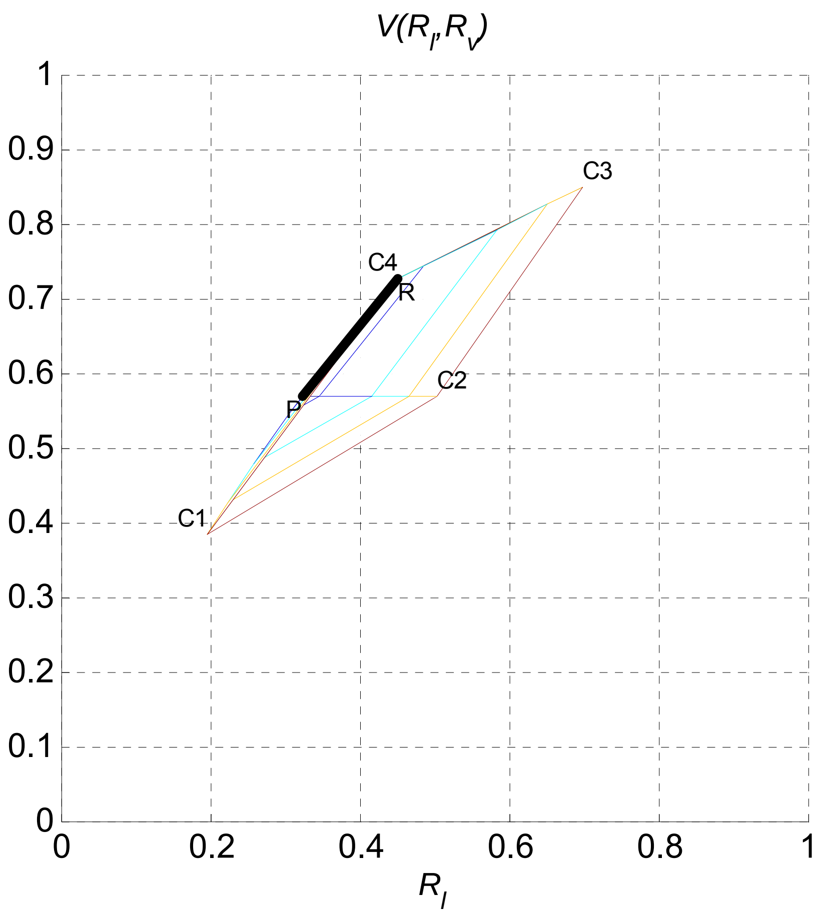


Minimum energy- Definitions and assumptions

- Vapour flow rate (V) generated from all reboilers is used as the energy measure
- Ideal Assumptions
  - Infinite number of stages
  - Constant relative volatility
  - Constant molar flow
  - Constant pressure
  - No internal heat exchange
- Then, exact analytic solution is obtained

Characterisitcs of operation

Petlyuk column boilup (V) as function of split ratios



Minimim Vapour Flow

Conventional : V_{min}=2.03
Petlyuk Column: V_{min}=1.37

Reboiler SAVINGS: 32.80%
Condenser SAVINGS: 32.80%

Feed composition

z_A: 0.33
z_B: 0.33
z_C: 0.33

Relative volatility

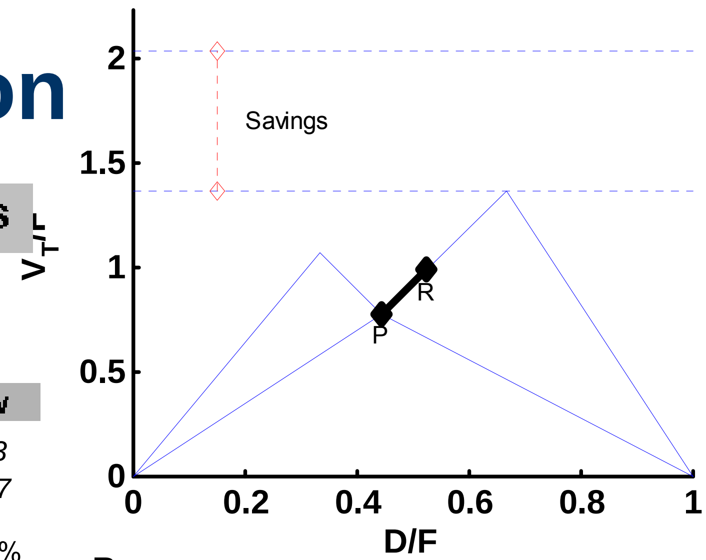
α_A: 4.00
α_B: 2.00

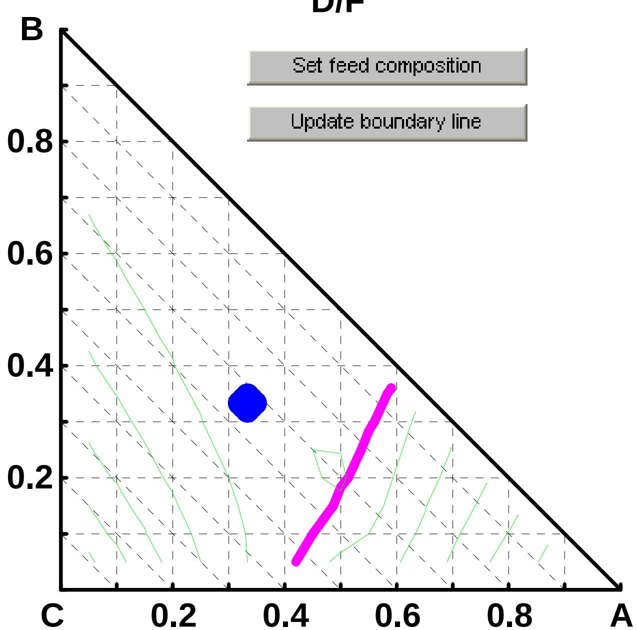
Liquid fration

q_f: 1.00

Defaults

View contour | Toggle rotation





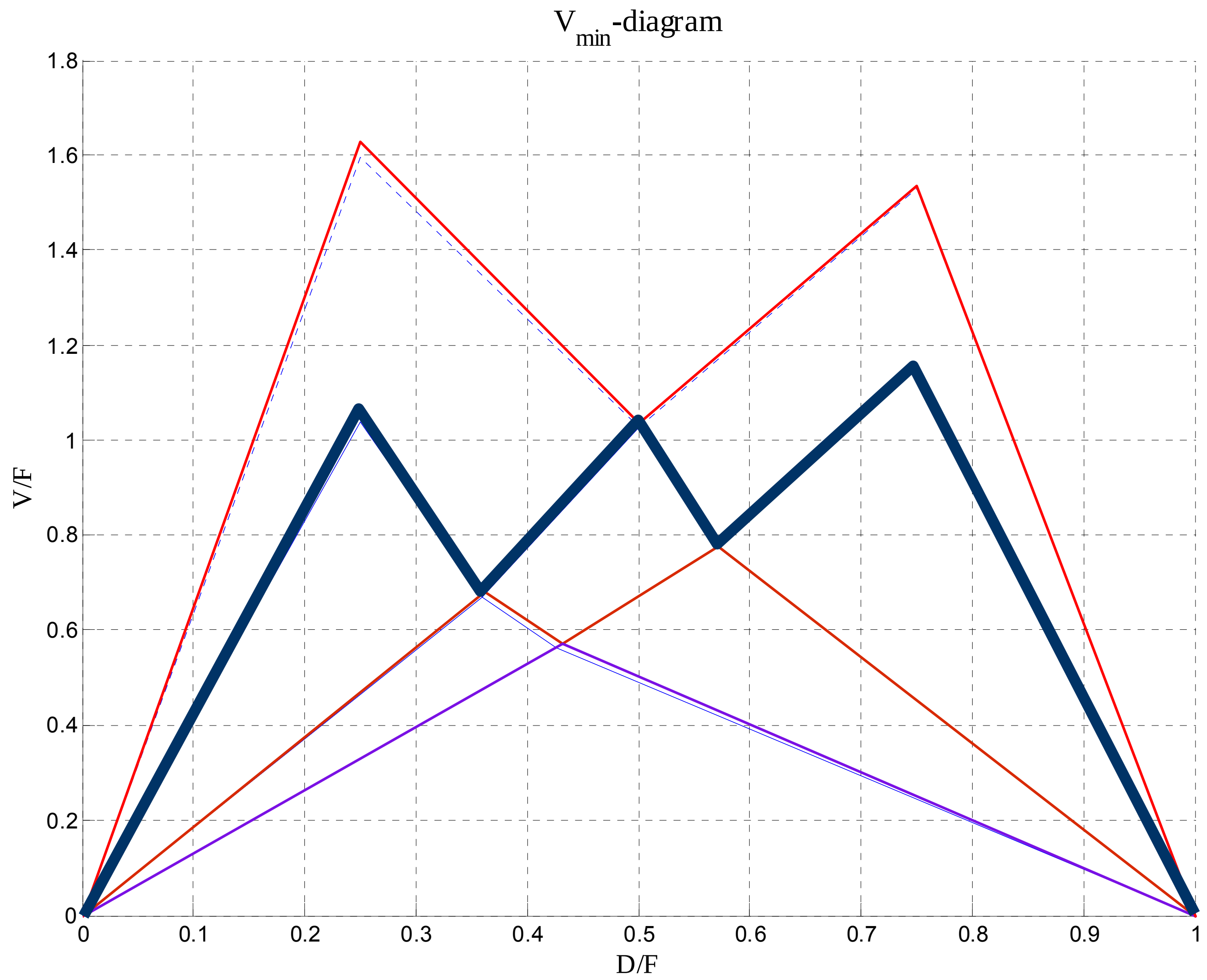
Feed condition for the Kaibel Distillation

- Four components: Methanol+Ethanol+1-Propanol+1-Butanol
- Flow rate F=1.0 Kgmole/h, q=1 (saturated liquid)
- Composition z=[0.25, 0.25, 0.25, 0.25]
- EOS Wilson
- Pressure Atmospheric
- Relative volatility α= [8.27: 4.84: 2.30: 1.0]

Minimum Energy – competition

No	Configuration	Ideal V_{min}/F	Ideal Savings	UniSim Savings
1	Four product extended Petlyuk	1.16	51%	
2	Kaibel column	1.59	33%	>26%
3	Prefractionator+ single main column	1.98	16%	
4	Conventional direct sequence (3 columns)	2.38	0% (reference)	0% (reference)
5	Prefractionator+ 2 separate columns	2.62	-10% (loss)	

V_{min}-diagram for the Kaibel column



How to apply DWC/Petlyuk columns

- Make sure to do a reasonable design in terms of placement of the dividing wall/design split.
- Important: Make sure to indentify the optimality region for the expected actual feed variations, and thereby clarify the requirements for on-line adjustment of:
  1. None of the split ratios (E.g. in case of quadrangle shaped reg.)
  2. Just the liquid split (In case of a line segment reg.)
  3. Both split ratios (in case of a very short line segment)
- Determine the final control strategy based the actual product value/energy cost, and dynamic controllability analysis.