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
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Introduction

- **Distillation is energy intensive process.**

- **Exergetic analysis requires minimizing irreversibilities:**
  - **mixing effect**
  - **large ΔT 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)**

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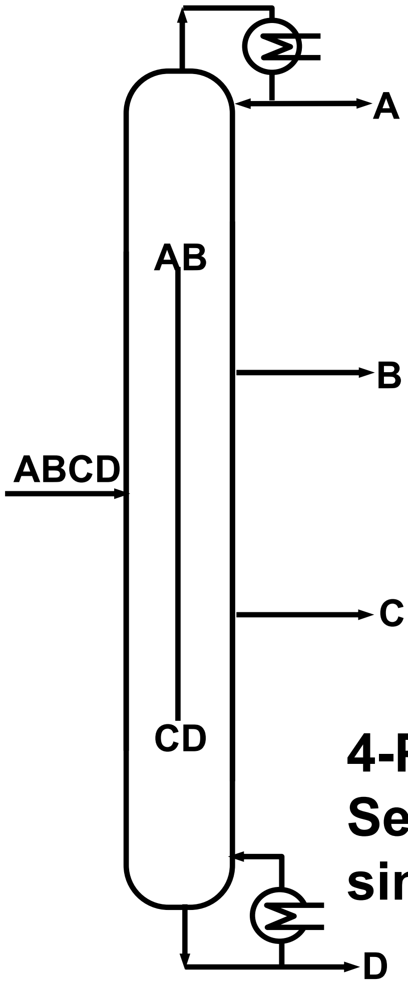
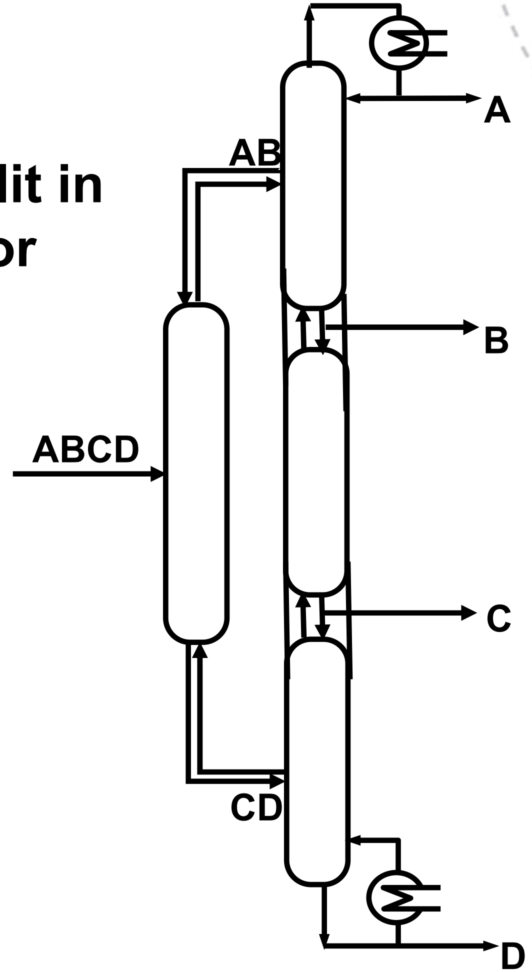
Kaibel Arrangement *



Sharp B/C Split in Prefractionator

4-Product Separation in single shell



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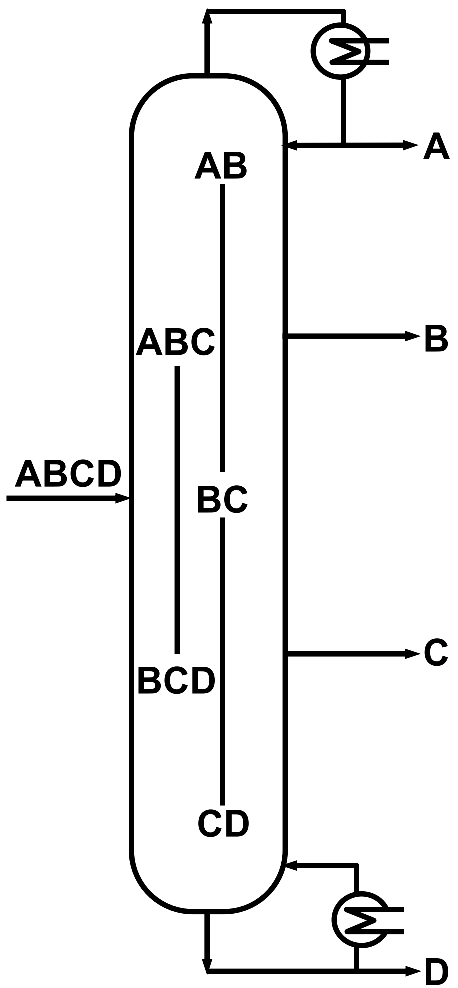
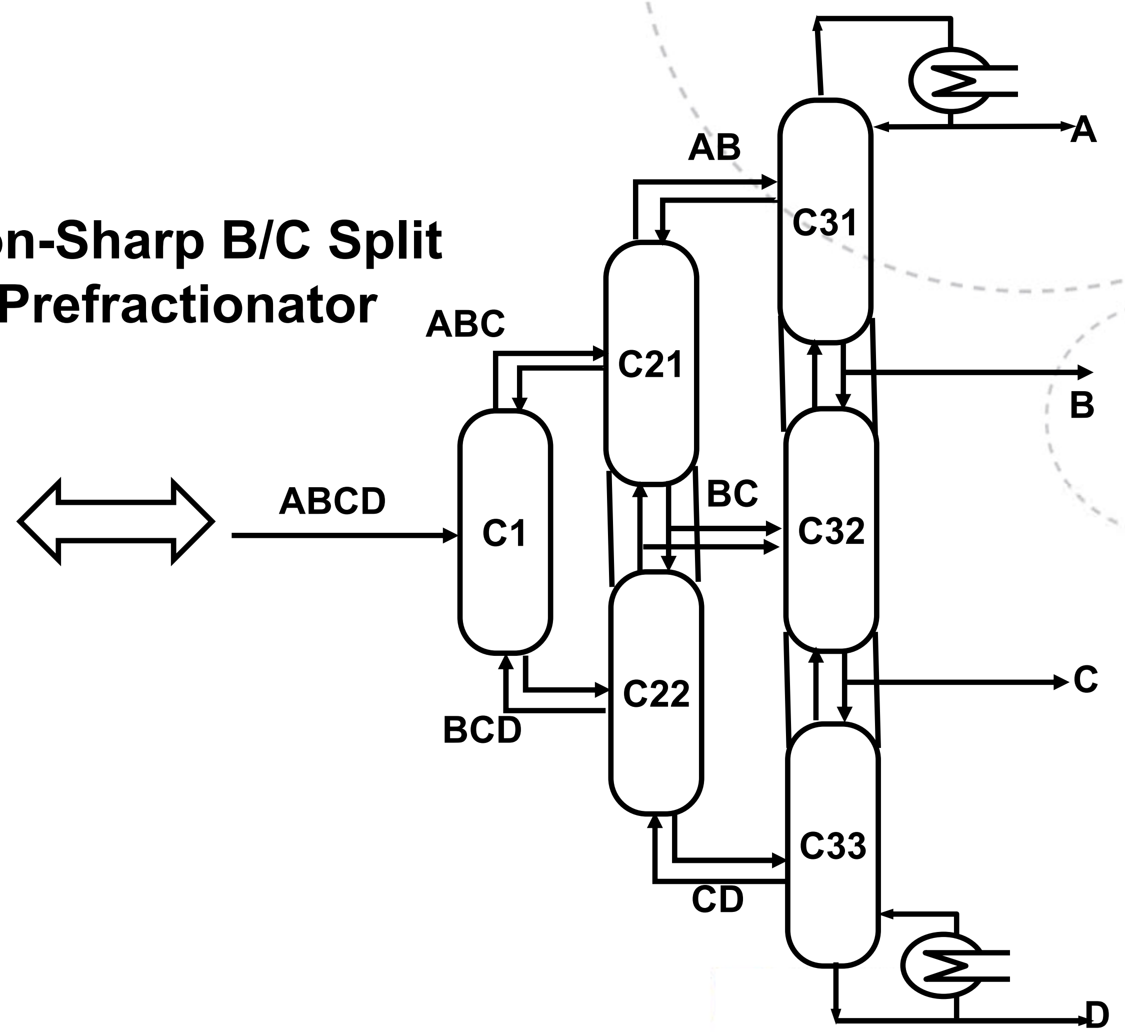
* Kaibel. G (1987)

Extended Petlyuk Arrangement *



Non-Sharp B/C Split in Prefractionator



*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)**
***** Kverland M. et. Al (2010)**

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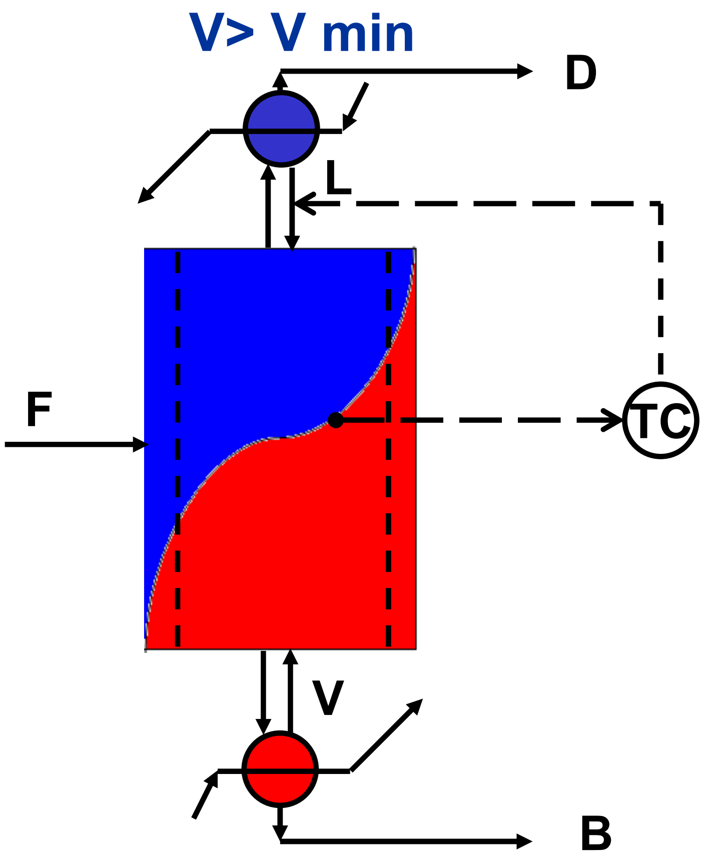
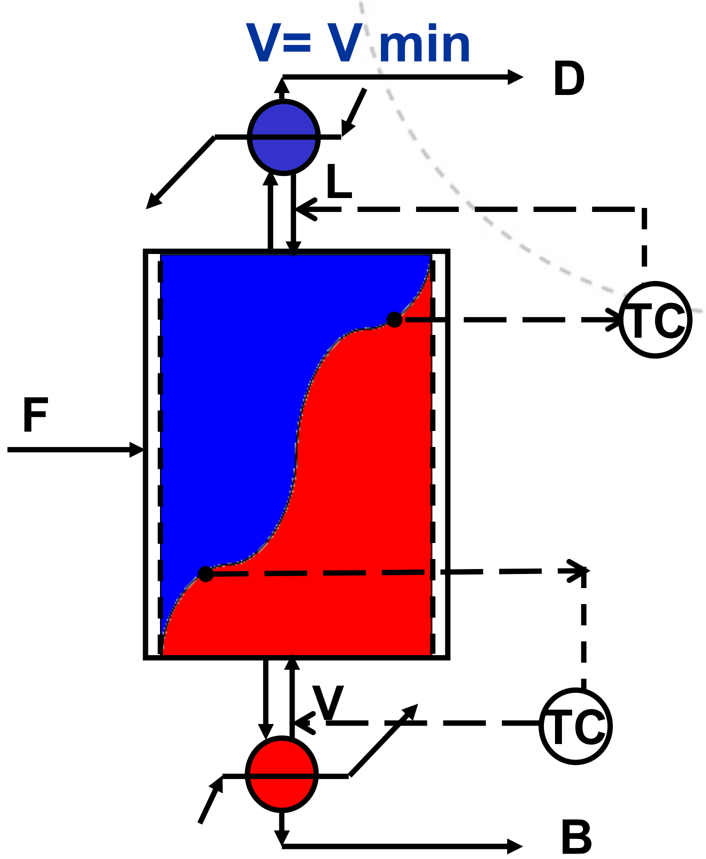
Control Structure (Ordinary Distillation)



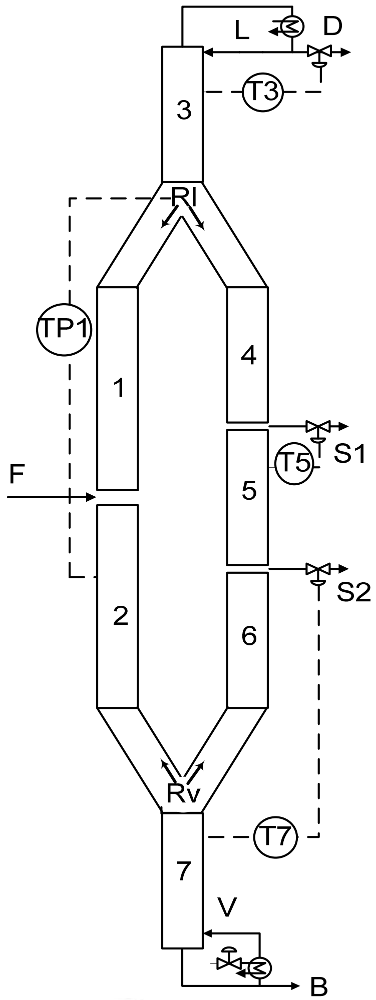
Single point control can stabilize the profiles



Two point control can stabilize column profiles

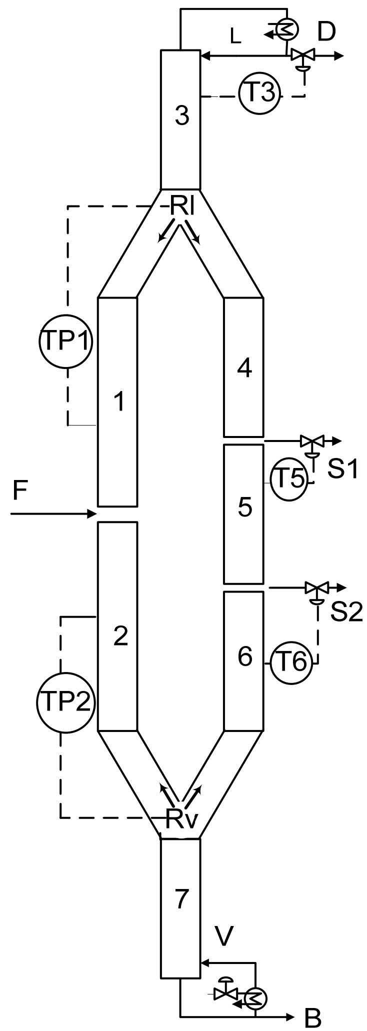
Control Structure (Kaibel Column)

V>Vmin



4-point temperature control with one temperature in prefractionator

V=Vmin



Rv Loop can be added

- **when V=Vmin, 2 temperatures may needed in prefractionator**
- **or, as DOF for any other economic objective**

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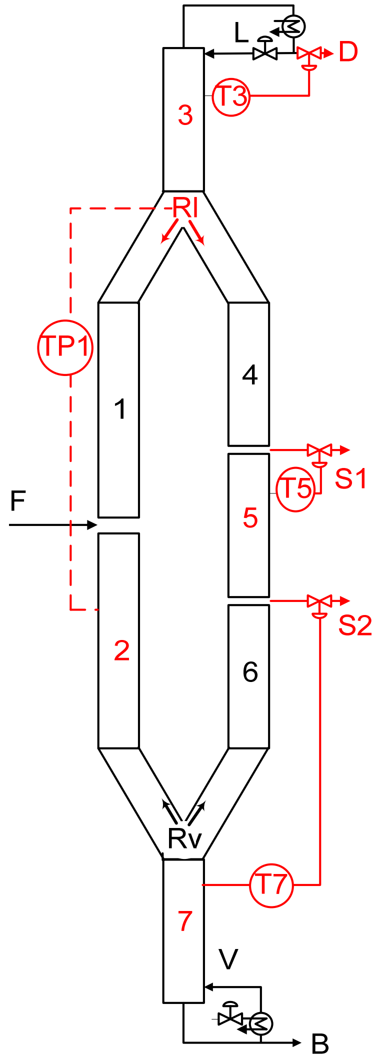
Control Structure (As used in experiments)

- 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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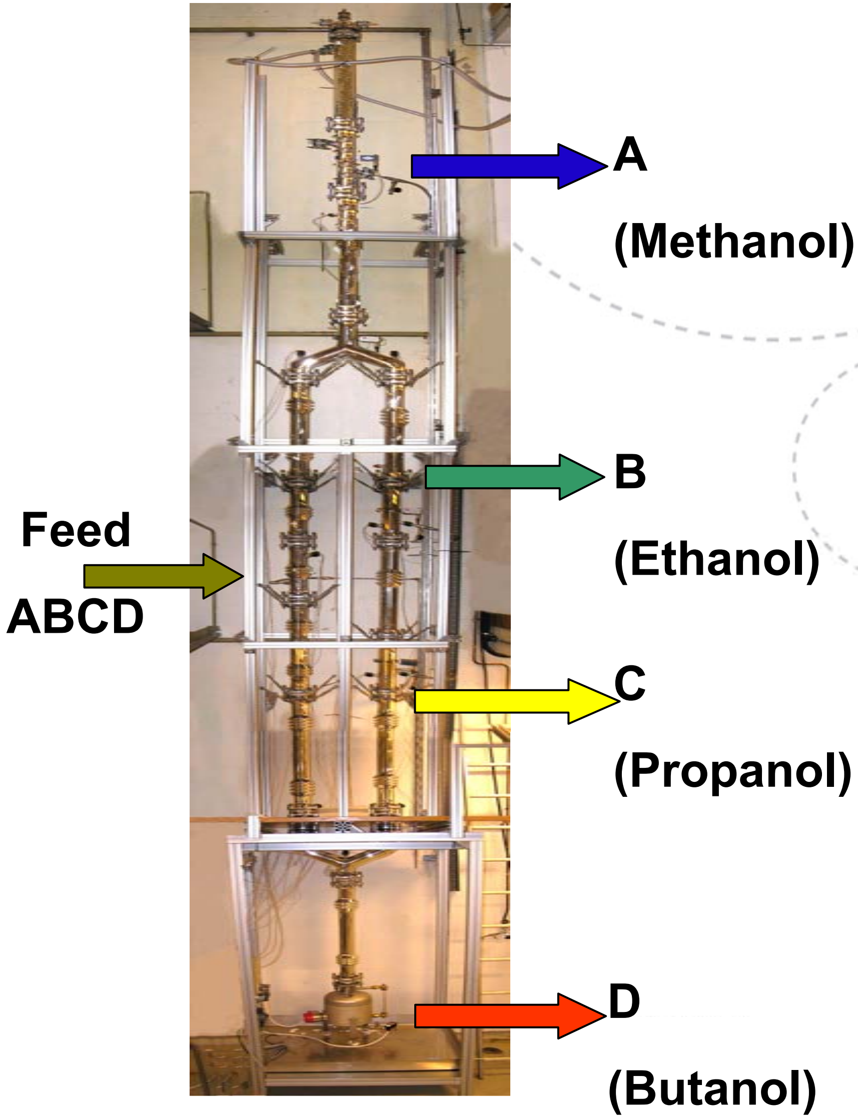
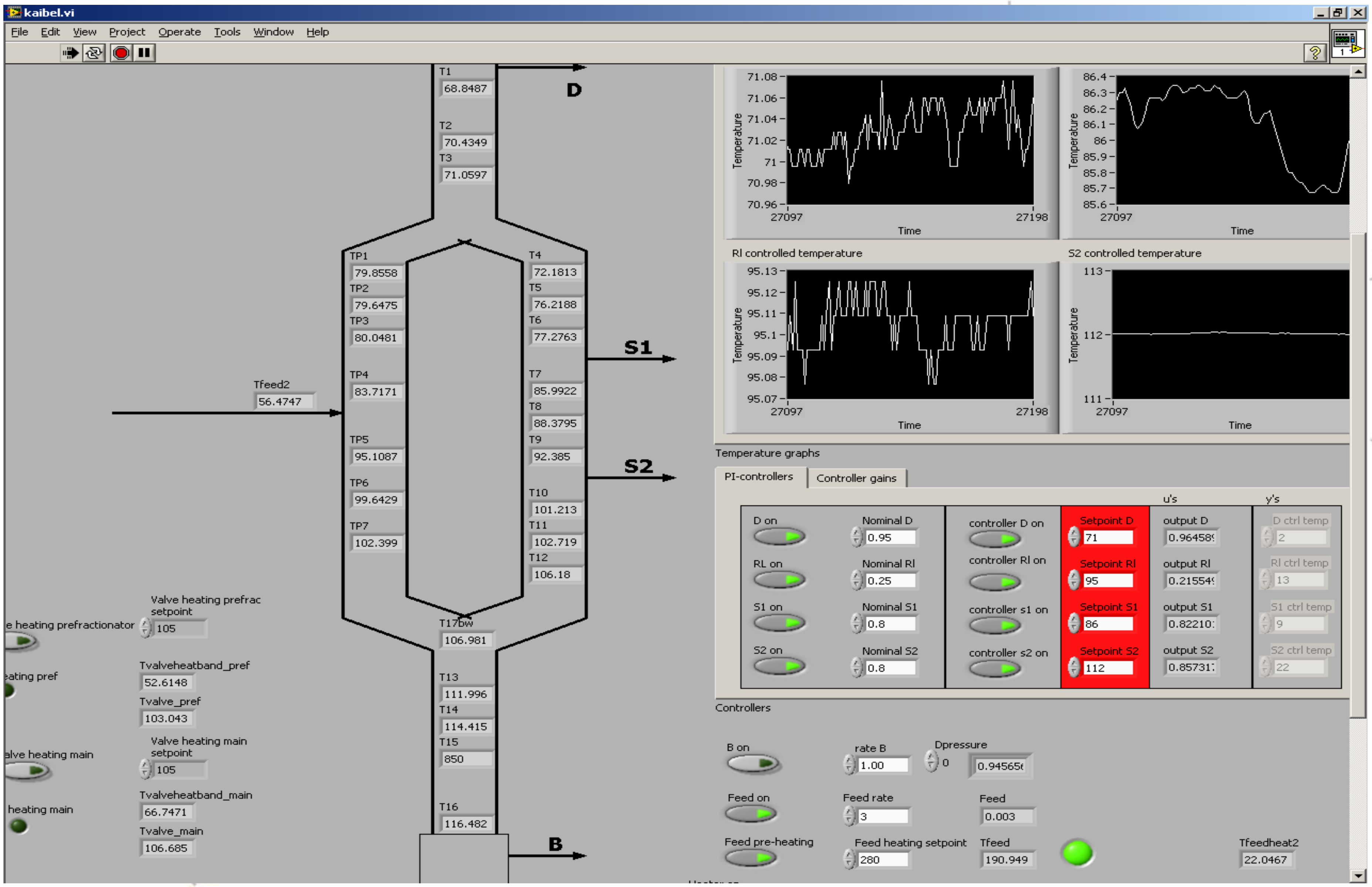
Experimental Set up

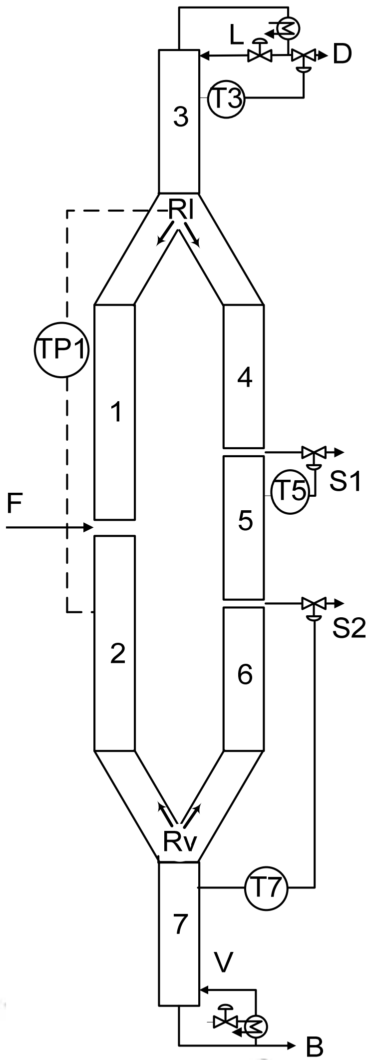
- 4 products
- Atmospheric pressure
- Packed Column
- Magnetic funnel-liquid split & Product valves
- Vapor split: Rack and Pinion
- Number of theoretical stages (experimentally determined):
  - Total stages in Prefractionator = 17
  - Total Stages in main column = 21
  - High Purity is impossible with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

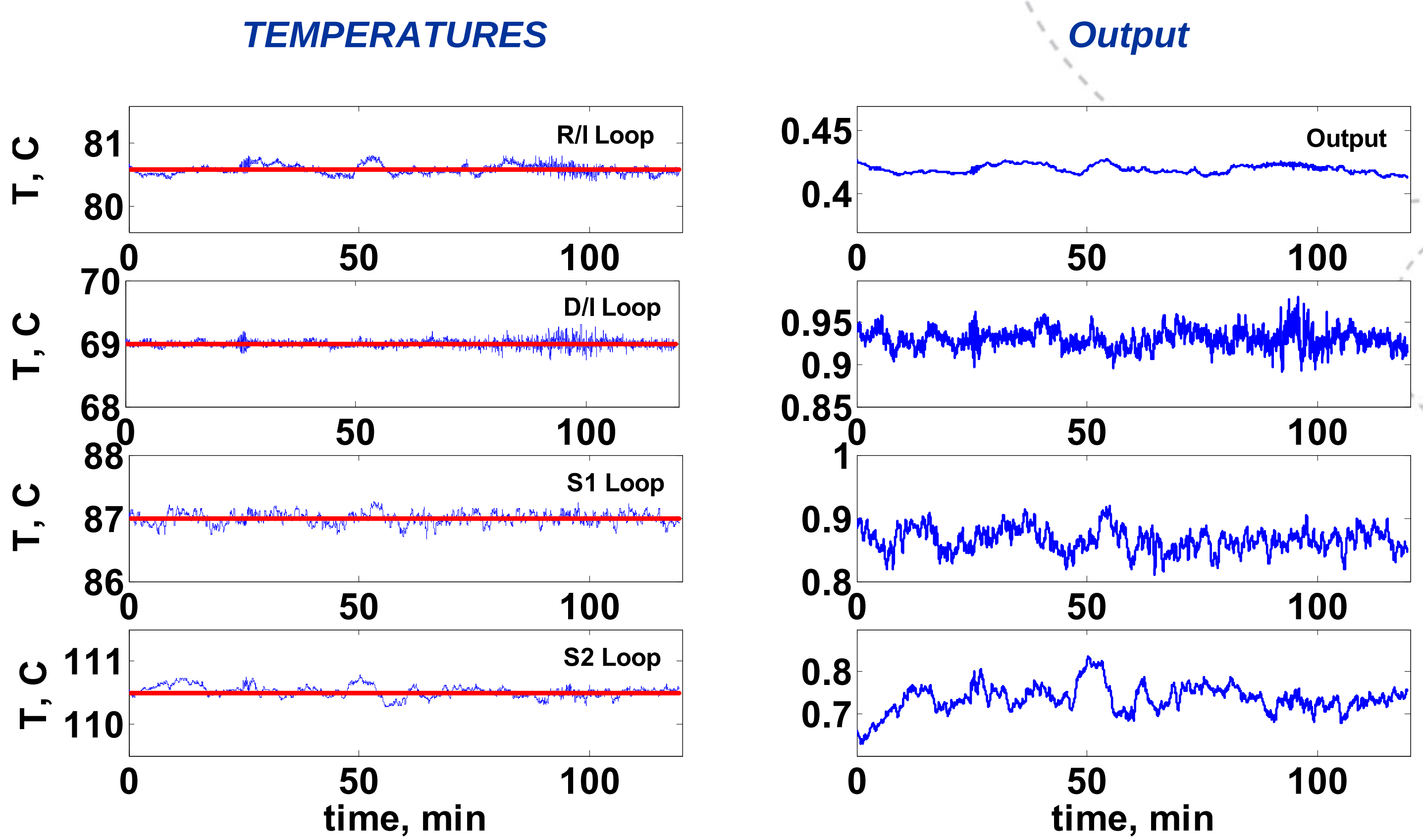


Experimental Set up (Labview Interface)…



Steady Profiles with 4 temperature loops





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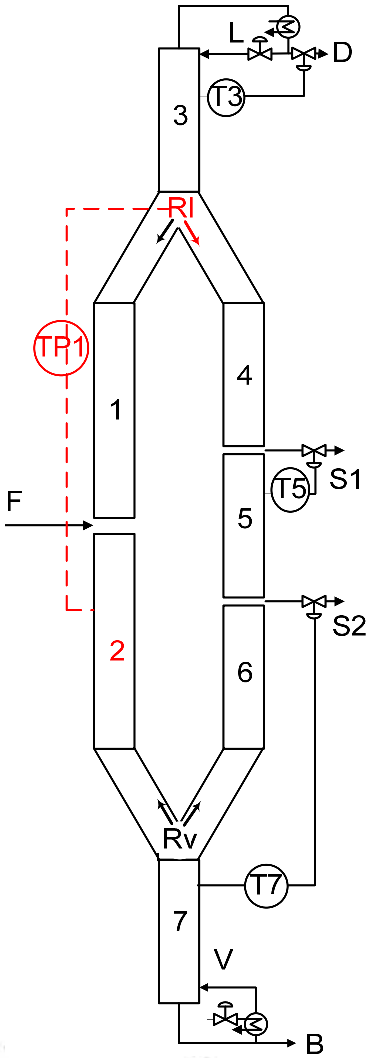
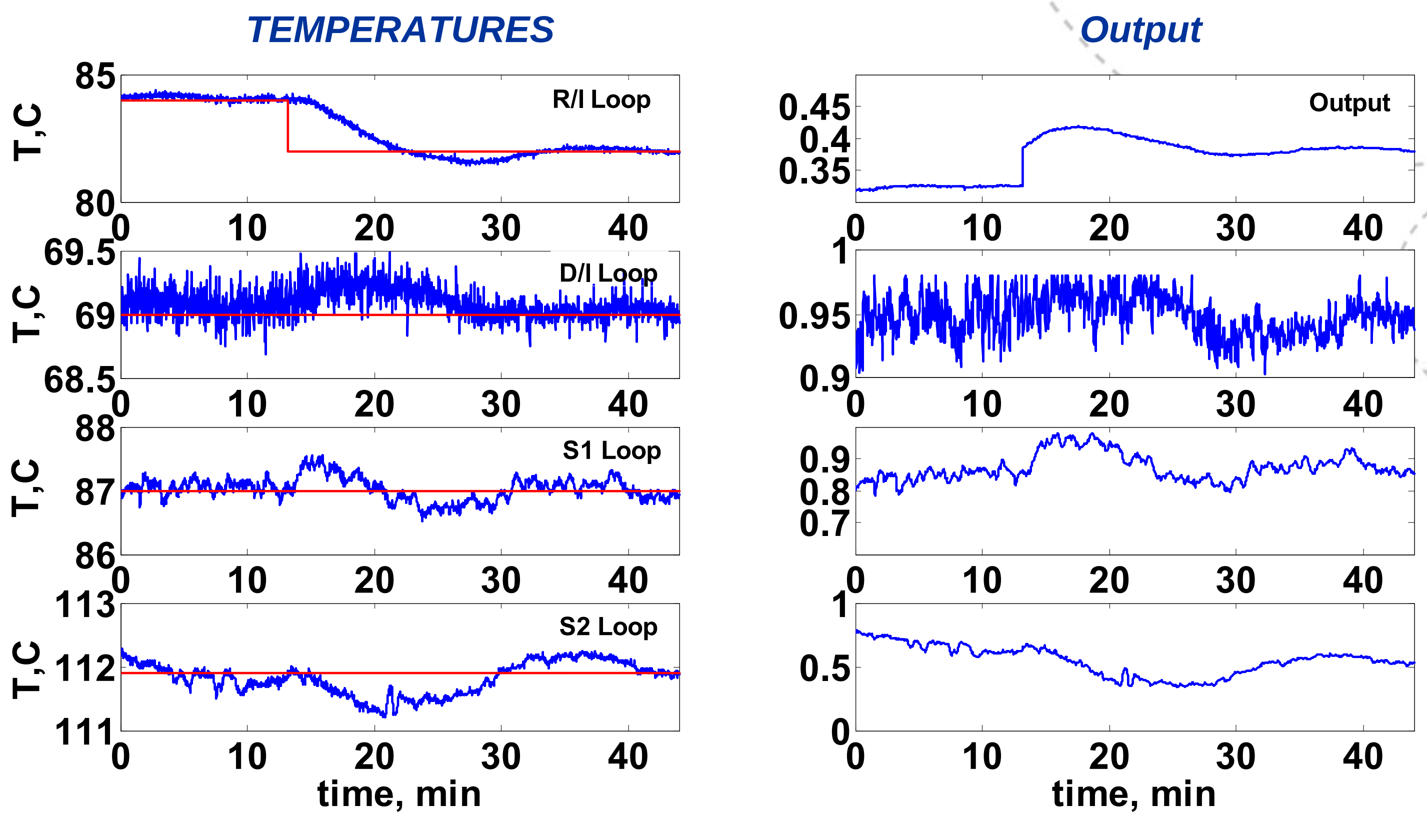
Steady Profiles with 4 temperature loops..



Liquid Split Loop -2 C



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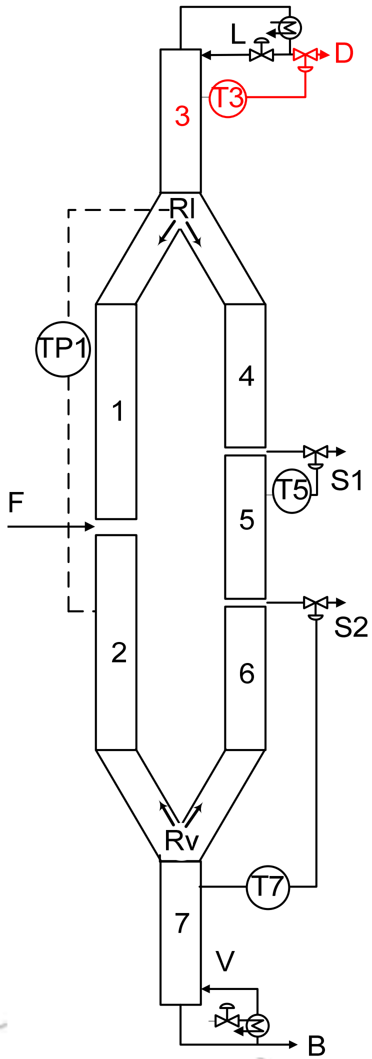
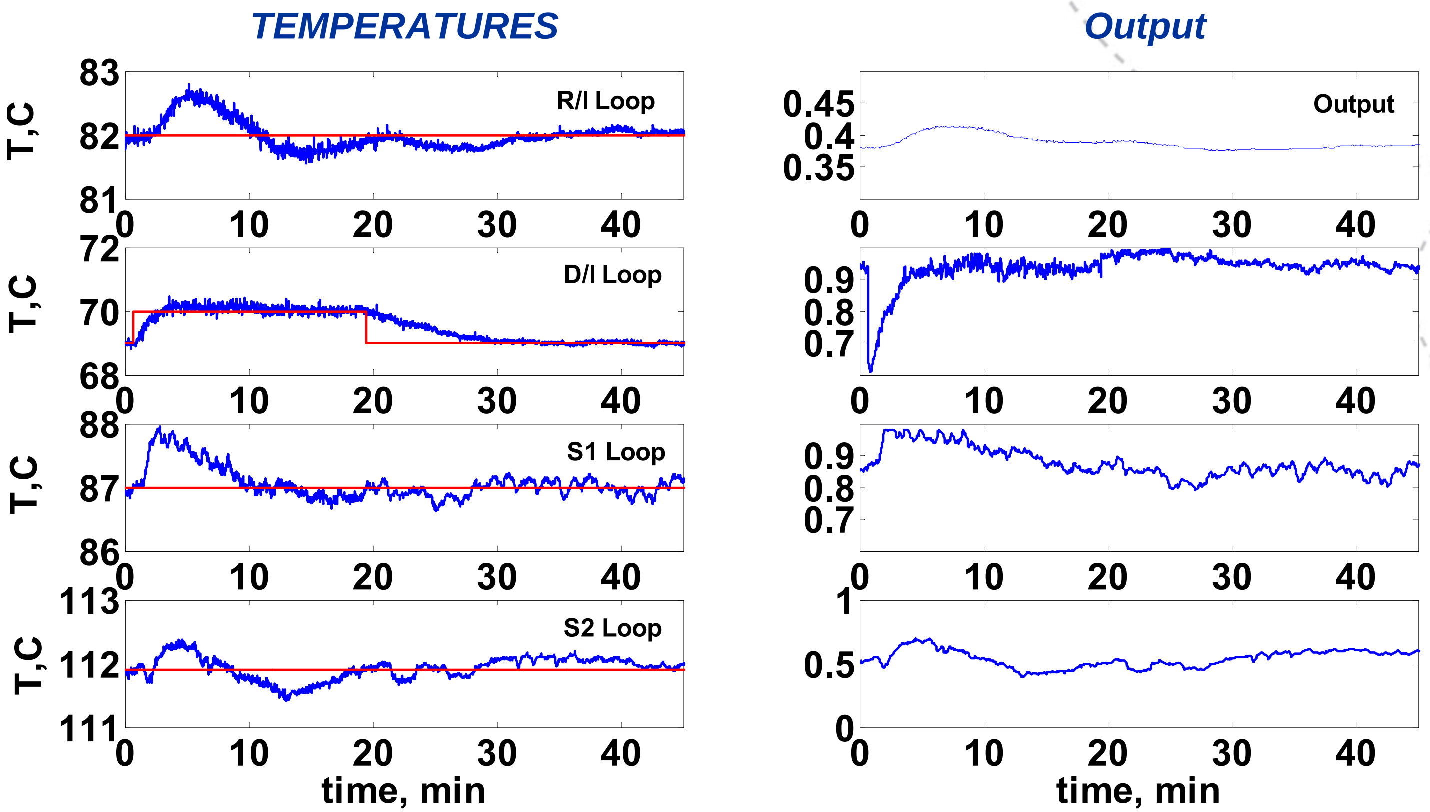
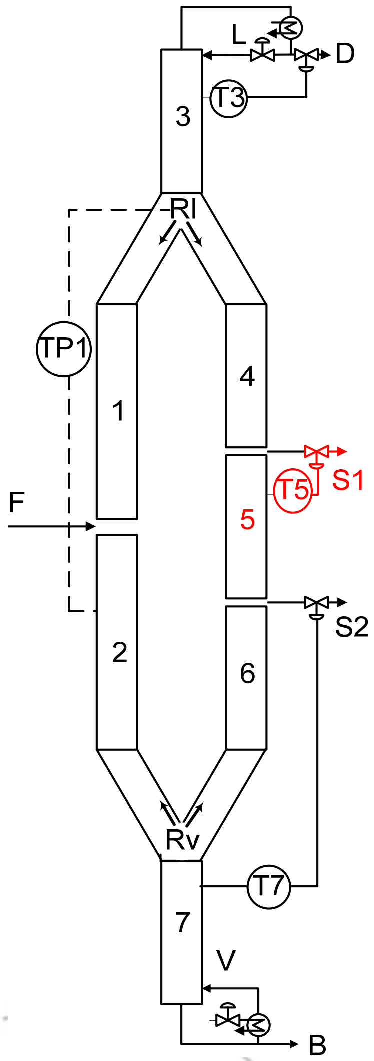
Steady Profiles with 4 temperature loops..



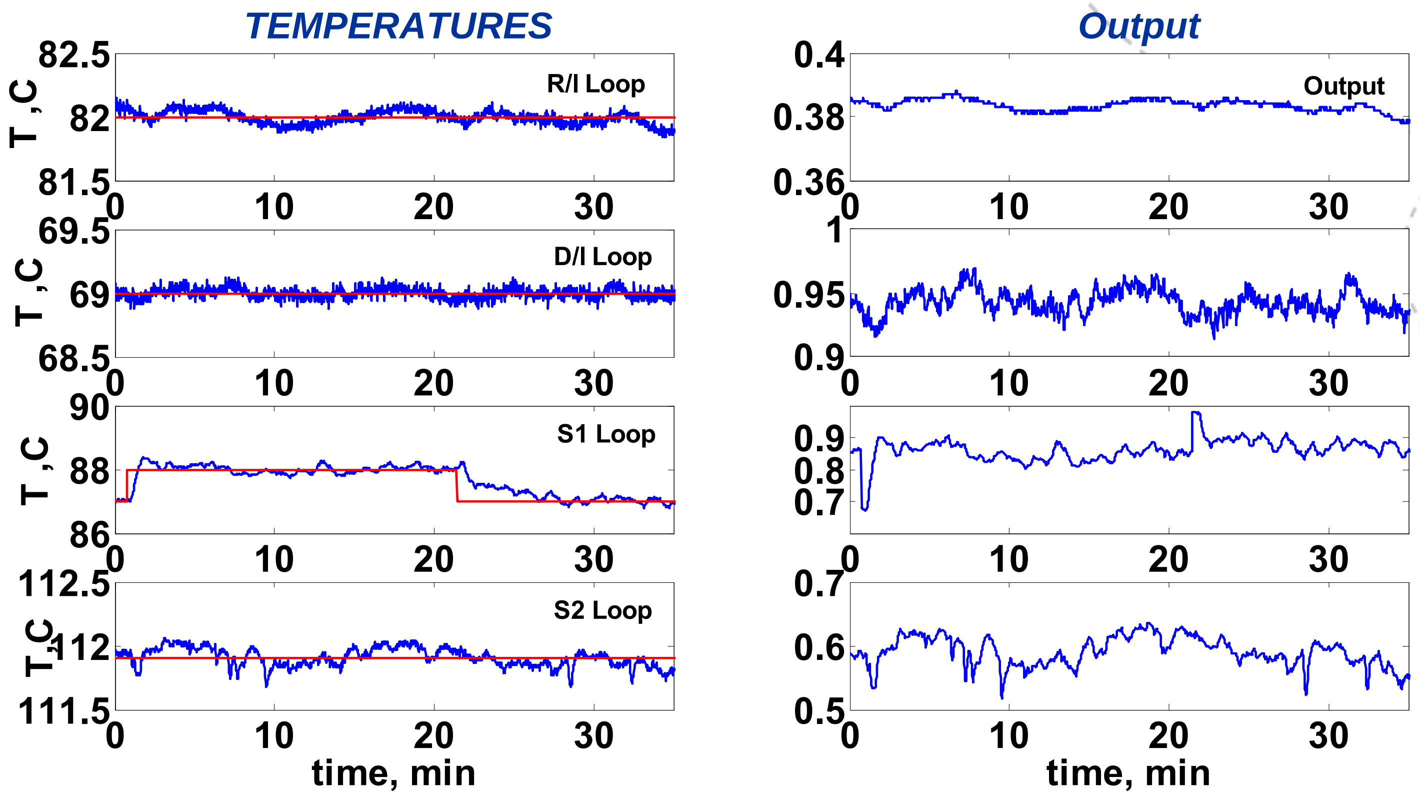
Distillate Loop ±1 C



Steady Profiles with 4 temperature loops..



S1 Loop ± 1 C



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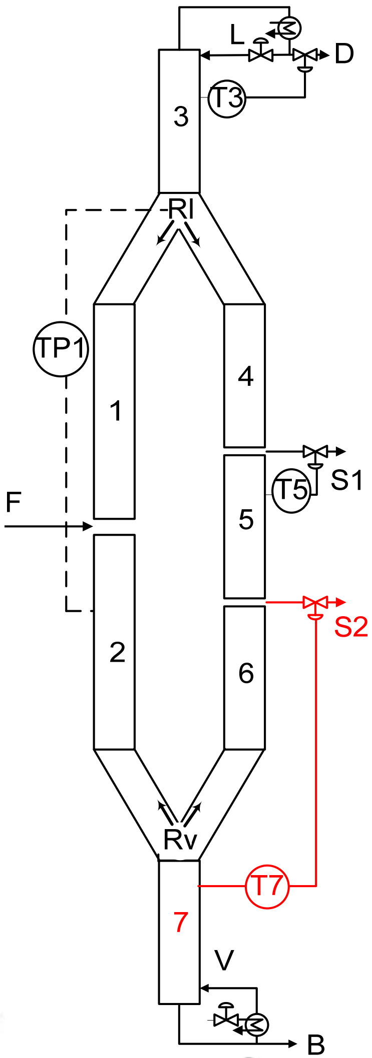
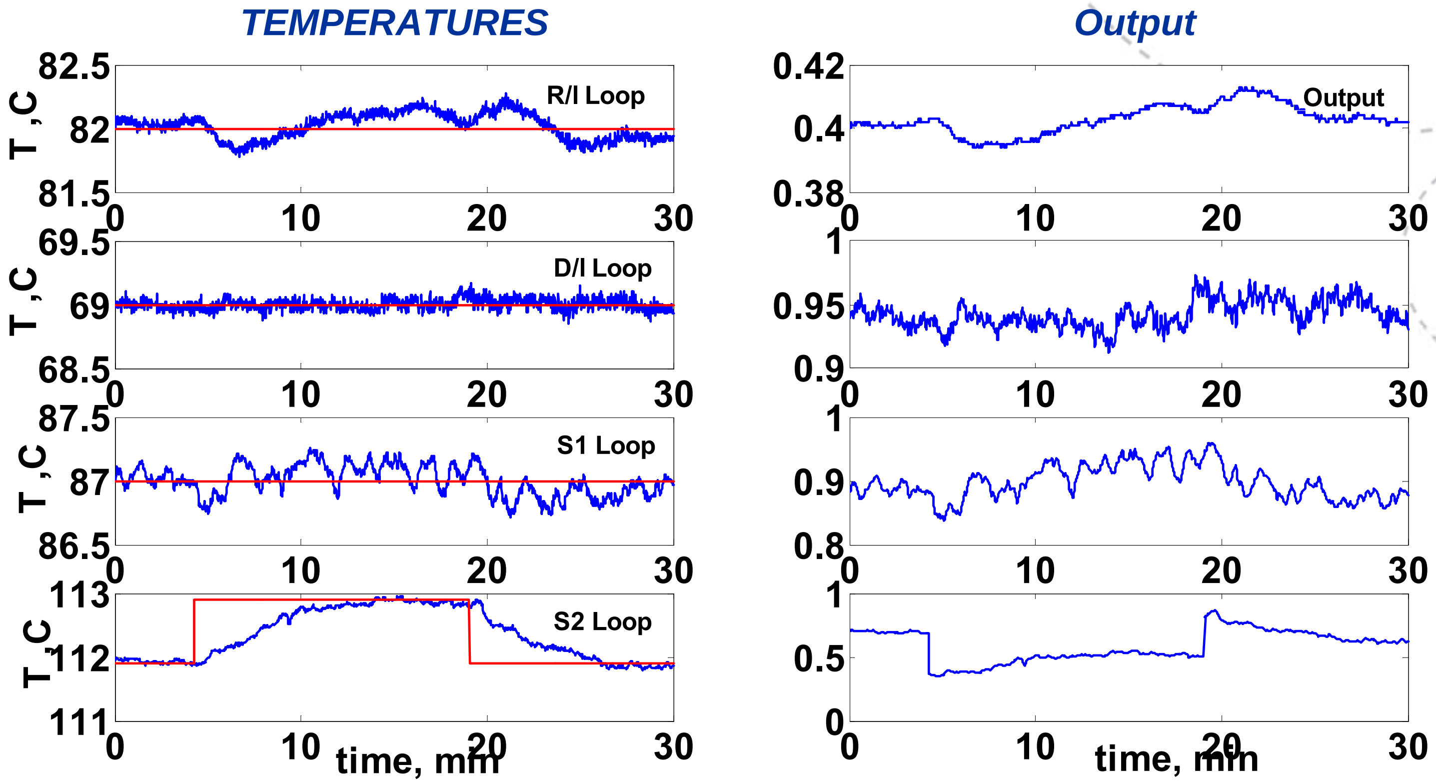
Steady Profiles with 4 temperature loops..

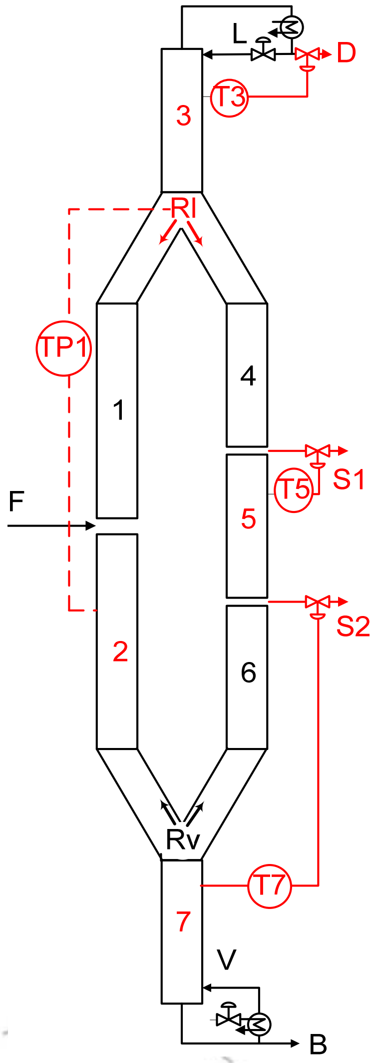


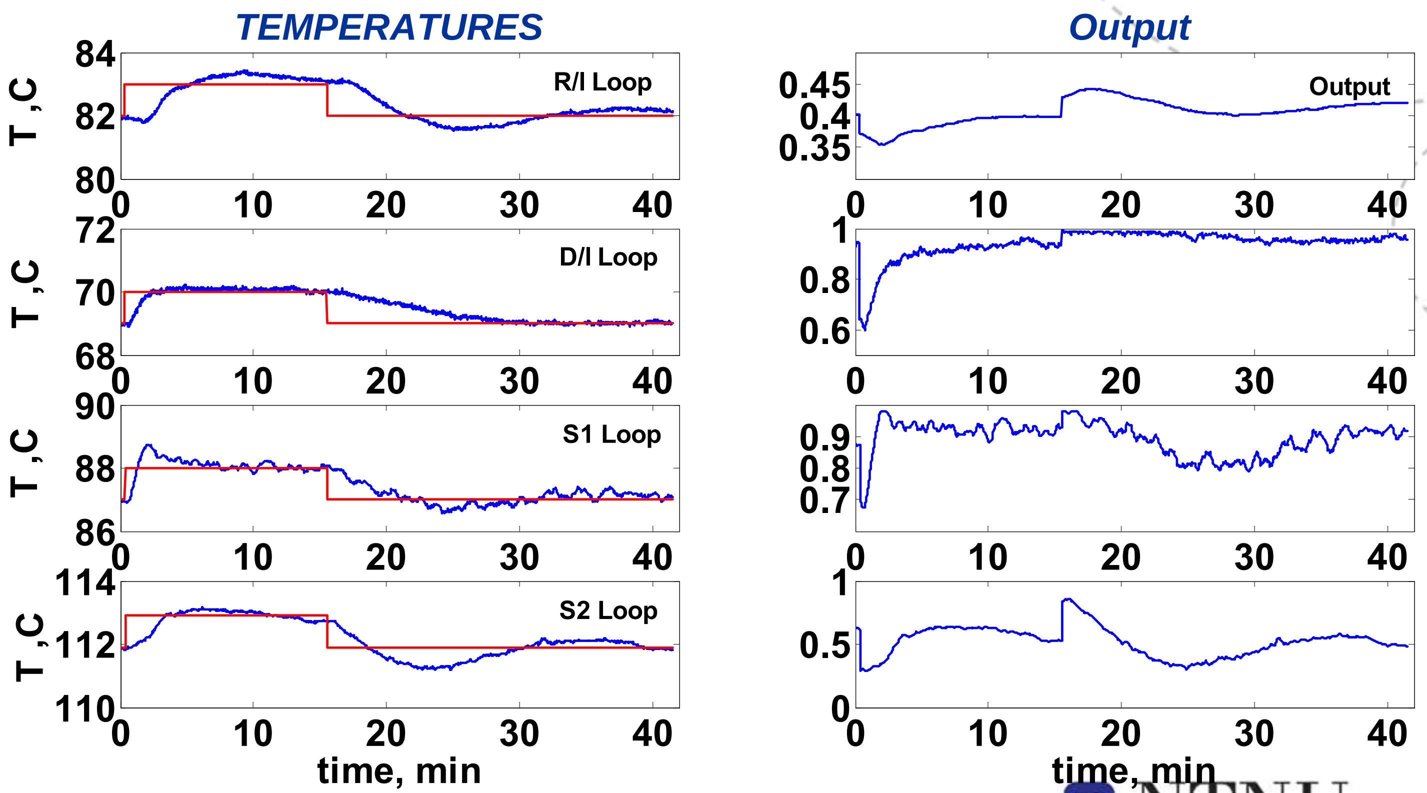
S2 Loop ± 1 C



Steady Profiles with 4 temperature loops..

All Loops ± 1 C





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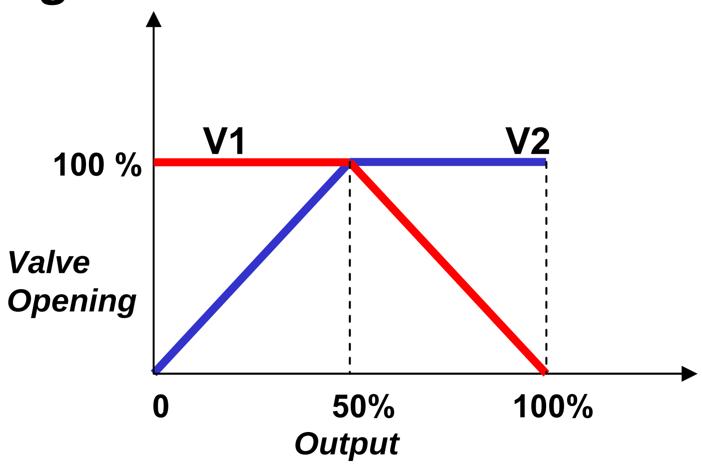
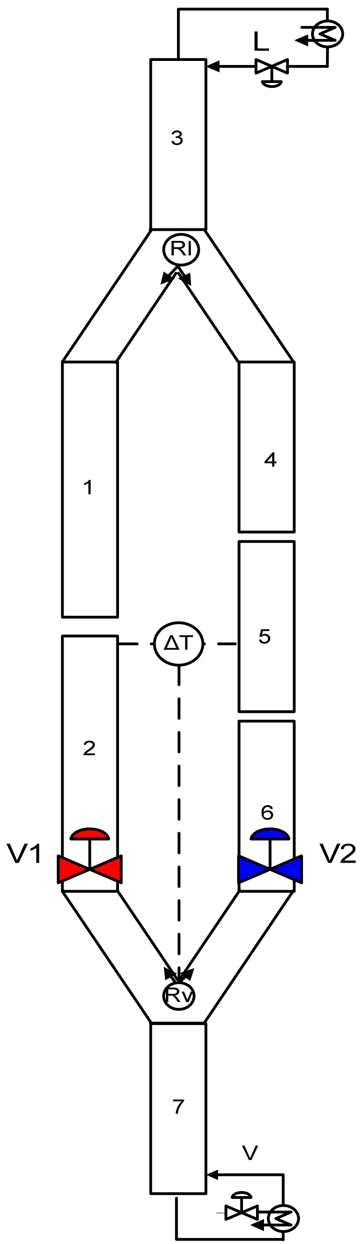
Vapor Split Experiment

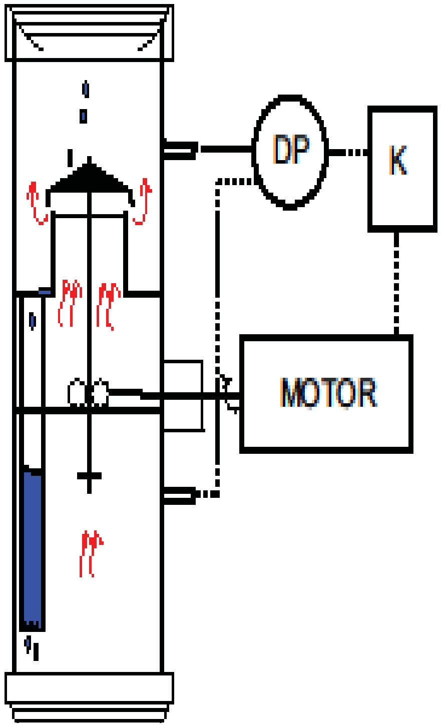
- **Total reflux operation**
- **Liquid Split Valve (R/l) in Manual**
- **Manipulated valve: Vapor Split Valve V1 & V2**
- **Controlled variable: T2-T5**

- ***Split Range logic***





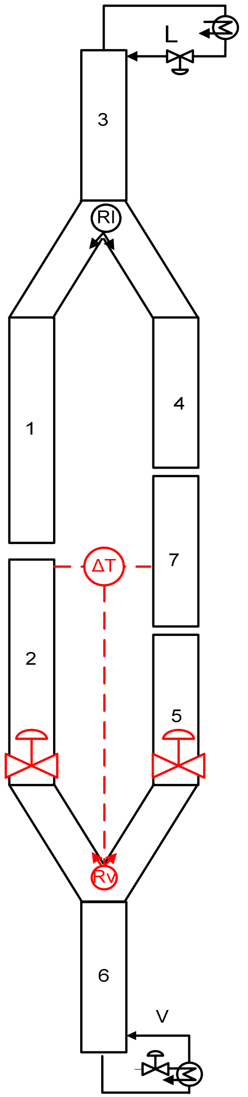
Vapor Split Experiment..

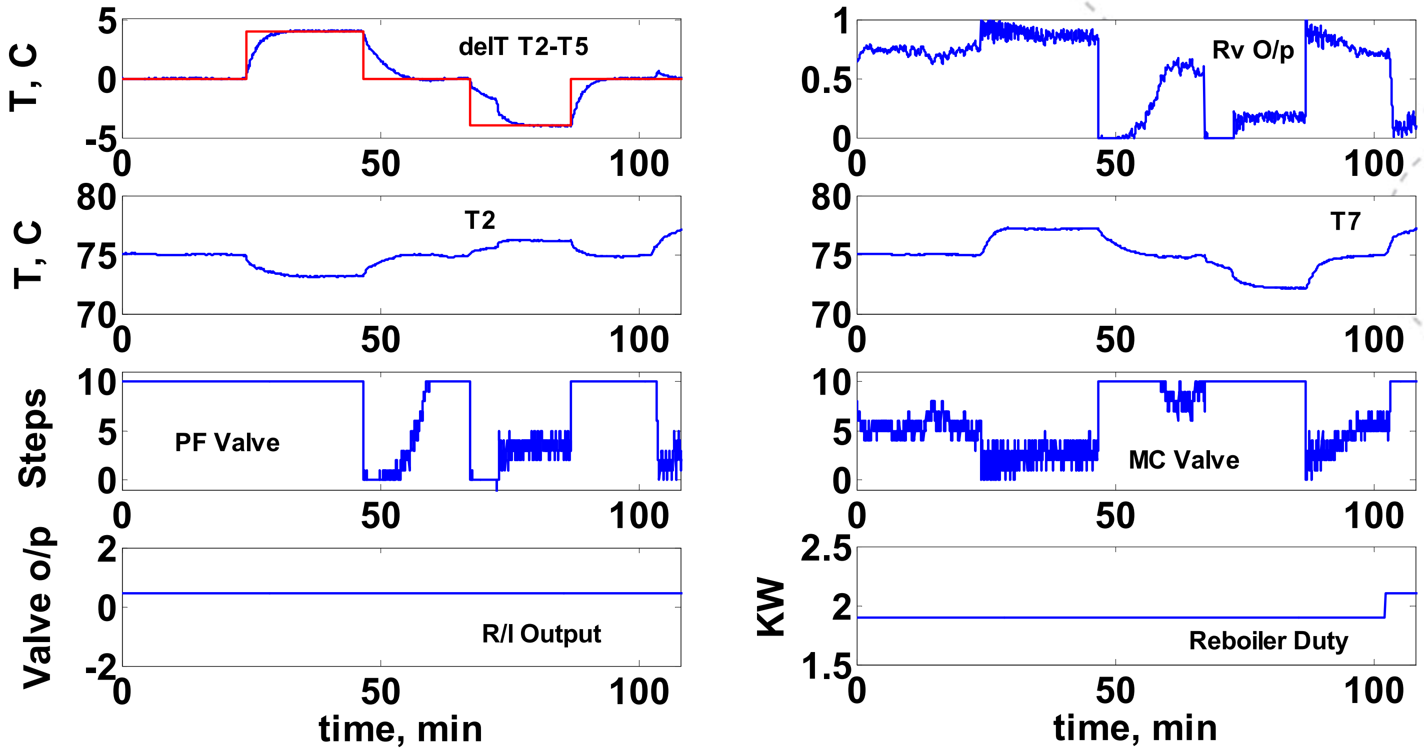


Schematic of the vapor split valve

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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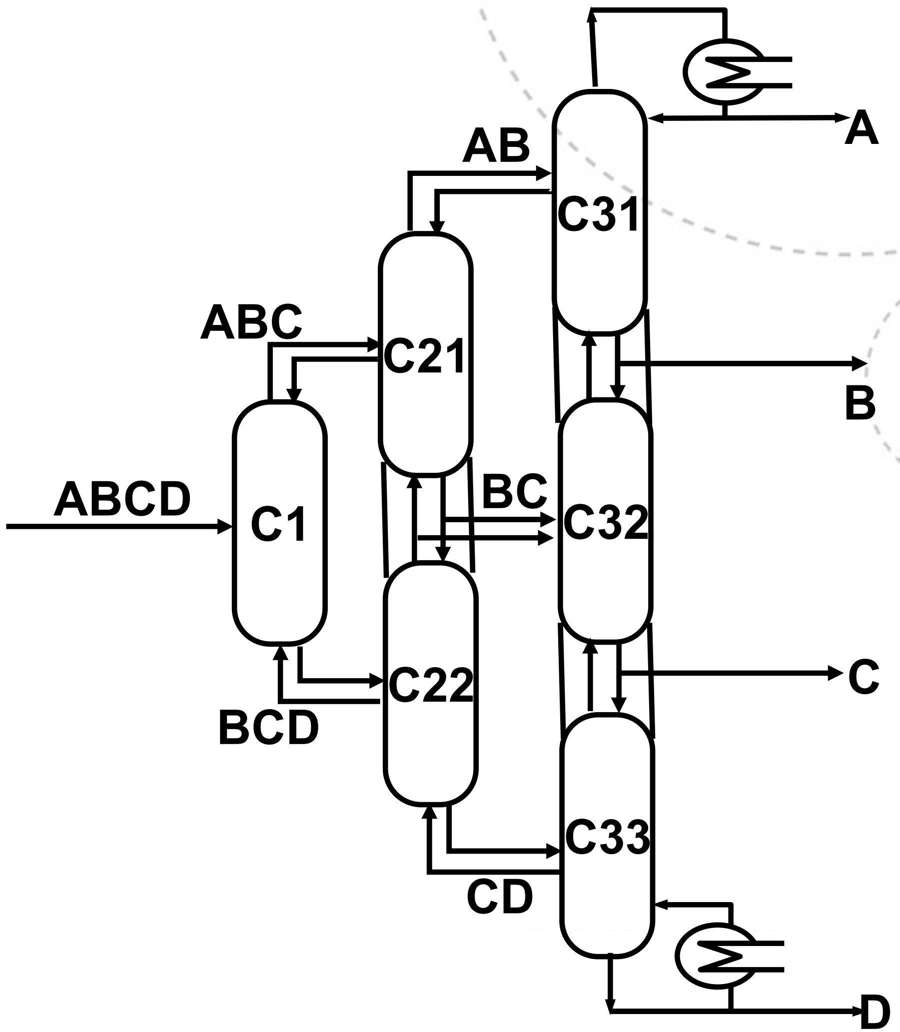
Petlyuk Arrangement- Model Details

Model Assumptions

- **Ideal vapor liquid equilibria**

- **40 Theoretical stages in each column**

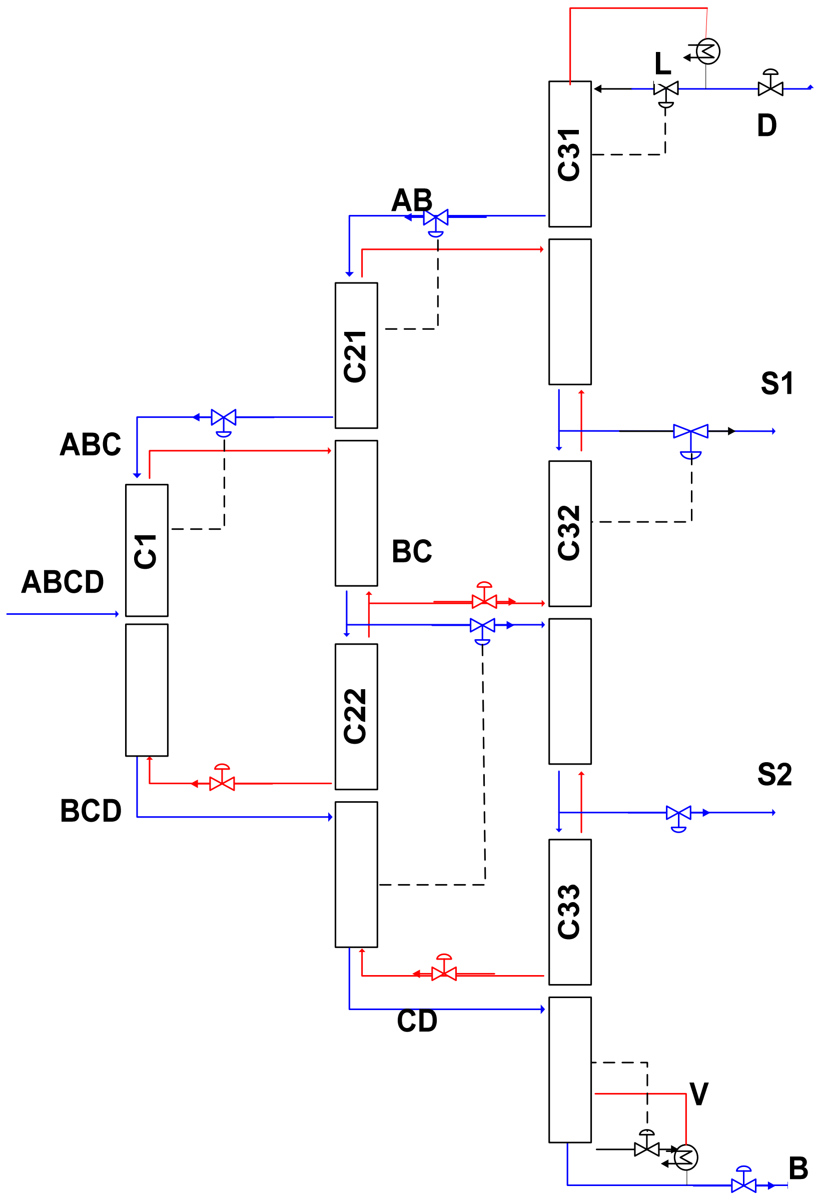
- **The base flows calculated from the Vmin diagram* which calculated the minimum**



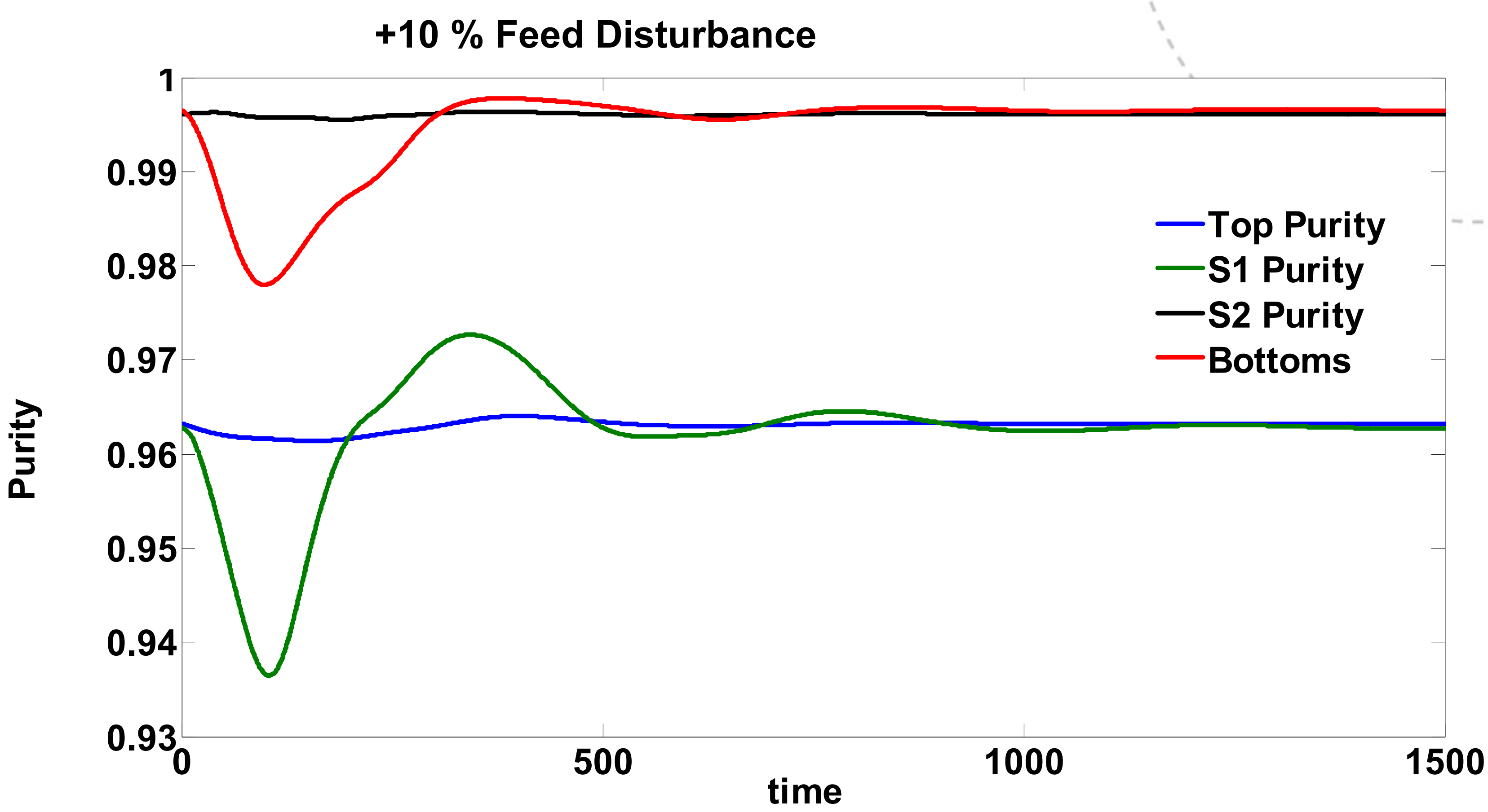
* Halvosen, I.J. & Skogestad, S. (2003)

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



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Conclusion

- 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

- **Jens Strandberg for building the column**

- Prof Heinz Presig
- Dr Mohammad Shamsuzuhha
- Jon Anta Buljo Hansen
- Terje Mugaas
- Filip Voss

References

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Thank you!!