Dividing Wall Column Technology

Recent Developments and Challenges

Žarko Olujić

Delft University of Technology (retired, guest associate)
Delft, the Netherlands

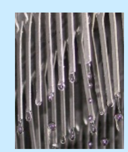
Thomas Rietfort
Helmut Jansen

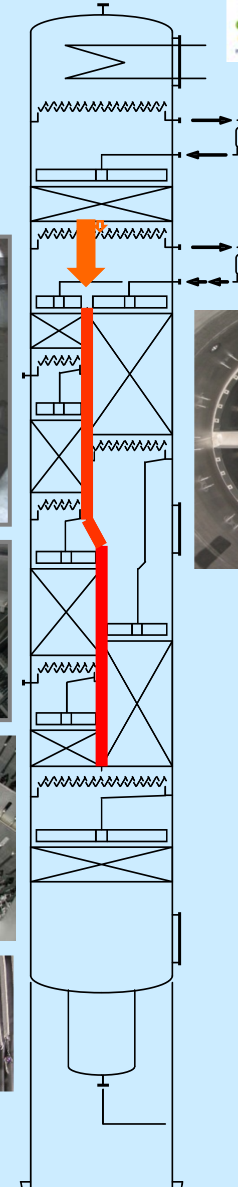
Julius Montz GmbH
Hilden, Germany

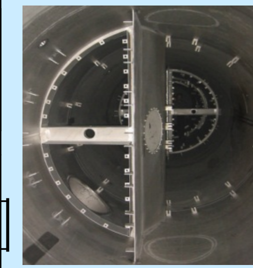
Igor Dejanović
The Univeristy of Zagreb
Faculty of Chemical Engineering and Technology
Zagreb, Croatia

EFCE WP FLUID SEPARATIONS

Annual Meeting, 12-13 May, 2016, Copenhagen, Denmark





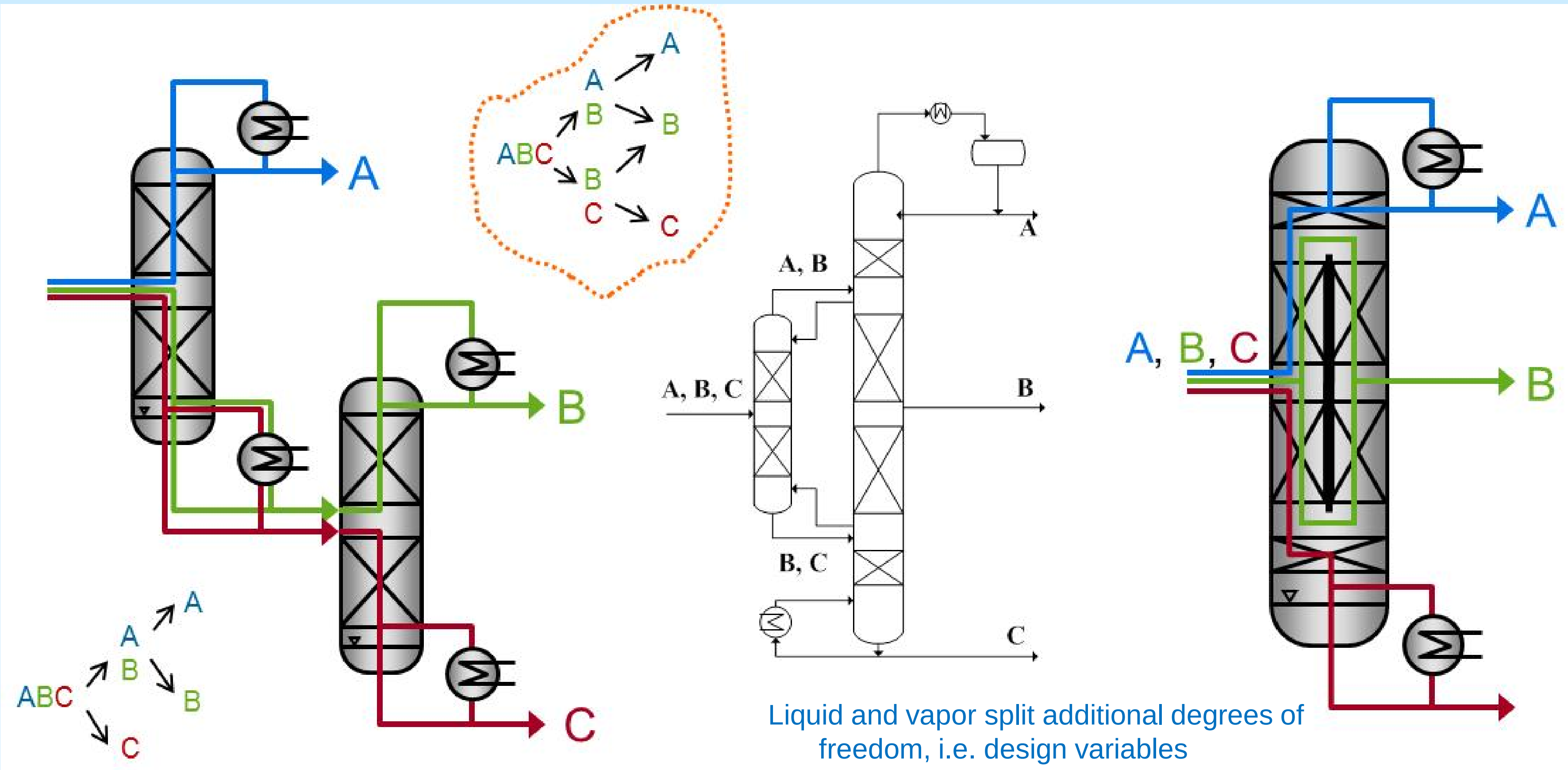


Towards a Sustainable Distillation Column

(Using less energy and material and doing less damage to the environment.)

Minimization of energy requirement by ***thermal coupling***

Thermodynamic efficiency of a sequence of two or more (n) conventional distillation columns as required for obtaining (n-1) pure products can be maximized by utilizing full thermal coupling. Where appropriate, full thermal coupling can be implemented in single shell. Such a configuration is generally known as Dividing Wall Column (DWC).



Conventional two-column sequence → Thermally coupled column → **Dividing Wall Column (DWC)**

Each with a number of alternatives

DWC Applications Range

Equipment size: Column diameters: 0.5 m – 6.5 m, Column heights: up to 100 m
Laboratory/pilot scale diameters: 0.04 – 0.2 m
Operating pressure: 0.002 to 10 bar
Nature of application: All kind of distillation applications/chemicals.
Purity requirements: From typical solvent recovery to ultra purity (in ppb range) specifications

Extractive distillation, Reactive distillation, ...

Benefits:

Low energy requirement

(Vapor throughput minimized, and repeated evaporation and/or condensation eliminated)

Reduced OPEX/CAPEX (~ **30** %) & footprint (plot area)

Shorter residence time

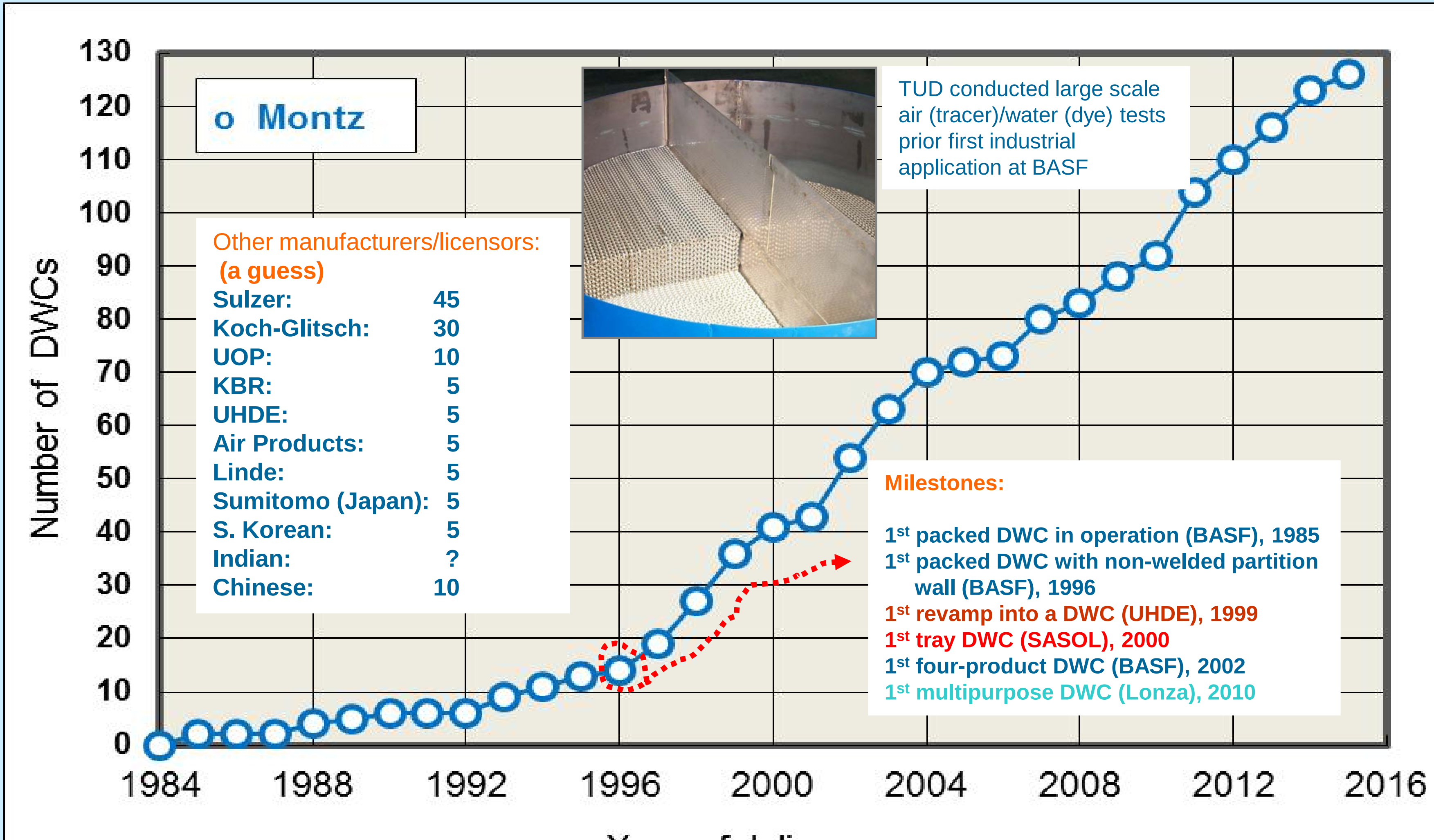
Higher yields, Less maintenance, ...

In revamps, energy saving enables capacity increase!

Dividing Wall Column

Number of industrial applications/Milestones

Columns in operation: > 250 (> 1/3 at BASF SE), ~ 90% are packed DWCs



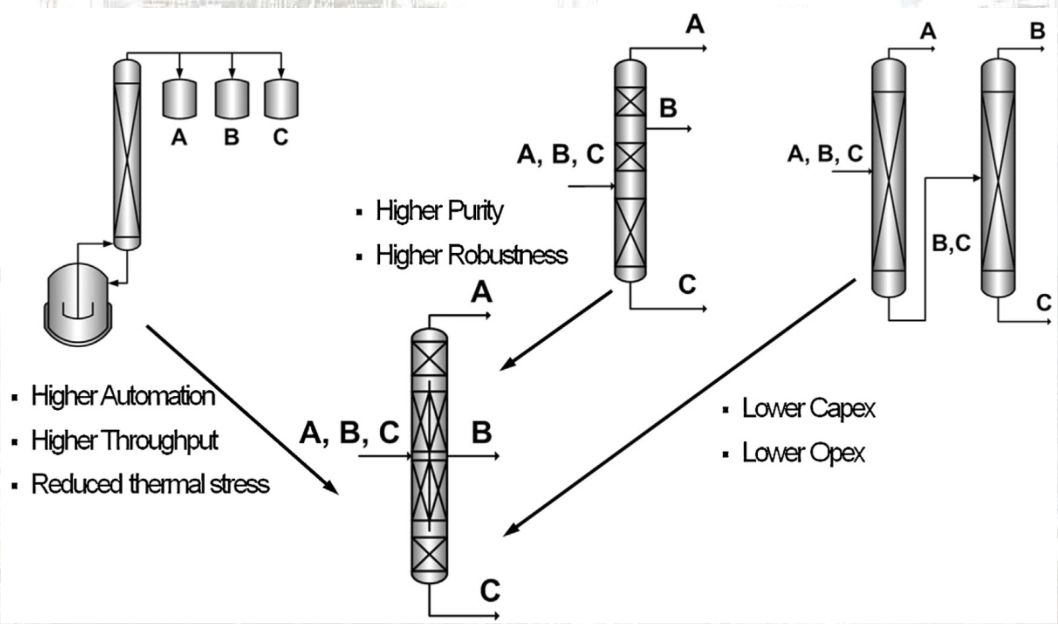
Courtesy of MONTZ

DWC Technology

New milestone

First multipurpose DWC at Lonza in Visp, Switzerland

Three periodic operations carried out in a DWC:



(i) A batch distillation column

(ii) A side product column

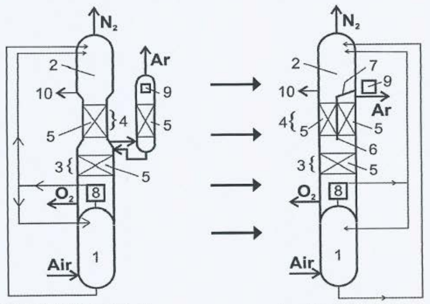
(iii) Conventional two-column sequence

Source: Staak, D., Grutzner, T., Schwegler, B., Roederer, D., ***Chem. Eng. Process.: Process Intensification*** 75 (**2014**) 48-57.

A Novel Field of DWC Application

Cryogenic Air Distillation

氩气增效采用隔板塔
Argon Rejection Using a Divided Wall Column



传统的侧线式设计
Traditional "sidearm" design

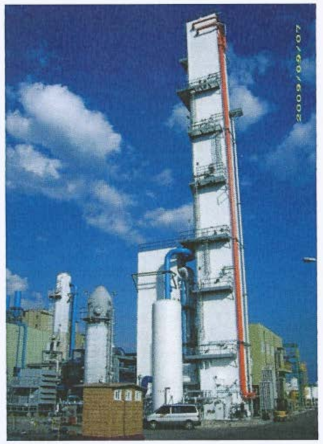
新型隔板塔设计
Novel divided wall design

- 氩气增效可降低主空压机能耗高达4%
  Main Air Compressor (MAC) power consumption may be reduced by up to 4% by rejecting argon
- 传统的侧线式氩塔价格昂贵
  Traditional "sidearm" argon column is expensive
- 利用隔板塔使设计更加紧凑和高效
  Design is more compact and efficient if implemented using a divided wall

AIR PRODUCTS

隔板塔技术在空气化工产品公司的历史和放大
History and Scale up of Divided Wall Technology at Air Products

- 于1999年申请专利，2002年在AP的实验室进行测试
  Patents filed in 1999, Field test at AP Labs in 2002
- 日产700吨氧气和30吨氩气的空分装置于2009年在韩国第三方客户的工厂投产
  700 tpd O_2/30 tpd Ar ASU commissioned in 2009 (Korea - 3rd Party Customer)
- 日产1250吨氧气和65吨氩气的空分装置于2010年在加拿大的AP工厂投产
  1250 tpd O_2/65 tpd Ar ASU commissioned in 2010 (Canada – AP plant)
- 日产8200吨氧气并附除氩功能的空分装置（3套）于2013年在中国的AP工厂投产
  ASU producing 8200 TPD (3 trains) Oxygen with Argon rejection - commissioned in 2013)n stream 2014) (China - AP plant)

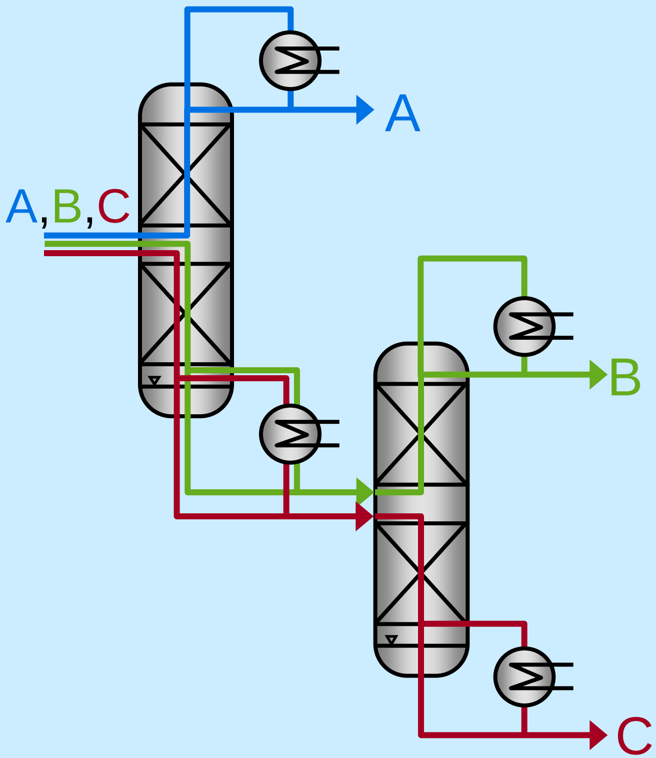


AIR PRODUCTS

Source, with permission of Air Products:
M. Kalbasi, Air Products, 2015 International Forum on Mass Transfer and Se[paration Engineering, **November 16-18, Tianjin, China**

Dividing Wall Column

Constraints and concerns



One operating pressure

Higher ΔT from top to bottom

Higher pressure drop

Temperature penalty

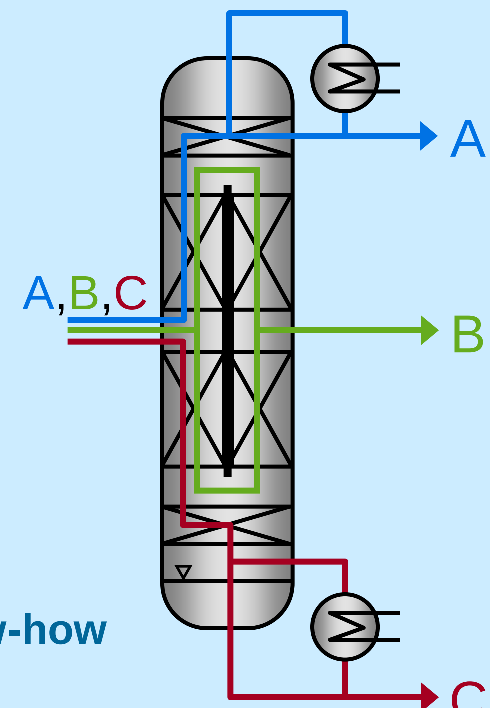
Taller column

ΔT across the partition wall

Vapor split ratio control

Lack of detailed design know-how

Existing patents restrictions

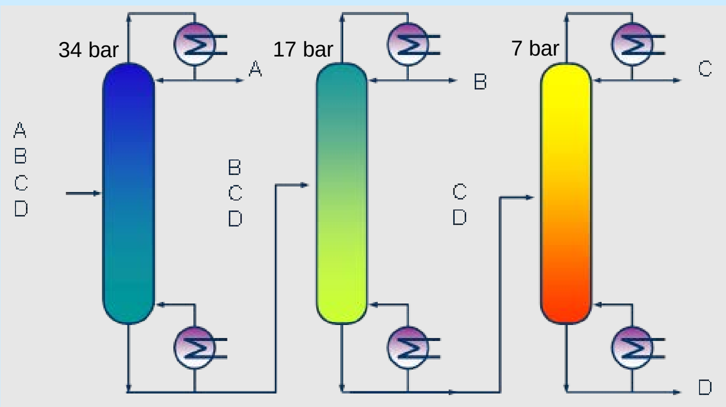


Dividing Wall Column

Constraints, an example

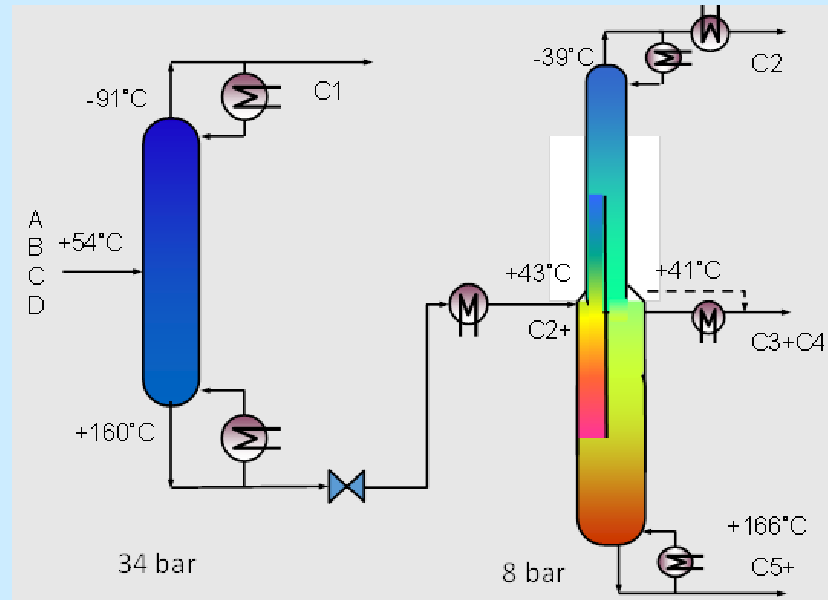
NGL fractionation in (F)LNG plants

C1*(A)/*C2*(B)/*C3&C4*(C)/*C5+*(D) *separation sequence



Configuration	Relative V/F (-)	Relative weight (-)	Condensing duties (kW) (-91°C)	(-27°C) (-40°C)	(40°C)
Conventional direct split sequence	1.00	1.00	-91	-164	-513
CC + 3-p DWC with vapor side product	0.83	0.91	-91	-265	-

Most promising DWC involving arrangement (11 options evaluated)



As well known, **benefits of thermal coupling fade away with increasing boiling point range of the feed.** In given cryogenic application example, the total energy requirement was significantly reduced (17%), but at the expense of an increased amount of much costlier refrigeration ("temperature penalty", i.e. an increased OPEX). Important consideration: **energy quality - quantity.**

Source: I. Halvorsen, I. Dejanović, K. A. Marak, Ž. Olujić, S.Skogestad**,** ***Chem. Eng. Technol*****.** 39 (**2016**) in print**.**

Dividing Wall Column

Ongoing challenges

Design, construction, and operation of a fully thermally coupled 4-product DWCs

Benefits increase largely, but at the cost of increased complexities in design, construction, and operation.

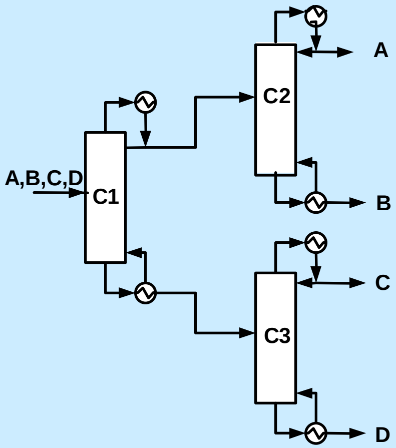
To exploit full potential of a 4-p DWC, a complex, multi partition internal arrangement required (single partition designs in operation)**.**

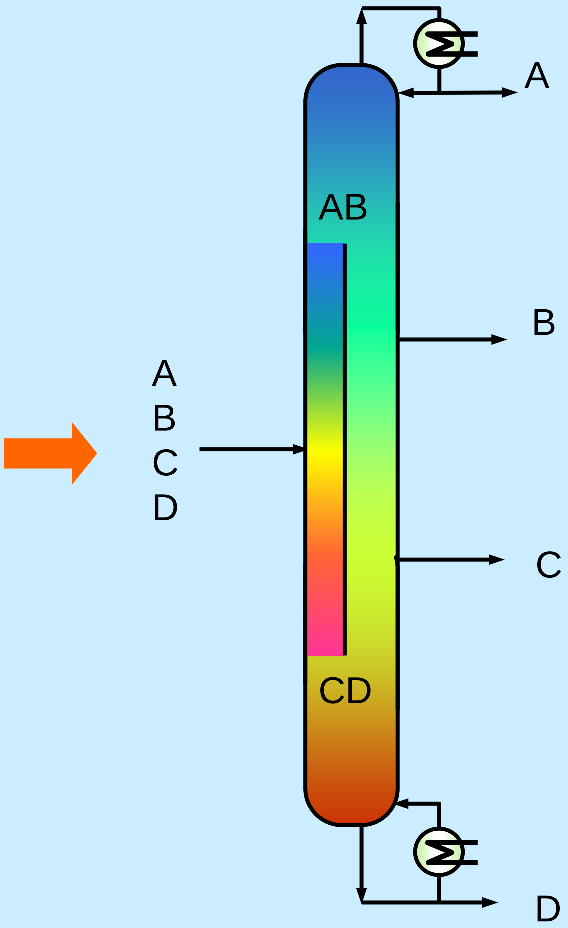
Details matter, and during preliminary evaluations – feasibility studies, dimensioning needs to be carried out with sufficient rigor to allow proper evaluation and choices among feasible alternative options.

The know-how available in public domain is sufficient in this respect, for packed DWCs.

Starting Point: 4-p Kaibel DWC ("2-4" configuration)

Proven in practice

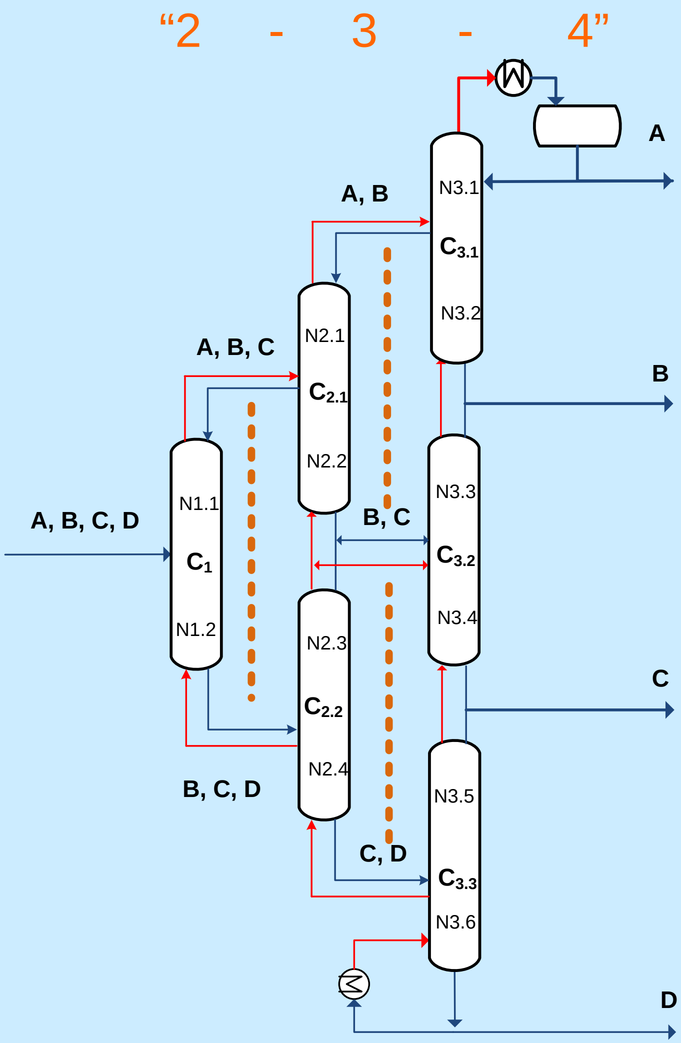


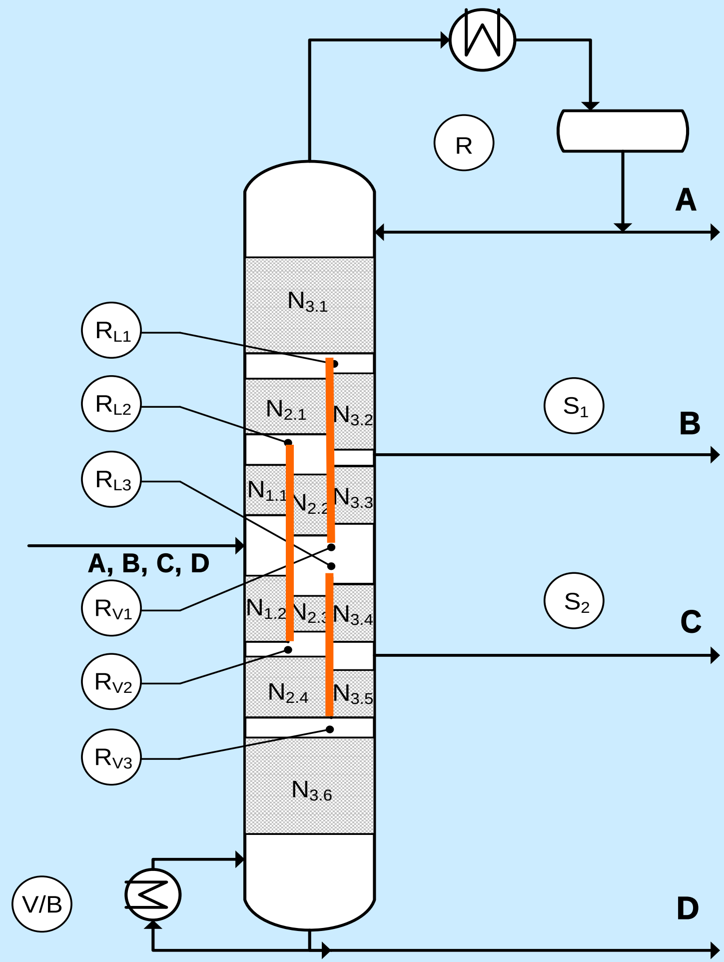


- Proposed by G. Kaibel 1987
- Single partition wall
- Theoretical savings: larger than experienced with 3-p DWCs (> 30%)
- Not a full Petlyuk arrangement, i.e. less efficient, but practical
- First application: 2002 at BASF

A Full Scale 4-p DWC ("2-3-4" configuration)

A 4-p Petlyuk arrangement accommodated within one shell





A DWC with three partition walls, i.e, **three vapor and three liquid splits** **(Not attempted yet in practice!)**

4-p DWC Design Method Development

The collaborating institutions/people (2009 on)

I. Halvorsen, **SINTEF** (Norway)
S. Skogestad, **NTNU** (Norway)

Identification and evaluation of feasible configurations (V-min diagram method)

Process control considerations*

I. Dejanović, **Univ. of Zagreb** (Croatia)

Detailed simulation and estimation of stage and reflux requirements

Ž. Olujić, **TU Delft** (Netherlands)

H. Jansen, **J. Montz** (Germany)
B. Kaibel (Presently with BASF SE)
T. Rietfort

Choice of equipment and dimensioning of packed DWCs

***SINTEF and NTNU process dynamics and control studies concerning four-product DWCs:**

Dwivedi, Strandberg, Halvorsen, Skogestad, *Steady state and dynamic operation of four-product dividing-wall (Kaibel) columns: Experimental verification*, ***Ind. Eng. Chem. Res***. 51 (**2012**) 15696-15709.

Dwivedi, Strandberg, Halvorsen, Preisig, Skogestad, *Active vapor split control for dividing-wall columns*, ***Ind. Eng. Chem. Res***. 51 (**2012**) 15176-15183.

Dwivedi, Halvorsen, Skogestad, *Control structure selection for four-product Petlyuk column*, ***Chem. Eng. Process***. 67 (**2013**) 49-59.

DESIGN CASE: 15 component feed ⟶ 4 products

Based on actual aromatics plant data

Identification and evaluation of feasible configurations (V-min diagram method)

(A stand-alone Matlab program or implemented in a commercial software package)

⇩

Detailed estimation of stage and reflux requirements

(Utilizing tools available in commercial simulation packages, initial guesses output of Vmin diagram method)

⇩

4-p packed DWC dimensioning

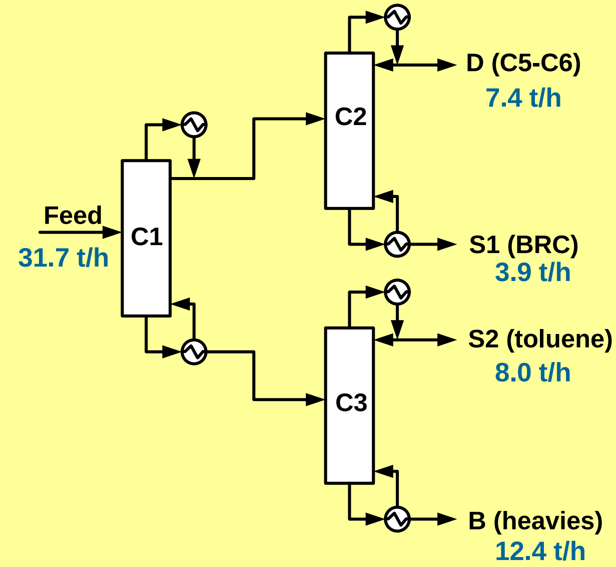
(An Excel soubroutine)

⇩

Total annualized cost estimation

(An Excel soubroutine)

Base case configuration



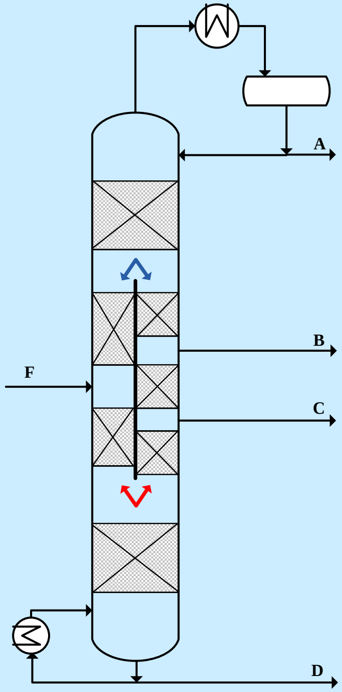
Product specs:

- C5-C6 fraction < 1.3 mass % benzene
- BRC > 67 mass % benzene
- Toluene purity > 97 mass %

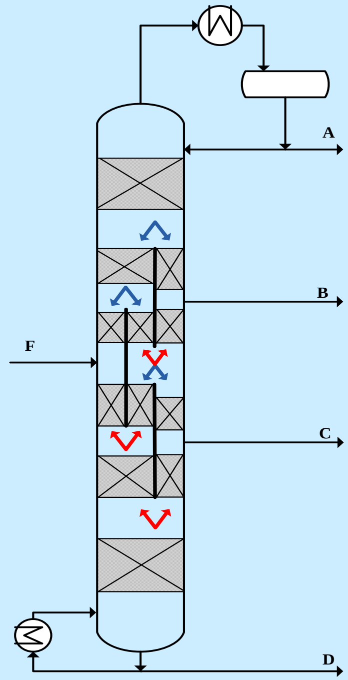
Four-product DWC

Alternative configurations for aromatics separation base case

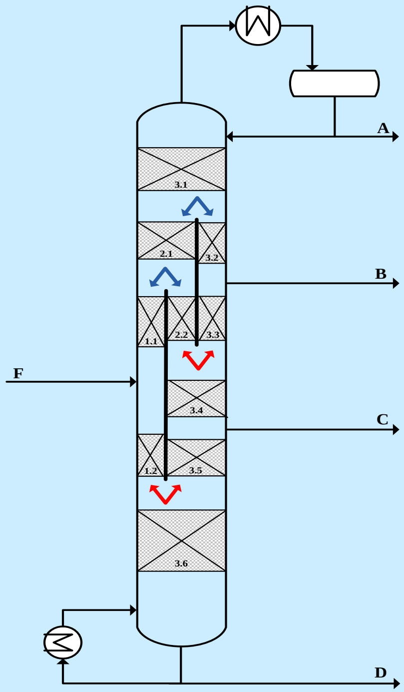
"2-4"



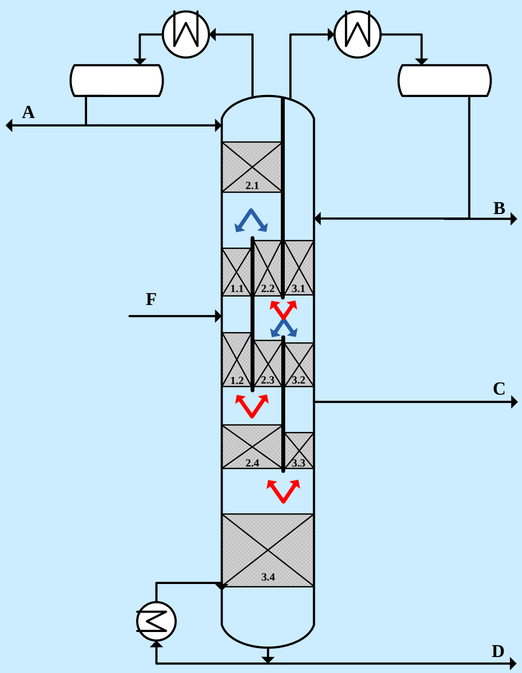
"2-3-4"



"2-2-4"



"2-3-3"



Single partition — **1** x (**V/V**) & (**L/L**)

Multiple partitions (thermodinamically equivalent)

- "2-3-4": **3** x (**V/V**) & (**L/L**); 2 x (V/V) & 3 x (L/L)
- "2-2-4": **2** x (**V/V**) & (**L/L**)
- "2-3-3": **3** x (**V/V**) & **2** x (**L/L**)

Details on preliminary rigorous simulation, dimensioning and cost estimation of these configurations can be found in:

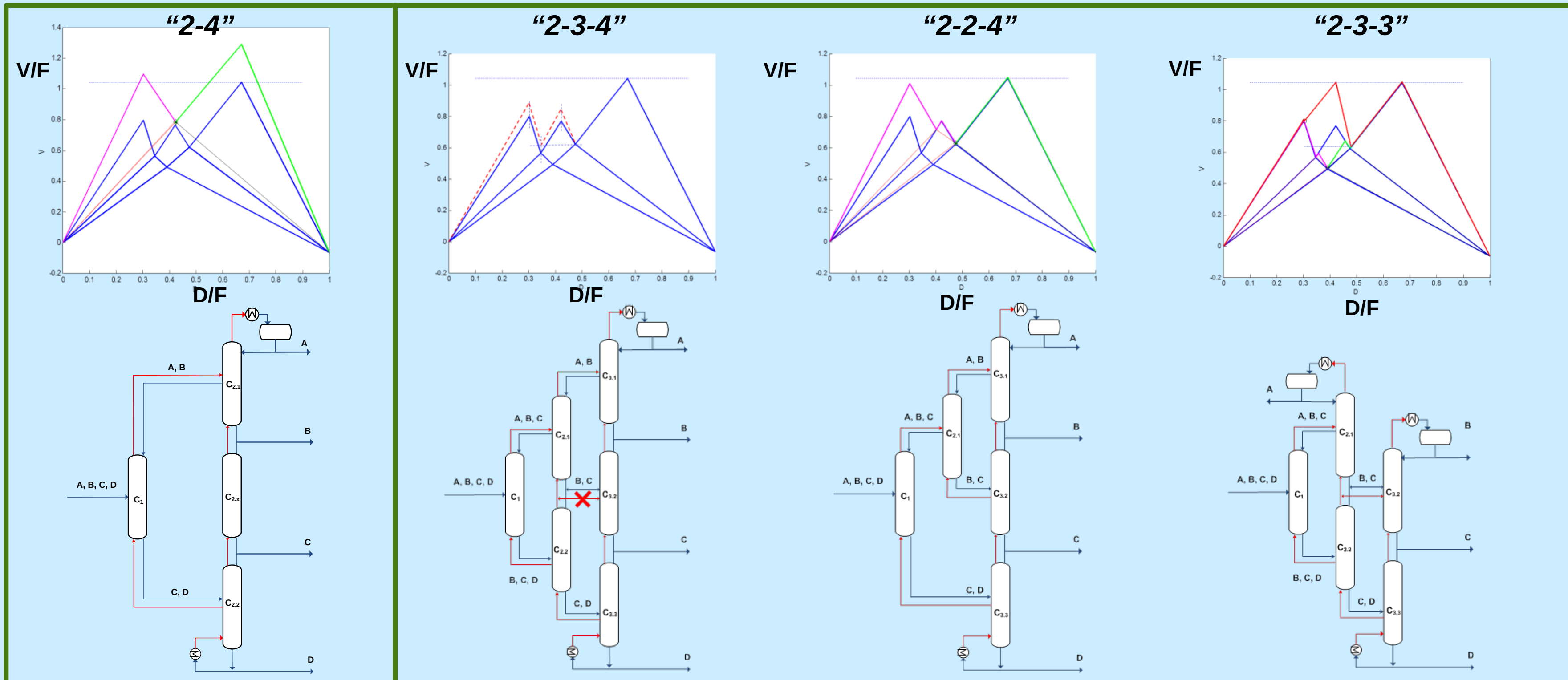
Dejanović, Matijašević, Halvorsen, Skogestad, Jansen, Kaibel, Olujić**, *Chem.Eng.Res.Des*.**, 89 (**2011**) 1155-1167.

Olujić, Dejanović, Kaibel, Jansen**, *Chem. Eng. Technol*.**, 35 (**2012**) 1392-1404.

Halvorsen, Dejanović, Skogestad, Olujić**, *Chem. Eng. Res. Des*.**, 91 (**2013**), 1954-1965.

V_{min} diagram method

Differences in peak heights give operational/design flexibility



$V_{con} >> V > Vmin$

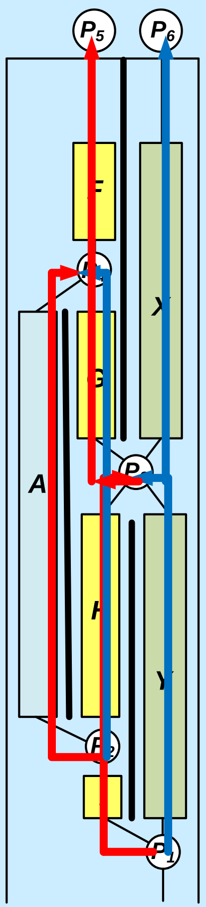
$V = Vmin$

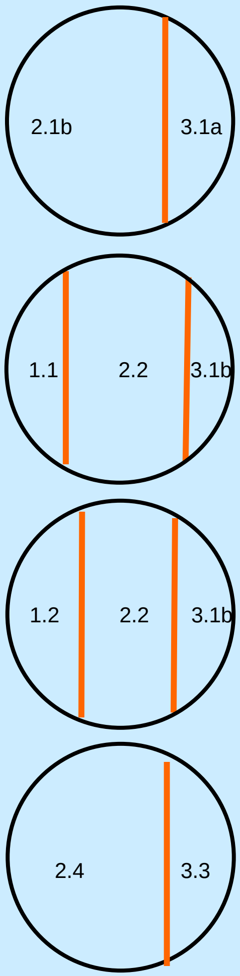
Configuration	C1-C2-C3	"2-4" DWC	"2-3-4" DWC	"2-2-4" DWC	"2-3-3" DWC
V/F (-)	2.21	1.34	1.11	1.11	1.11
Saving (%)	-	40	50	50	50

Halvorsen, Skogestad: ***Ind. Eng. Chem. Res***. 42 (**2003**) 616- 629; Halvorsen, Skogestad, ***J. Nat. Gas. Sci. Eng***. 3 (**2011**) 571-580.
Halvorsen, Dejanović, Skogestad, Olujić, **Chem. Eng. Res. Des.** 91 **(2013)** 1954-1965
Dejanović, Halvorsen, Skogstad, Jansen, Olujić, **Chem. Eng. Process.** 84 **(2014)** 71–81

4-p (“2-3-3”) DWC

Pressure drop balancing in partitioned part





For $p_5 = p_6$:

$$\Delta p_I + \Delta p_H = \Delta p_Y$$

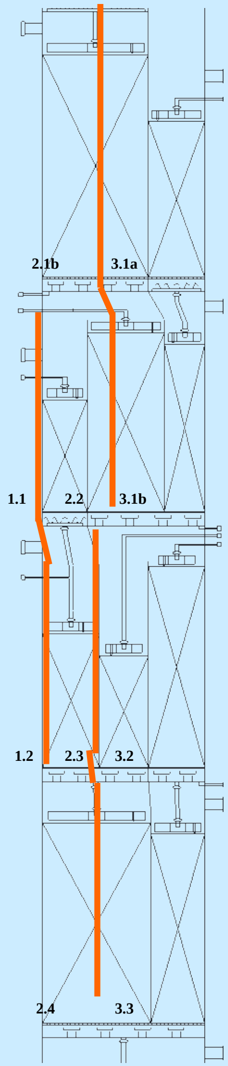
$$\Delta p_H + \Delta p_G = \Delta p_A$$

$$\Delta p_G + \Delta p_F = \Delta p_X$$

Fine-tuning by adjusting free area of collectors

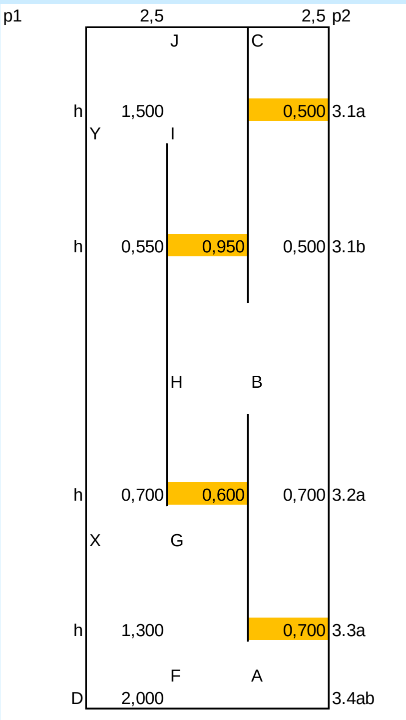
Range: 5 – 30%

If insufficient: *additional flow resistance needs to be introduced, where appropriate to generate missing Δp!*



Hydraulic Design in EXCEL Solver

Interactively, by adjusting free area of liquid collectors



Pressure drop estimation:

Packed column internals

Rix, Olujić, ***Chem. Eng. Process.*** 47 (**2008**) 1520-1529.

Structured packings: **Delft Model**

(all working equations can be found in:)

Dejanović et al., ***Ind. Eng. Chem. Res.*** 50 (**2011**) 5080-5092.

Relevant numbers for four alternative arrangements:

Olujić, Dejanović, Kaibel, Jansen, ***Chem. Eng. Technol.*** 50 (**2012**) 1392-1404.

Dejanović, Halvorsen, Skogestad, Jansen, Olujić, ***Chem. Eng. Process.*** 84 (**2014**) 71-81.

$$\Delta p_{int} = \left(\frac{n_{cc}\varsigma_{cc}}{\varphi_{cc}} + \frac{n_{ct}\varsigma_{ct}}{\varphi_{ct}} + \frac{n_{ld}\varsigma_{ld}}{\varphi_{ld}} \right) \frac{F_G^2}{2}$$

$$\varsigma_{cc} = 1.5 \cdot (2.5 - 2.5\varphi)$$

$$\varsigma_{ct} = 1.2 \cdot [1 + 2.5(1-\varphi)]$$

$$\varsigma_{ld} = 1.2[1.5 - \varphi(2.5-\varphi)]$$

Collectors (An example from preliminary calculations)

Position		2.1a	2.1b	3.1a	1.1	2.2+3.1b	1.2+2.3	3.2	2.4+3.3	3.4a	3.4b
M_L	kg/h	25604	24054	4969	1727	25625	46304	17448	59414	59613	63948
ρ_L	kg/m^3	605	658	714	698	729	728	738	734	732	713
V_L	kg/h	42,3	36,6	7,0	2,5	35,2	63,6	23,6	81,0	81,4	89,7
u_{Le}	m^3/m^{2}h	16,7	14,5	11,3	3,5	14,4	29,4	24,1	25,8	25,9	28,6
Type	-	CC	CT	CC	CC	CT	CT	CT	CT	CT	CT
$\varphi_{cc/ctc/distr}$	-	0,30	0,30	0,06	0,30	0,17	0,07	0,30	0,25	0,25	0,25
F_G	Pa$^{0.5}$	1,40	1,27	1,50	1,38	1,27	1,39	1,56	1,53	1,55	1,73
dp	mbar	**0,28**	**0,29**	**12,09**	**0,28**	**1,08**	**8,83**	**0,45**	**0,65**	**0,66**	**0,83**

Total MC dp 15,76 mbar

Pressure drop paths	dp
i	0,76
ii	0,00
iii	0,00

$\varphi_{cc/ctc/distr}$

Boundary values

Lower	0,05
Upper	0,30

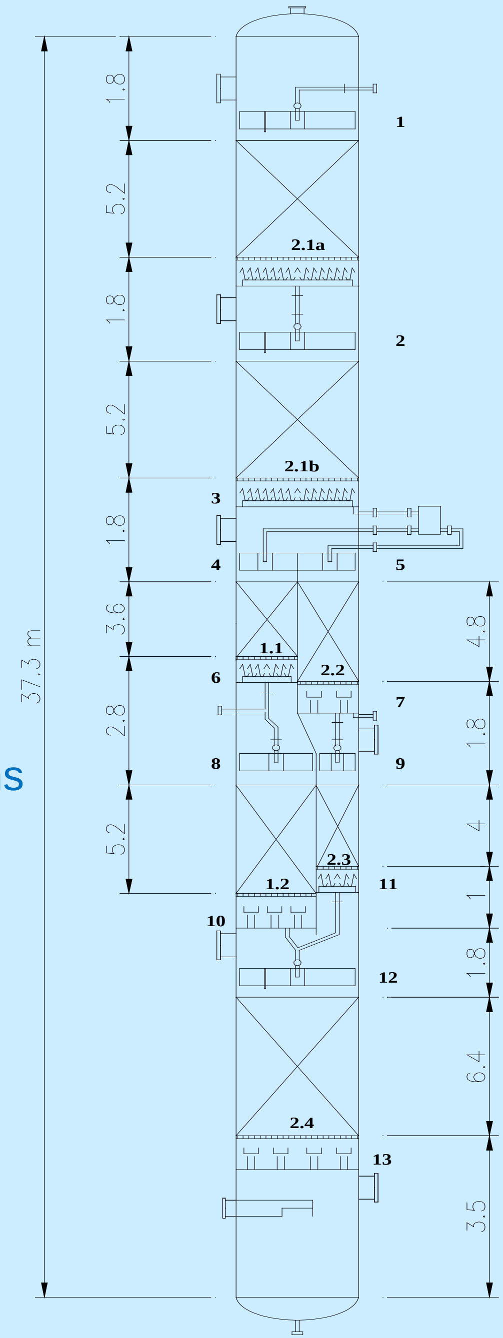
Similar computational Excel tables for all packed beds and liquid distributors.

DWC Technology Summary

Limitations, concerns, issues, etc.

Increasing, when a 4-p DWC is considered!

- **One** operating **pressure**
- Larger **Δp** and **ΔT** over the column,
  -> expensive cooling and/or heating!?
- Larger **column height**, -> large h/d ratio!?
- Fraction of **wall zone** area much larger
  -> a serious concern for packed columns!
- Non-circular cross section areas in partitioned sections
  -> internal liquid (mal)distribution patterns may be different!
- Large ΔT across the partition wall
  -> thermal insulation (packed columns-high purities!)
- Very high purities (ppm & ppb):
  -> leak-free non-welded wall!?
- **Revamp (retrofit)**
  -> time available for this may become a limiting factor!
- **Control of vapor split** by design **-> control devices**!



Dividing Wall Column

Vapor split control concerns and challenges

A vapor split is arranged by design, and can to a lesser extent be controled by manipulation of liquid split (limited range!)

Active control of vapor split needed to enable full operational flexibility of a DWC.

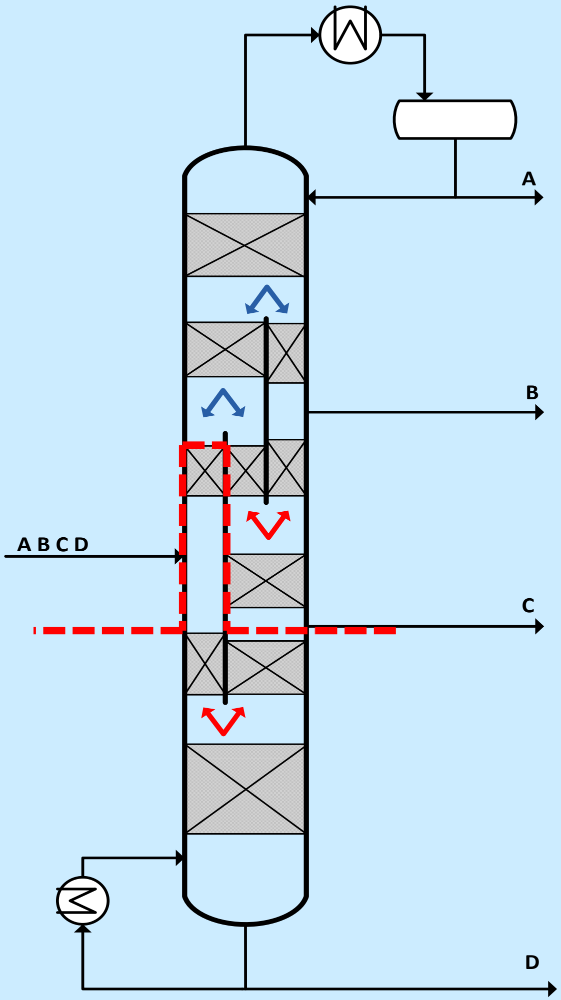
Availability of such devices would stimulate design and building multipartition DWCs for four and more products (OPEX and CAPEX savings in range of 50% and more!).

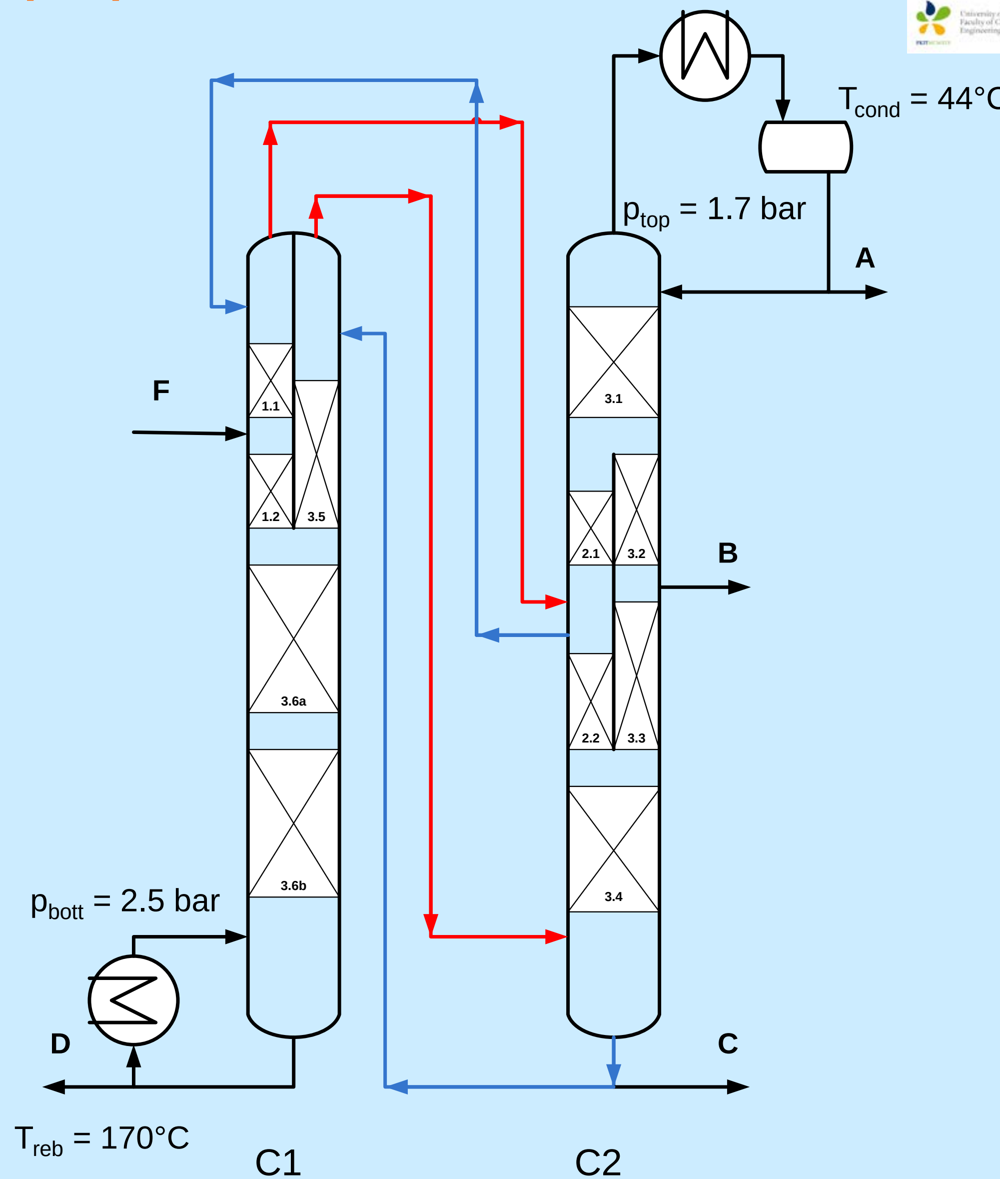
Two designs of a vapor-splitter described in Chinese patents. Prototypes tested extensively in air/water and cold mass transfer tests.

Not yet fully develped to be implemented in industrial practice.

4-p DWC: 2-2-4 as retrofit option

Circumventing multiple vapor split problem!





Jansen, Dejanović, Kaibel, Olujić
Chem. Engineering (August **2014**) 40–48.

Concluding Remarks

A **DWC is a genuinely sustainable distillation column** (minimum energy, capital and plot-area)**!**

Four-product DWCs -> higher gains **(**± **50 %**)!

Single-partition DWC proven; **multi-partition maximizes energy efficiency**/savings

New designs or retrofit (single shell revamps not an option, two shells in series yes!)

Two-partition, two vapor splits ("2-2-4") DWC, a feasible configuration to start with, either as new design, or a retrofit!

Arranging and control of **multiple vapor splits**, a serious concern/challenge!

Status of DWC technology in general.

Manufacturers know how to make it, and some **daring** on industrial side is required!

H. Schoenmakers (former BASF) :

"The choice of a dividing wall column for a separation task is a question of readiness for decision making, it is not really a risk, neither for construction nor for operation"

GO FOR IT, where appropriate!!!

THANK YOU

for your interest and kind attention!


Courtesy of J. Montz