Motivation
Design of energy efficient distillation processes for the separation of non-ideal multicomponent mixtures

- Conventional separation methods: extractive, heteroazeotropic or pressure swing distillation
- High capital costs
- Low energy efficiency

Innovative process concept: membrane assisted hybrid processes
- Strong synergies due to interactions between both unit operations
- Overcoming limitations of stand-alone processes
- Lack of general design methodology and in-depth understanding of complex interactions
- Significant economical potential hardly exploited in industry

Development of a reliable methodology for the optimisation based design of hybrid separation processes

Design of hybrid processes

- State of the art:
  - Early decision on process configuration
  - Design approaches mostly based on short-cut methods and simplified models, especially for membrane separation
  - Application of rigorous approaches limited to binary systems

Generic design approach

- Process superstructures for the consideration of all possible process alternatives
- Generic process model with rigorous models for both unit operations
- Experimental determination of membrane parameters at lab-scale and experimental validation of hybrid process at pilot-scale

Motivation

- Production of acetone by dehydrogenation of isopropyl alcohol (IPA)
- Separation of ternary azeotropic system acetone-IPA-water
- Potential use of membrane:
  - To cross the distillation boundary (Fig. 1)
  - To separate the close boiling binary mixtures at high organic concentrations (Fig. 2)

Chemical system

- Conventional separation methods: extractive, heteroazeotropic or pressure swing distillation
- High capital costs
- Low energy efficiency

Evolutionary Process Optimisation

- Algorithm based on „modified differential evolution“ approach (Fig. 3)
- Economic objective function (= fitness)

Modelling

- Non-equilibrium stage model of distillation
- Multicomponent mass and heat transfer
- Hydrodynamics of column internals considered
- Calculation of optimal diameter based on correlation of Maćkowiak

Experimental parameter determination

- Pervaporation of IPA-water mixture
- Hydrophilic PVA/PAN membrane (Sulzer Pervap 2201D)
- Membrane area: 162 cm²
- Experimental conditions:
  - \( W_{\text{feed}} / W_{\text{dry}} = 2.5 \text{ to } 18 \text{ wt.}\% \)
  - \( T_{\text{feed}} = 60 \text{ to } 70 ^\circ \text{C} \)
  - \( P_{\text{feed}} = 2 \text{ bar} \)
  - \( P_{\text{perm}} = 30 \text{ mbar} \)
- Model parameters determined for an empirical correlation (Fig. 4)

Optimisation of hybrid process

- Hybrid process
  - Packed column (Sulzer BX)
  - Pervaporation module with Sulzer Pervap 2201D
  - Simultaneous optimisation of
    - 3 discontinuous and
    - 9 continuous variables (Fig. 5)
- Objective function: costs per ton of purified acetone (CPT)

Future work

Future work will focus on the development and optimisation of more complex superstructures, which consider all possible process configurations.

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