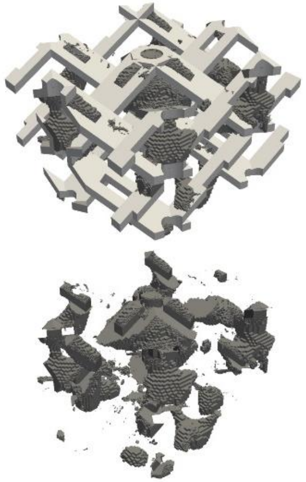
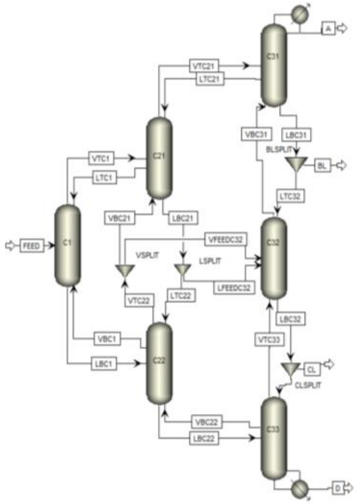
Impact of Number of Stages on Operational Flexibility of Vapor and Liquid Split Ratios





Dr.-Ing. Lena-Marie Ränger

Ulm University (Ulm, Germany) and NTNU (Trondheim, Norway)

Introduction

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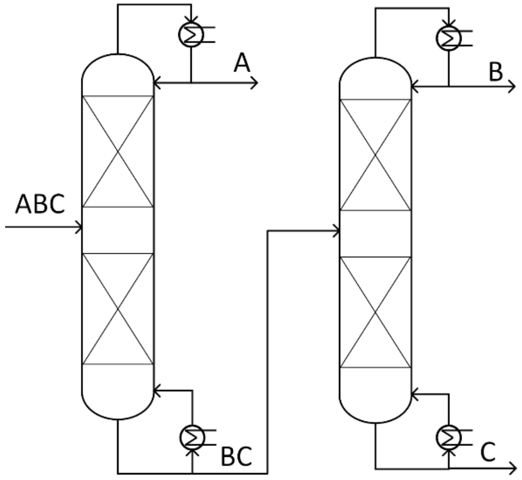
High energy consumption of distillation

(USA: 2.5 - 10 % of total energy used[1, 2, 3])

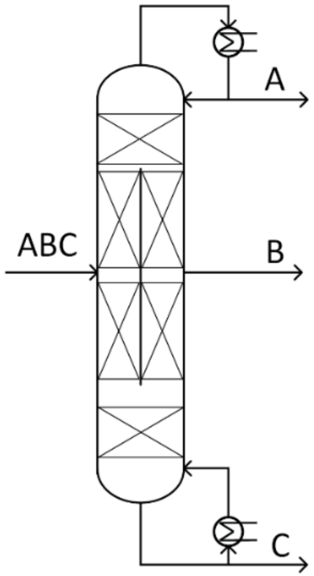
Potential for savings

Column sequence



replace

Dividing wall column

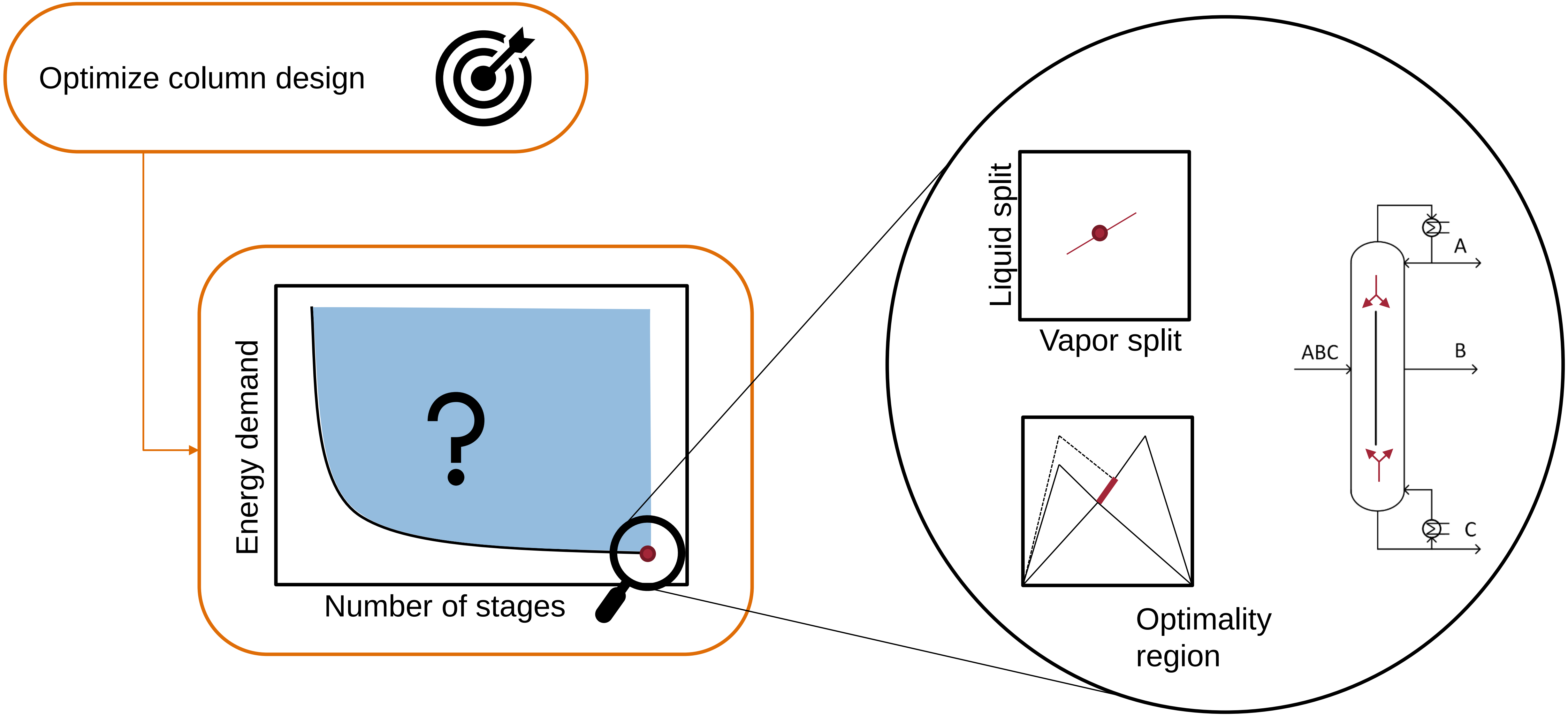


- 30%

Increased complexity

[1] J. L. Humphrey, G. E. Keller, Separation process technology, Chemical engineering books, McGraw Hill, New York 1997.
[2] Energy Information Administration, National Energy Information Center, Annual Energy Review 2001, Washington DC 2002.
[3] D. S. Sholl, R. P. Lively, Seven chemical separations to change the world, Nature, 2016.

Introduction



Content of presentation

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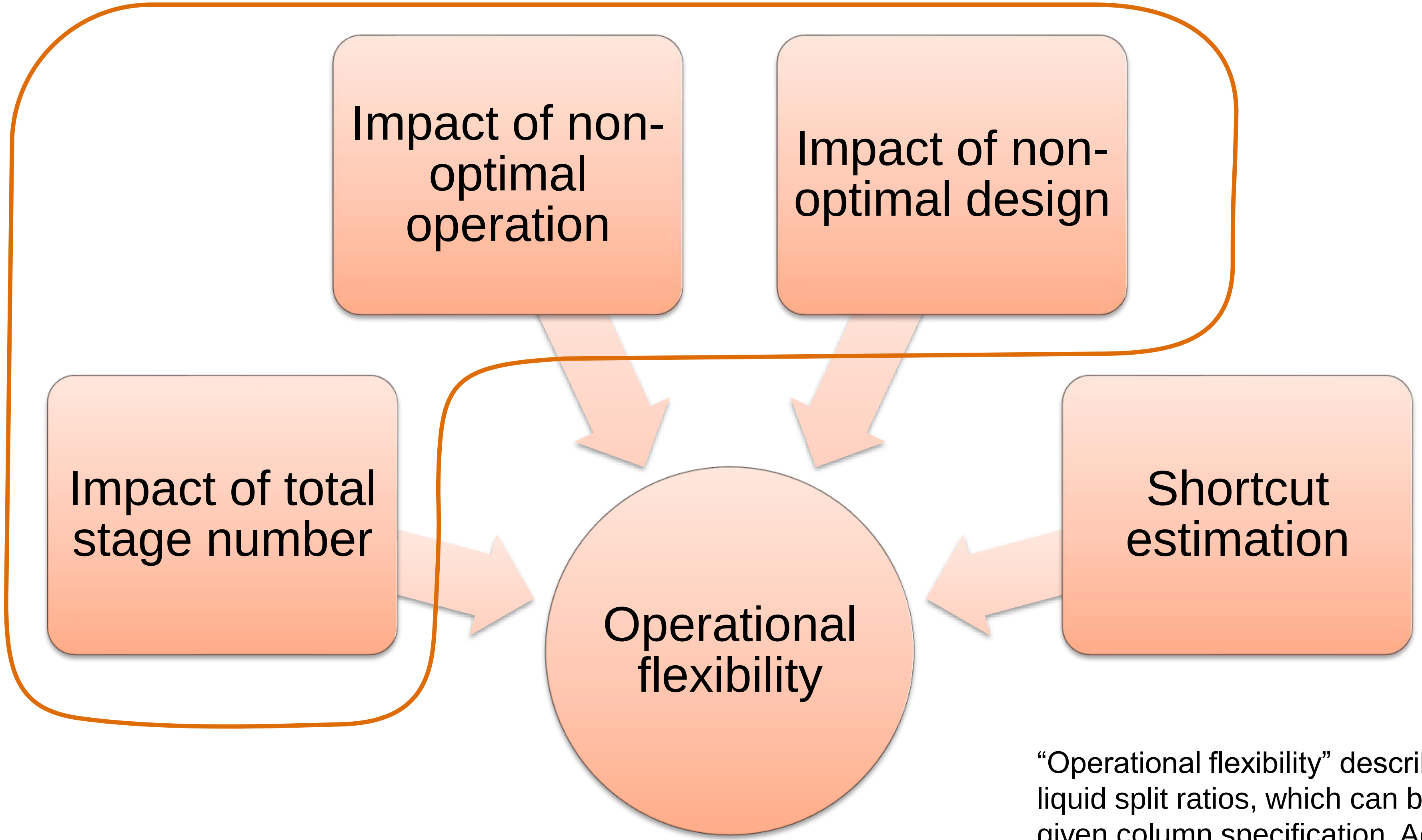
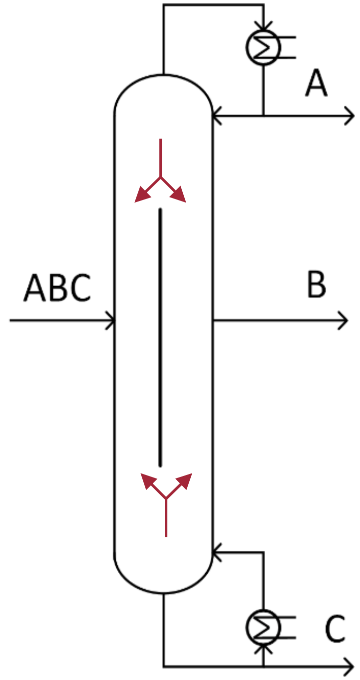
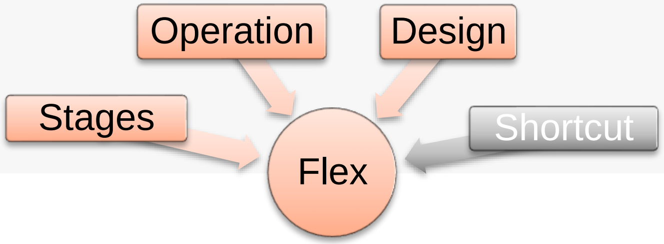




"Operational flexibility" describes the possible range of vapor and liquid split ratios, which can be used to achieve a separation task for given column specification. Accordingly, this includes the optimality region, but also additional scenarios.

Methodology



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How to determine flexibility of vapor and liquid split ratios

Optimization

Find...

- optimal stage allocation
- minimum energy demand
- Pareto-optimal compromises

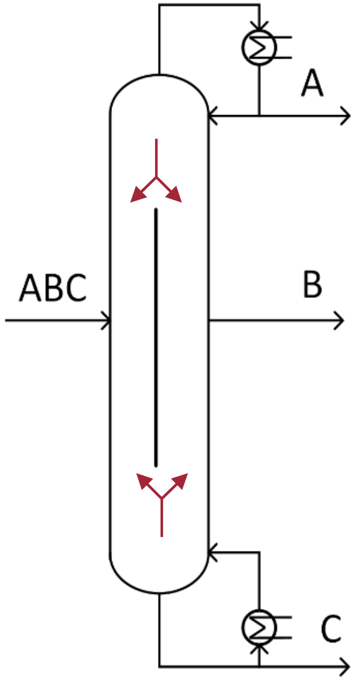
➢ Solving $\min\left(\Sigma N, \dot{Q}\right)$

Screening

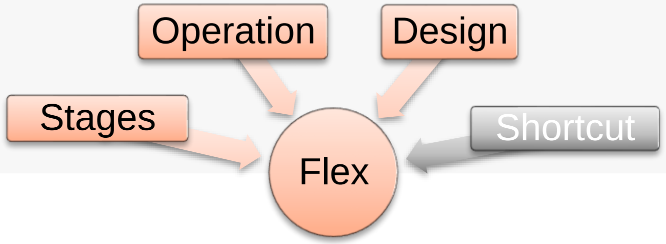
Determine...

- Product compositions for different vapor and liquid spit ratios
- Filter according to desired purities

➢ Systematic screening of a grid of split ratios



Methodology



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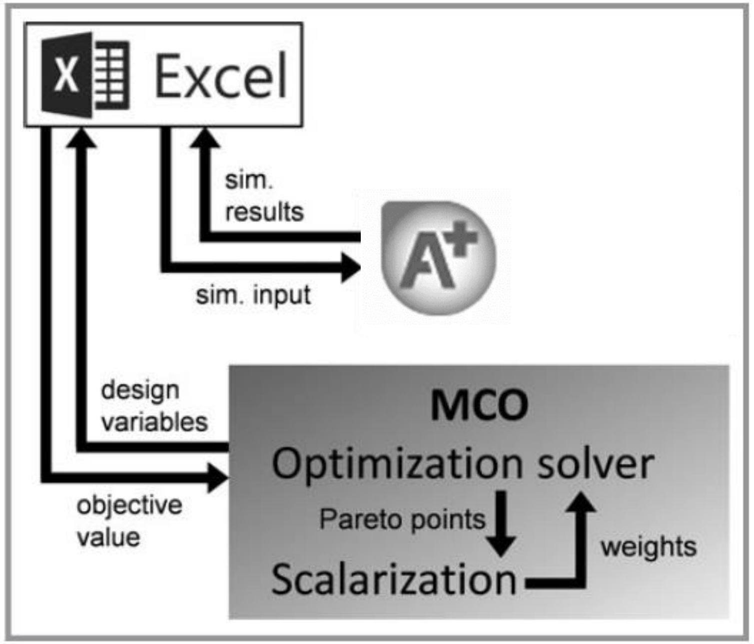
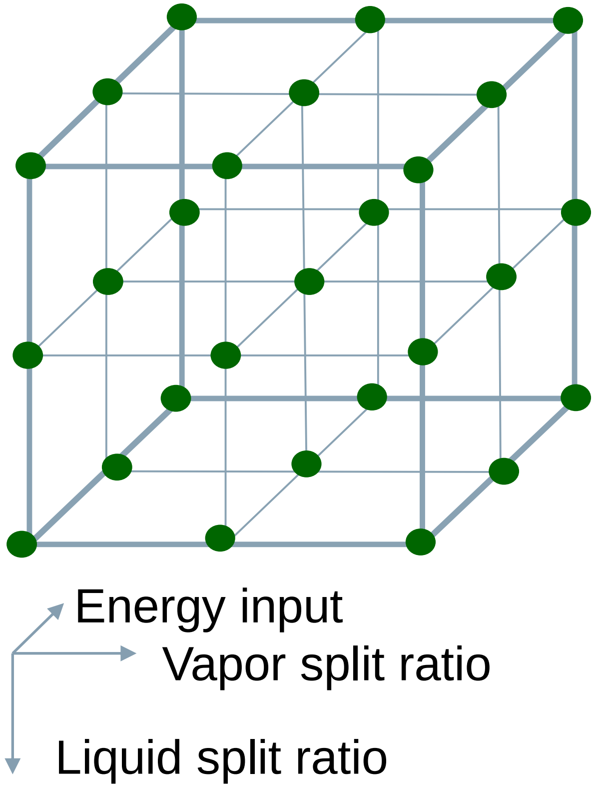
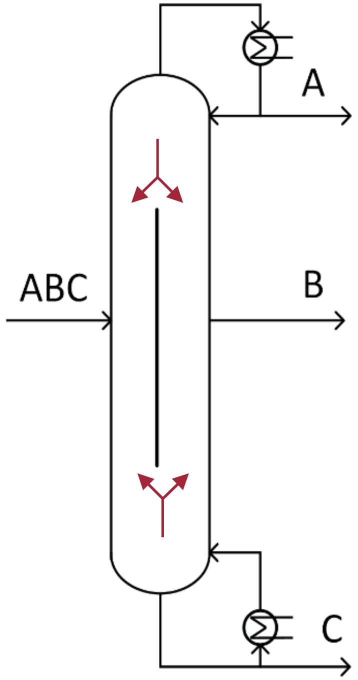
How to determine flexibility of vapor and liquid split ratios

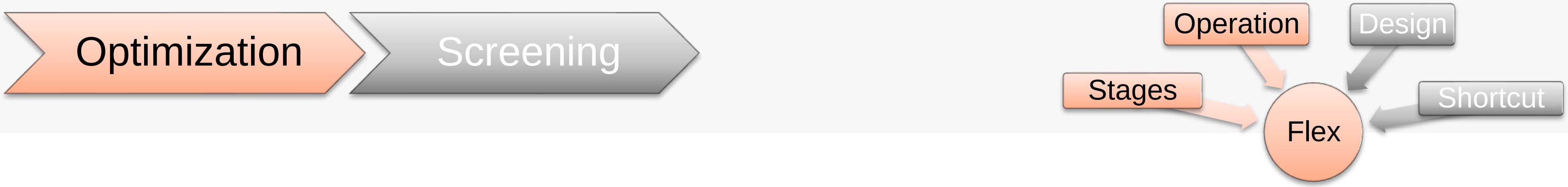
Optimization → Screening







Mixture: Methanol, Ethanol, n-Butanol, equimolar, bubble point, 95 mol% product purities



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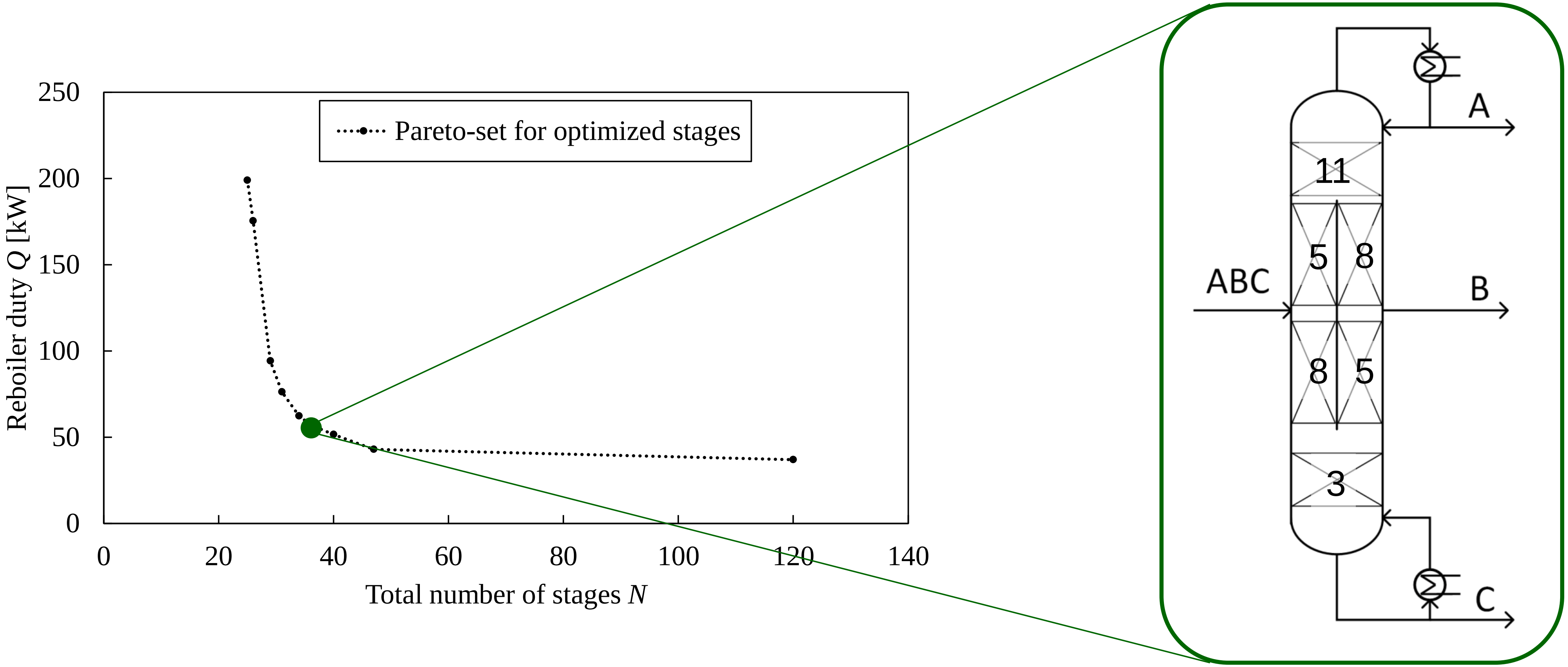
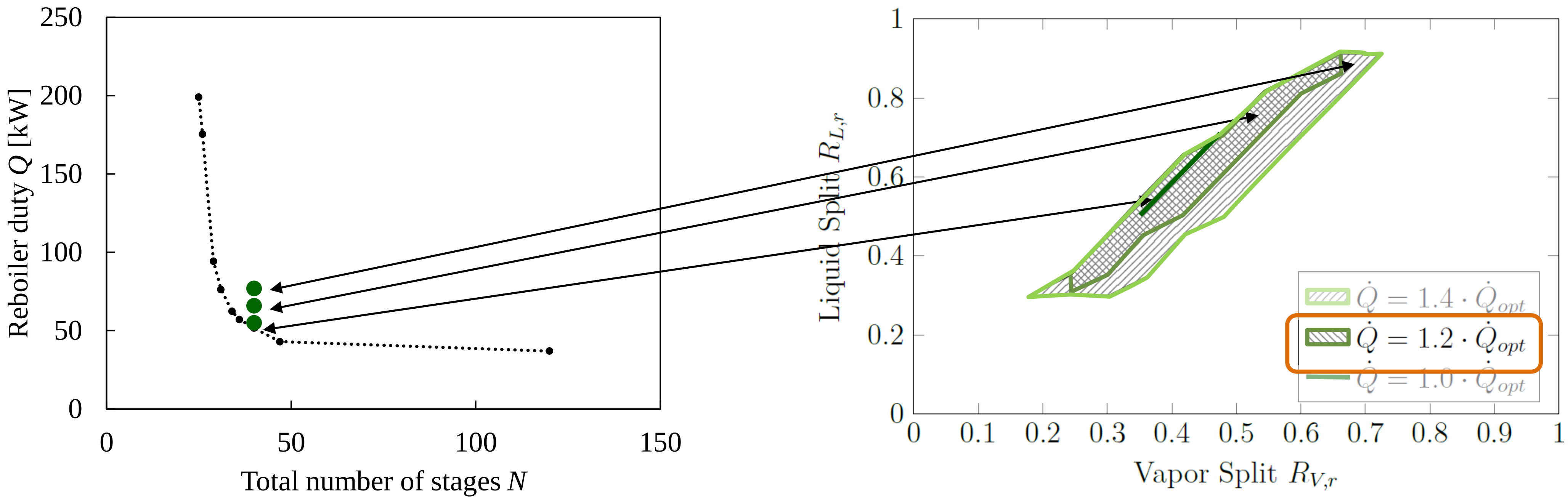


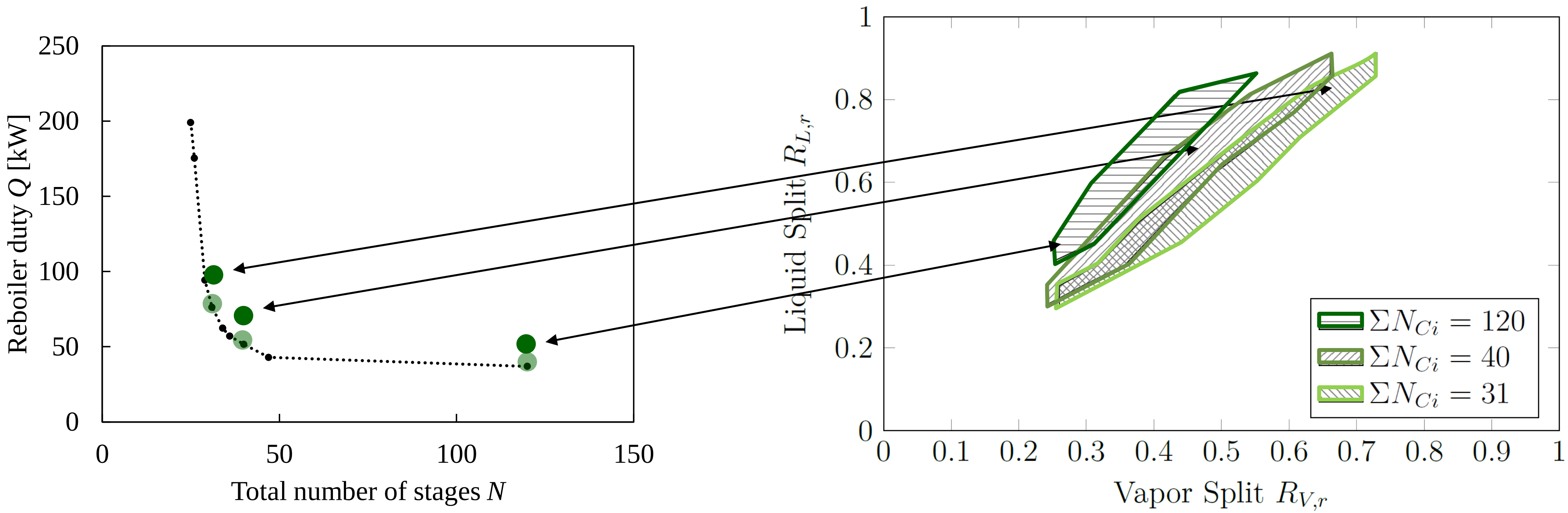
- Optimal stage allocation in the column sections is non-uniform

Impact of distance to energetic optimum: Flexibility at $N = 40$



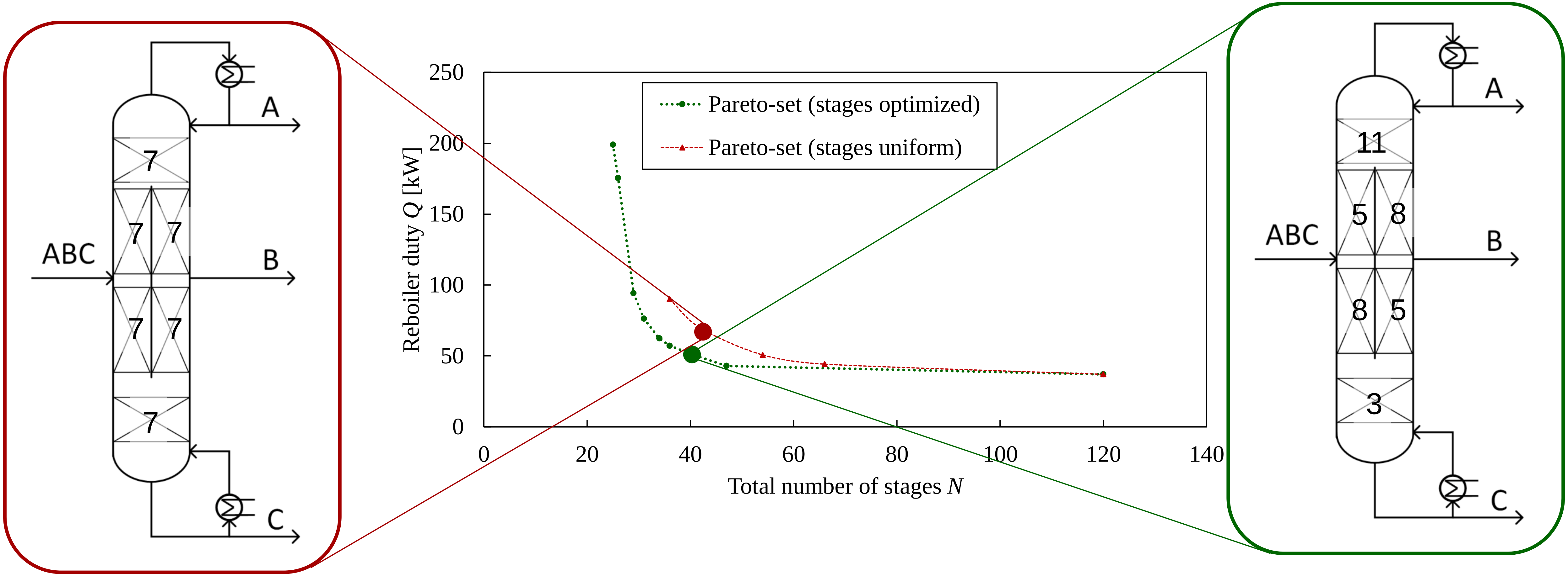
- Optimal energy input: Feasbile combinations located on straight line
- More energy input (“close to Pareto-optimum”): Flexibility “field”

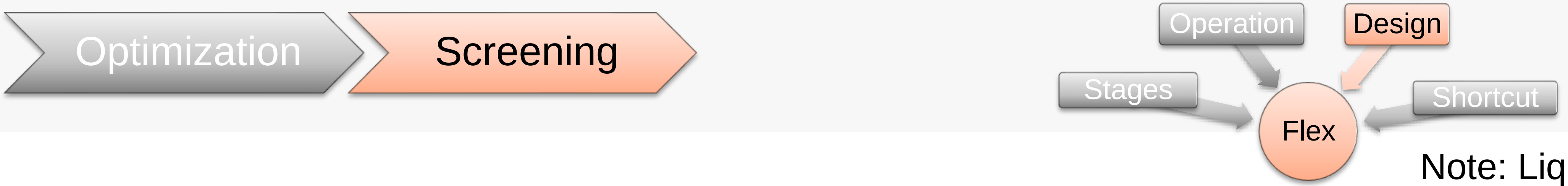
Impact of stage number: Flexibility at $Q = 1.2\ Q_{min}$



- Flexibility range depends on total stage number

Impact of non-optimal stage design on energy demand





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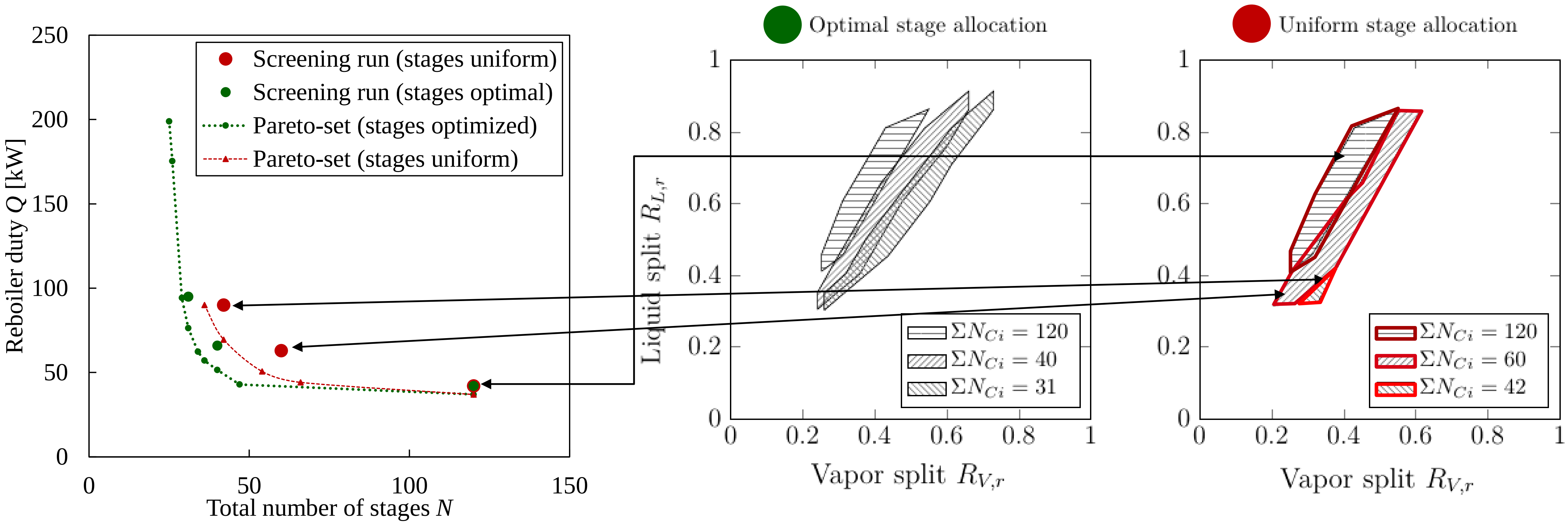
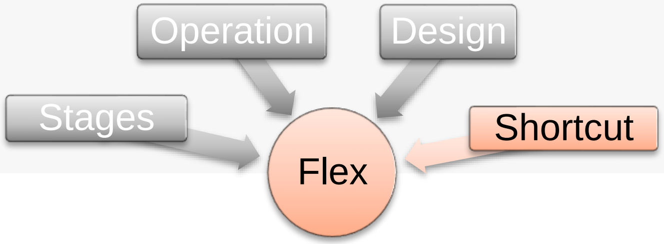
Note: Liquid split ratio limited due to liquid side draw

Impact of non-optimal stage design on flexibility at $Q = 1.2\ Q_{min}$



- Significant reduction of flexibility range towards lower stage number for non-optimal design

V_{min} diagram



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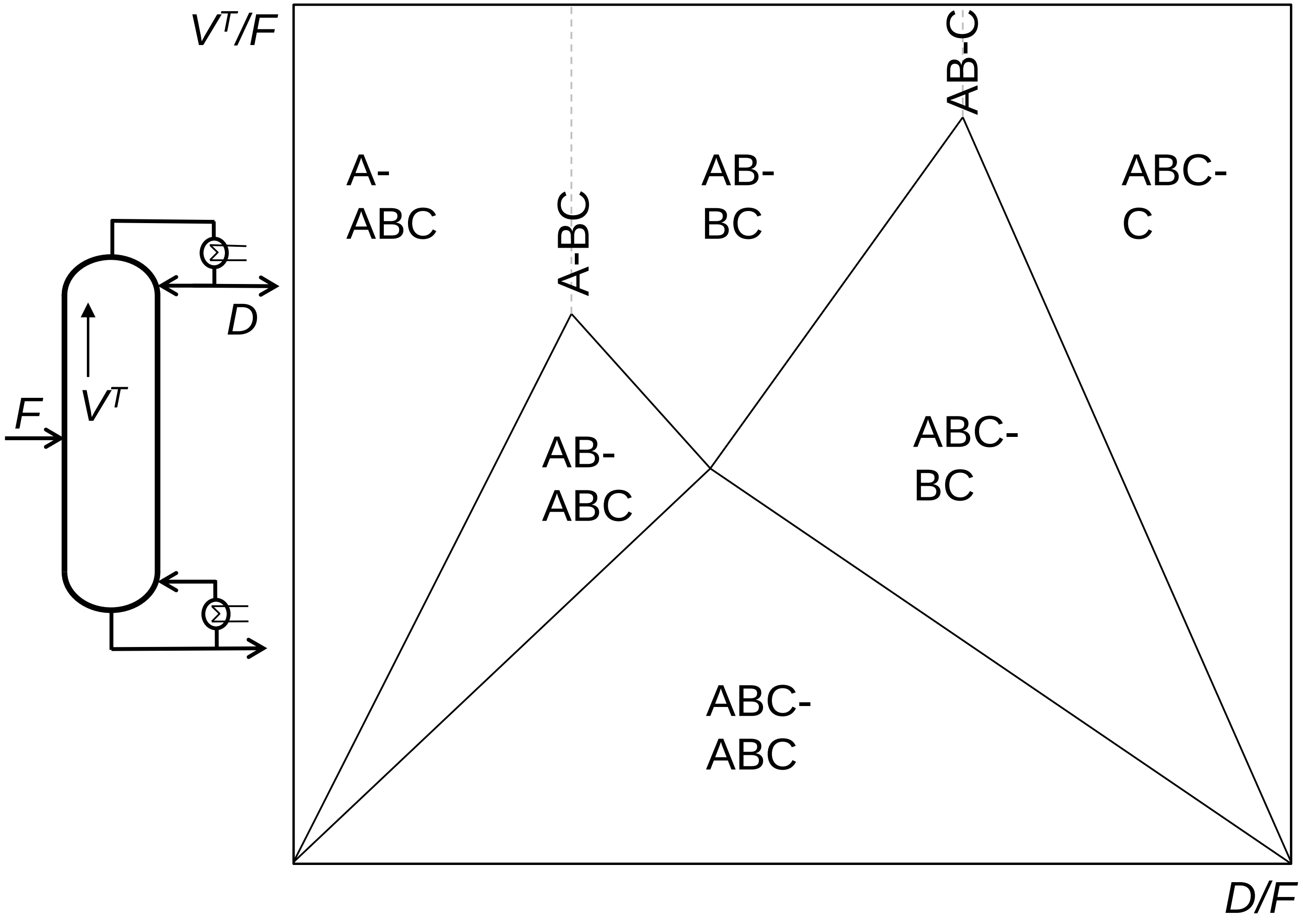
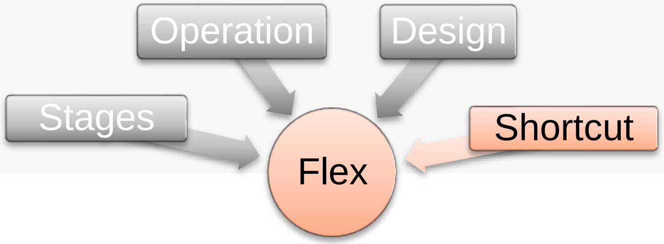
- Visualization of minimum energy demand for separation of given feed stream
- Assumptions for shortcut calculation
  - Infinite stage numbers
  - Constant molar flows
  - Constant relative volatilities
- Directly applies for dividing wall columns (optimal operation)



V_{min} diagrams for dividing wall columns



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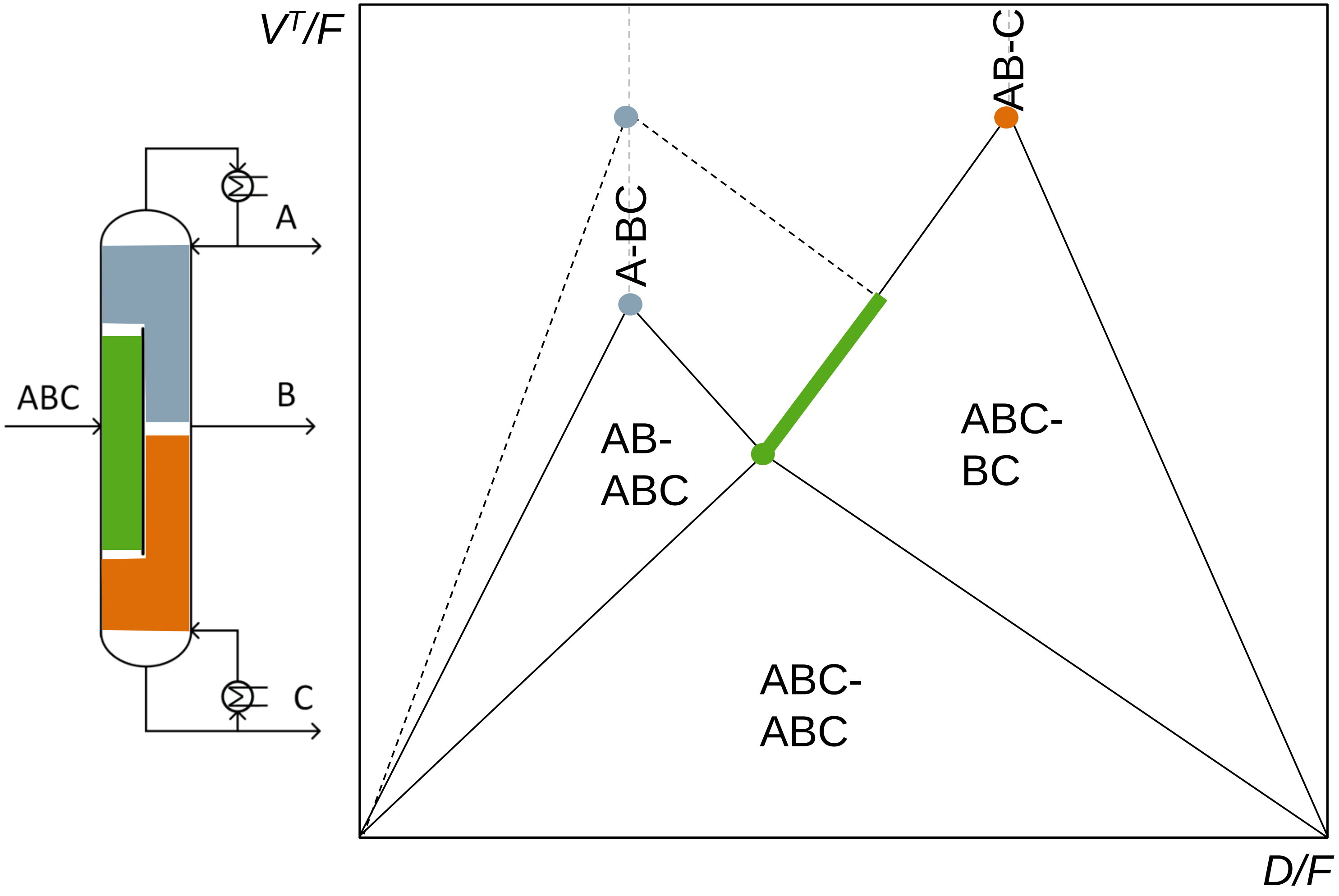
- Highest peak → Total energy demand of the column
- Mass balance: Vapor provided at bottom will arrive at top

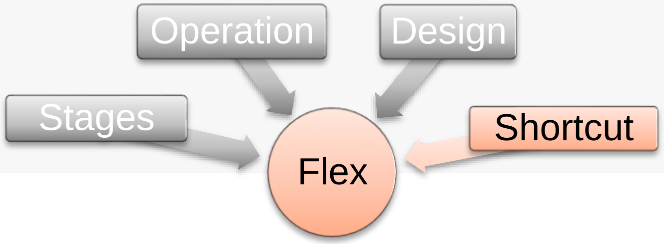
➢ Operational flexibility for the prefractionator

➢ Different liquid and vapor split ratios feasible



Estimation of flexibility range

Note: for sharp separations



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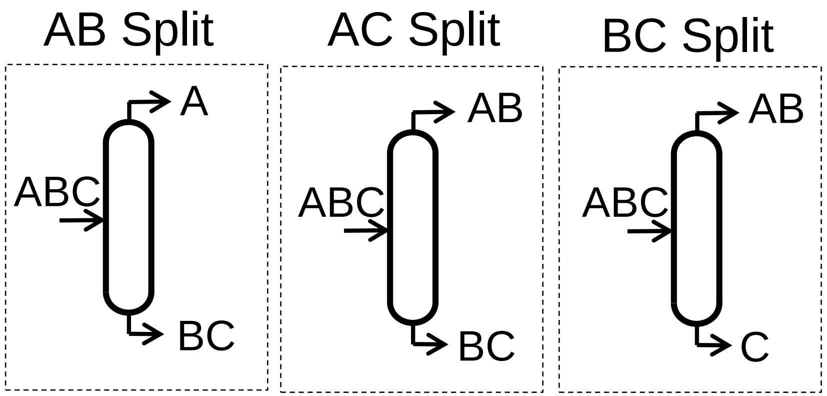
Extension of V_{min} diagram by the dimension

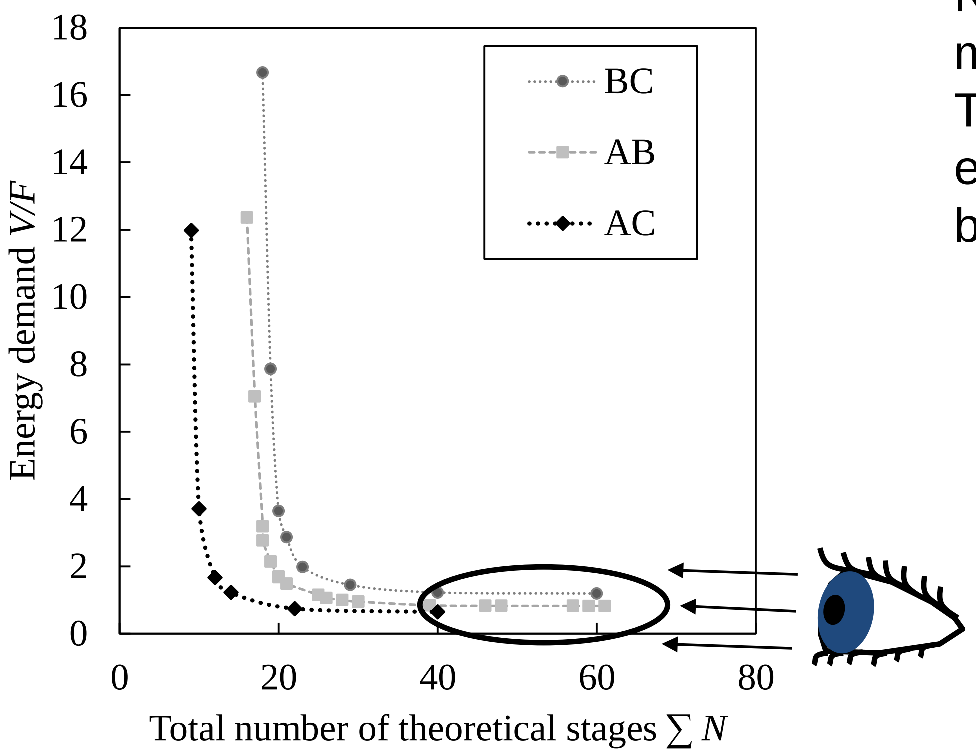
$$n_i = \frac{N_i}{N_{\min,i}}$$

- Bi-objective optimization of sharp separations (99.9 mol%)

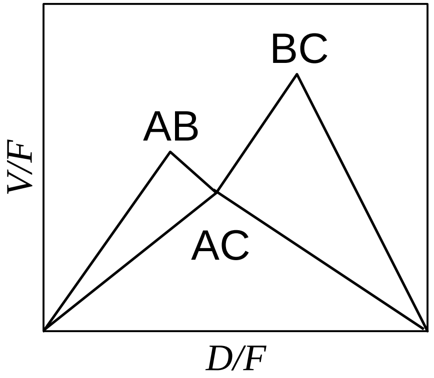
$$\min\left(\Sigma N, \frac{V}{F}\right)$$

- Ternary example:

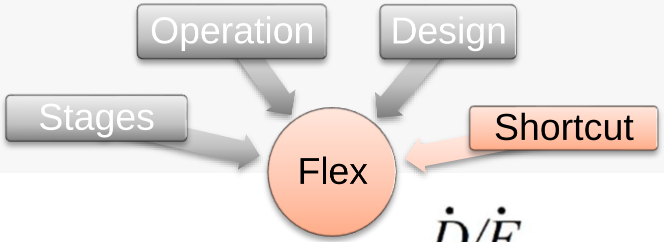




Note: This is another mixture: Benzene, Toluene p-Xylene, equimolar, liquid boiling



Extended V_{min} diagram



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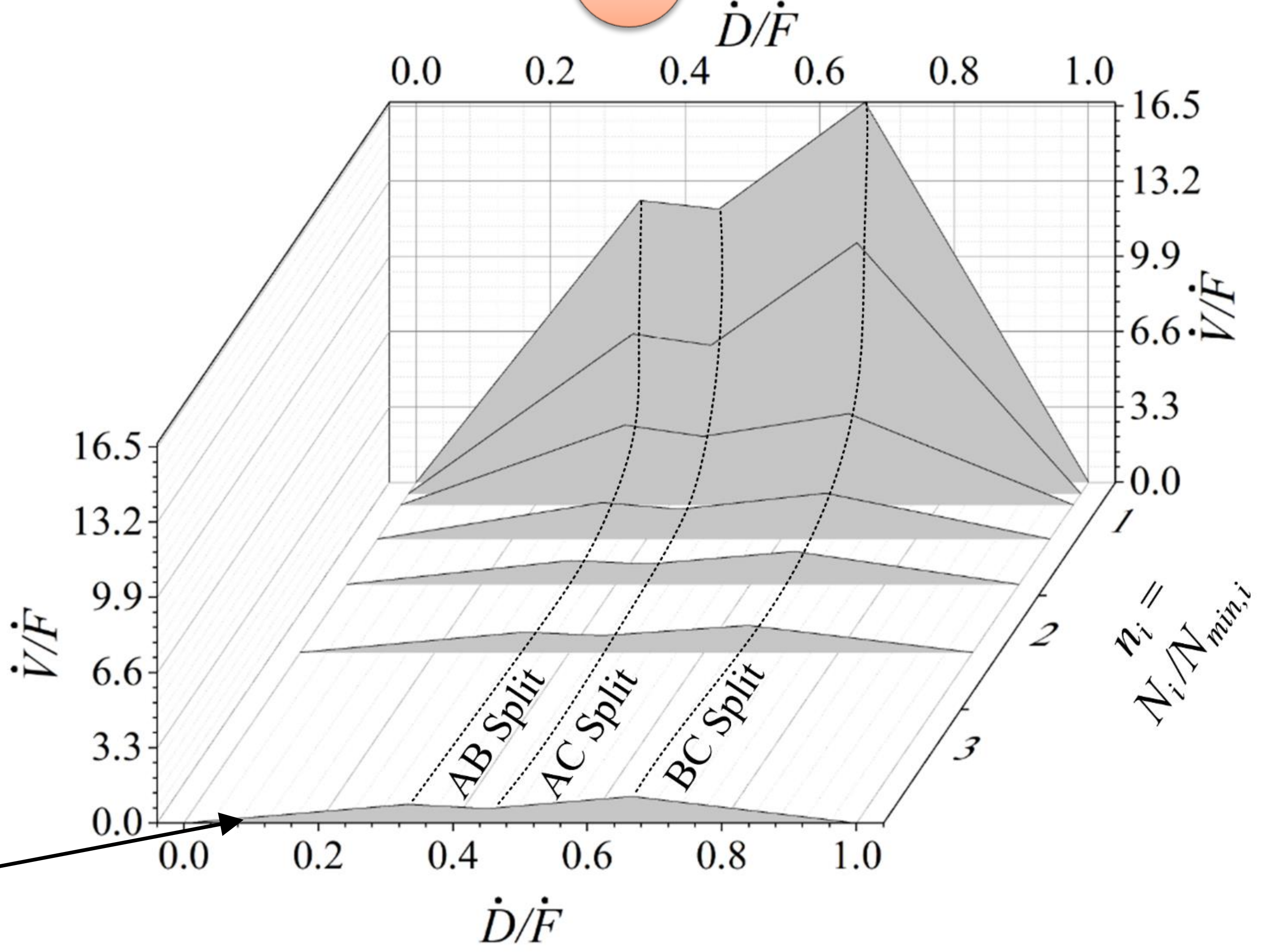
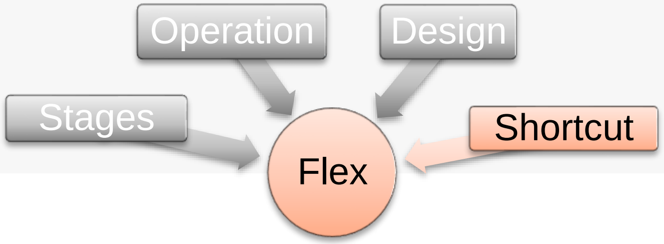
- Development of *V/F* with lower stage numbers

$$\frac{\dot{V}_i}{\dot{F}} = \frac{\dot{V}_{min,i}}{\dot{F}} \cdot \left(\frac{0.27}{\left(\frac{N_i}{0.97 \cdot N_{min,i}}\right)^2 - 1} + 1 \right)$$

➢ For given stage number a „stage-adapted" V_{min} diagram can be derived



Extended V_{min} diagram



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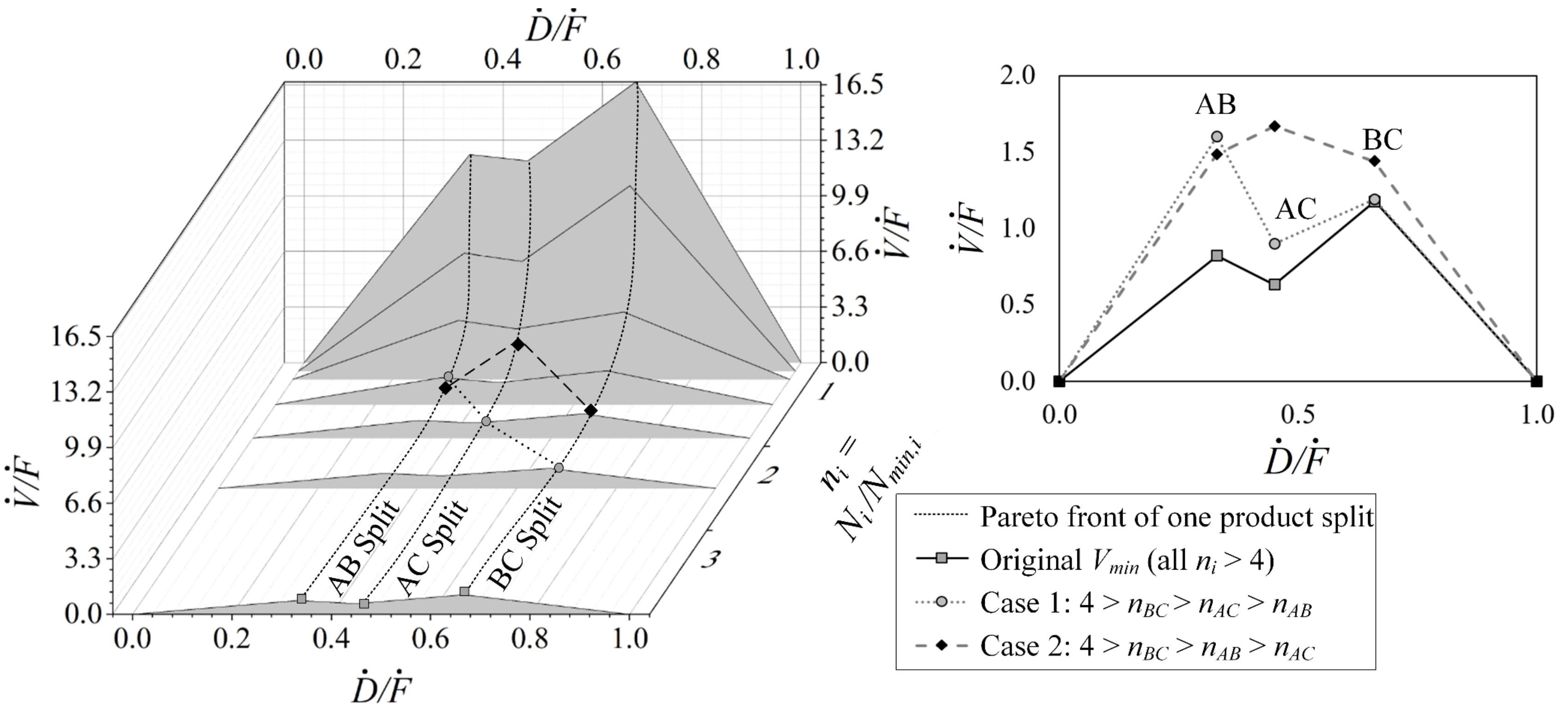
Example for stage-adapted V_{min} diagram



Remember: Flexibility for prefractionator (AC) results from height difference between AB and BC peak

- With non-optimal stage allocation, not only the energy demand might increase but also the flexibility range may widen or shrink and shift

Summary

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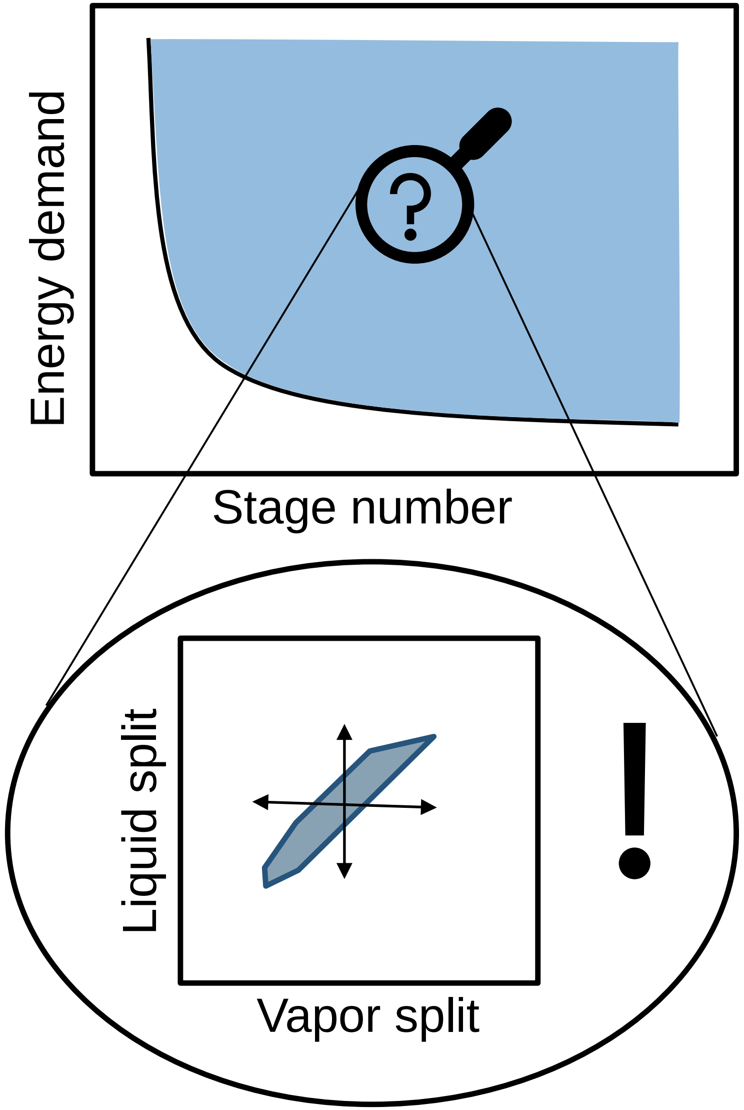
- Operational flexibility of liquid and vapor split ratios at finite stage numbers
- Flexibility range and location depends on stage number, allocation and distance to related energetic optimum
- Estimation of range possible based on stage-adapted V_{min} diagram



Related work

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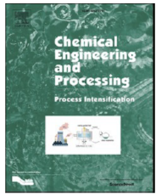

Check for updates

Vapor and liquid split flexibility in dividing wall columns in relation to the theoretical stage allocation

Lena-Marie Ränger [a,*], Lea Trescher [a], Martin von Kurnatowski [b], Michael Bortz [b], Thomas Grützner [a]

[a] Ulm University, Institute of Chemical Engineering, Laboratory of Thermal Process Engineering, Ulm, Germany
[b] Fraunhofer Institute of Industrial Mathematics (ITWM), Kaiserslautern, Germany

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Multi-Objective Optimization of Simple and Multiple Dividing Wall Columns and their Operational Flexibility Close to the Optimum

DISSERTATION

Chemical Engineering & Technology Research Article 1919

Lena-Marie Ränger
Thomas Grützner*

Shortcut Method for Initialization of Dividing-Wall Columns and Estimating Pareto-Optimal *NQ*-Curves

In early project stages, often no simulation results are available for dividing-wall columns. Hence, shortcut methods are used to estimate suitable vapor and liquid splits. In a previous paper, it was demonstrated that $\dot{V}_{min}$ diagrams are a suited tool to satisfy this need. However, it has turned out that it shows weaknesses for columns with finite or non-optimal stages. This contribution closes that gap and presents an extended approach to derive suited initial guesses. For this purpose, the original $\dot{V}_{min}$ diagram is combined with a heuristic approach to calculate Pareto-optimal column designs resulting in a stage-adapted $\dot{V}_{min}$ diagram. A comparative study illustrates that the new approach is a powerful tool to generate reliable guesses for multiple dividing-wall column simulations with finite stage numbers.

Keywords: Dividing-wall columns, Pareto-optimal column design, Shortcut methods, Vapor-liquid split, $\dot{V}_{min}$ diagram

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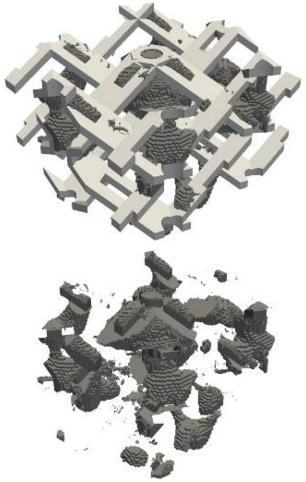
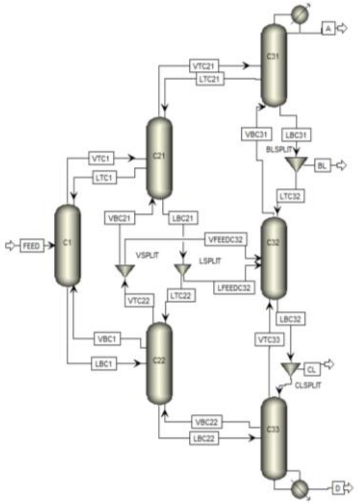
Thank you for your attention





DFG Deutsche Forschungsgemeinschaft

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