Control Structure Design for Optimal Operation of 4-Product Thermally Coupled Columns

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Outline

• Introduction
• System 1: 4- Product Kaibel Column
  – Previous Work
  – Control Structure
  – Experimental Setup
  – Experimental Runs- Steady state profiles
  – Experimental Runs- Vapor Split Experiment
• System 2: 4- Product Extended Petlyuk Column
  – Model Details
  – Control Structure
  – Close Loop Results
• Conclusions
Introduction

- Distillation is energy intensive process.

- Exergetic analysis requires minimizing irreversibilities:
  - mixing effect
  - large $\Delta T$ across column

- This leads to Complex distillation arrangement:
  - Kaibel Arrangement
  - Petlyuk Arrangement
  - intermediate Reboilers & Coolers etc
  - HIDIC distillation

- Potential Energy Savings up to ~50 % for 4 product extended Petlyuk & up to ~30 % in Kaibel Arrangement*

* Halvorsen et. al. (2003)
Kaibel Arrangement *

Sharp B/C Split in Prefractionator

4-Product Separation in single shell

* Kaibel, G (1987)
Extended Petlyuk Arrangement *

*Petlyuk, F.B. et al (1965)
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Previous works

Simulation based studies carried with a plant wide perspective

- Stabilizing operation of a 4-product Kaibel column *
  - Close 4 temperature loops for stabilization & Inventory Control

- Optimal steady-state solutions for operating under economic objectives**

- Model predictive control of the 4-product kaibel column ***

Thus there is an incentive to carry out experimental studies on operation of 4-product column

* Strandberg, J. et. al (2006)
** Ghadrdan, M. et. al (2010)
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Control Structure (Ordinary Distillation)

V > V_min

Single point control can stabilize the profiles

V = V_min

Two point control can stabilize column profiles
Control Structure (Kaibel Column)

V > V_{min}

4-point temperature control with one temperature in prefractionator

V = V_{min}

Rv Loop can be added
• when V = V_{min}, 2 temperatures may needed in prefractionator
• or, as DOF for any other economic objective
Control Structure (As used in experiments)

• Decentralized Control with 4 PI Controllers

• 4 temperature sections 2, 3, 5, 7 in regulatory layer with R/I, D, S1 & S2

• V=Vmax, Vapor Split (Rv) not part of regulatory layer

Next couple of slides summarize experimental validation
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Experimental Set up

- 4 products
- Atmospheric pressure
- Packed Column
- Magnetic funnel-liquid split & Product valves
- Vapor split: Rack and Pinion
- Number of theoretical stages (experimentally determined):
  - Total stages in Prefractionator = 17
  - Total Stages in main column = 21
  - High Purity is impossible with given number of stages and flooding limitation
- Labview interface
Experimental Set up (Labview Interface)…
Steady Profiles with 4 temperature loops

TEMPERATURES

Output

Control Structure Design for Optimal Operation of Thermally Coupled Columns Distillation Columns

www.ntnu.no

Norwegian University of Science and Technology

16/03/2011
Steady Profiles with 4 temperature loops.

Liquid Split Loop -2 C

TEMPERATURES

Output

NTNU
Norwegian University of Science and Technology

Control Structure Design for Optimal Operation of Thermally Coupled Columns Distillation Columns
Steady Profiles with 4 temperature loops..

Distillate Loop ±1 C

TEMPERATURES

Output

Control Structure Design for Optimal Operation of Thermally Coupled Columns Distillation Columns

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Steady Profiles with 4 temperature loops..

S1 Loop ± 1 C

TEMPERATURES

Output

NTNU
Norwegian University of Science and Technology
Steady Profiles with 4 temperature loops.

S2 Loop ± 1 C

Temperatures

Output

Control Structure Design for Optimal Operation of Thermally Coupled Columns Distillation Columns
Steady Profiles with 4 temperature loops..

All Loops ± 1 C

TEMPERATURES

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Vapor Split Experiment

- Total reflux operation
- Liquid Split Valve (R/I) in Manual
- Manipulated valve: Vapor Split Valve V1 & V2
- Controlled variable: T2-T5

- *Split Range logic*

![Diagram of vapor split experiment]

**Valve Opening**

<table>
<thead>
<tr>
<th>Output</th>
<th>V1</th>
<th>V2</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
<td>100%</td>
</tr>
<tr>
<td>50%</td>
<td>50%</td>
<td></td>
</tr>
<tr>
<td>100%</td>
<td>100%</td>
<td>0</td>
</tr>
</tbody>
</table>

**Legend:**
- **L**: Liquid
- **V**: Vapor
Vapor Split Experiment.

Schematic of the vapor split valve

From top left: Valve in fully open position
Top right: Rack and pinion arrangement.
Vapor Split Experimental run (Total Reflux, two component)
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Petlyuk Arrangement- Model Details

Model Assumptions

• Ideal vapor liquid equilibria

• 40 Theoretical stages in each column

• The base flows calculated from the Vmin diagram* which calculated the minimum

Control Structure: Petlyuk Column

• Two Liquid Levels & 6 Sensitive Temperatures are CVs in Regulatory layer

• The loops were closed and tuned sequentially from left to right

• All loops tuned by the SIMC rules
Close loop results: Petlyuk Column

+10 % Feed Disturbance

Purity

Top Purity
S1 Purity
S2 Purity
Bottoms
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• 4 – Product Kaibel Column
  – Experimental Studies Confirm Stable Profiles with 4 point
temperature control
  – A lab scale prototype of vapor split valve effectively controlled
  vapor flow between prefractionator and main column

• 4- Product Extended Petlyuk Column
  – Simulation studies suggest that 4-product extended petlyuk
column can be controlled and operated with 6 point
temperature control in the regulatory layer
Acknowledgements

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References

• Strandberg, J., Skogestad, S., Stablizing Operation of a 4-Product lintegerated Kaibel Column. SYMPOSIUM SERIES NO. 152, Distillation & Absorption
Thank you!!