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Heat transfer challenge and design evaluation for a multi-stage temperature swing adsorption (TSA) process

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Heat transfer challenge and design evaluation for a multi-stage temperature swing adsorption (TSA) process

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Content

• Introduction
• Problem definition
• Practical work
• Conclusion
• Outlook
Introduction | Continuous CO₂ adsorption, TSA

• Adsorption kinetics fast
  → TSA limitation: Heat exchange (HEX)

• Contactors may be designed as fixed / moving bed
  → poor HEX rates!

• Solution: Multi-stage bubbling fluidized bed (BFB) columns with counter-current flow of gas & solids

• Considered particles: Geldart Type B
Introduction | Continuous CO$_2$ adsorption, TSA

Fig. 1. Principle of continuous TSA
Introduction | Continuous CO$_2$ adsorption, TSA

- Heat exchanger design: **tube bundles**
- Design parameters
  - Tube diameter ($d_t$)
  - Tube spacing ($p_h$, $p_v$)
  - Tube arrangement
  - Tube alignment
  - Tube surface

*Fig. 2. Characteristical tube bundle design parameters*
Problem definition | Pt.1

• Restricted BFB pressure drop $\Delta p_{fb}$ | sf.gas velocity $U$
  $\rightarrow$ Limitation of installable HEX surface ($A_{HEX} \sim \Delta p_{fb} \sim 1/h$)

• Trade-off 1: $U$ | $h$

• Trade-off 2: Heat exchanger design | $h$

Fig. 3. Calculated HEX rates for single tube (Molerus et al., 1995) and selected tube bundles (Lechner et al., 2013)
Problem definition | Pt. 2

- Resistance to particle flow
  - Tube alignment
  - Residence time dist. (RTD)

- Scale-up
  - Forces to tubes
  - Durability

- Maintainability

Fig. 4. Horizontal tubes and particle flow possibilities (red = transversal, blue = longitudinal)
Practical work

• TSA needs most accurate heat exchanger design for efficient operation

• Evolved calculation models for single tube heat transfer rate available → significant quantity-differences (e.g. Martin, Molerus et al., ...)

→ HEX measurements

Fig. 5. HEX-rate comparison
HTMT — Heat transfer measurement test device

Fig. 6. HTMT construction assembly

Fig. 7. HTMT lab unit
Conclusion

• Adsorption kinetics fast $\rightarrow$ HEX limits TSA efficiency
• TSA heat exchanger design highly dependent on:
  • Restricted fluidized bed pressure drop
  • Intended superficial gas velocity
  • Scalability
  • Durability
  • Maintainability
• Heat transfer measurement test device successfully put into operation
Outlook

• HEX measurements with various
  • Bulk materials
  • Heat exchanger designs
• Investigate effect of tube bundles to residence time
distribution (RTD) of particles

• Determine optimal tube bundle design for TSA
Questions & suggestions are appreciated!

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