New results for divided-wall columns

Deeptanshu Dwivedi (PhD Candidate, NTNU)
Ivar Halvorsen (Senior Scientist, SINTEF)
Sigurd Skogestad * (Professor, Department of Chemical Engineering, NTNU, Trondheim)

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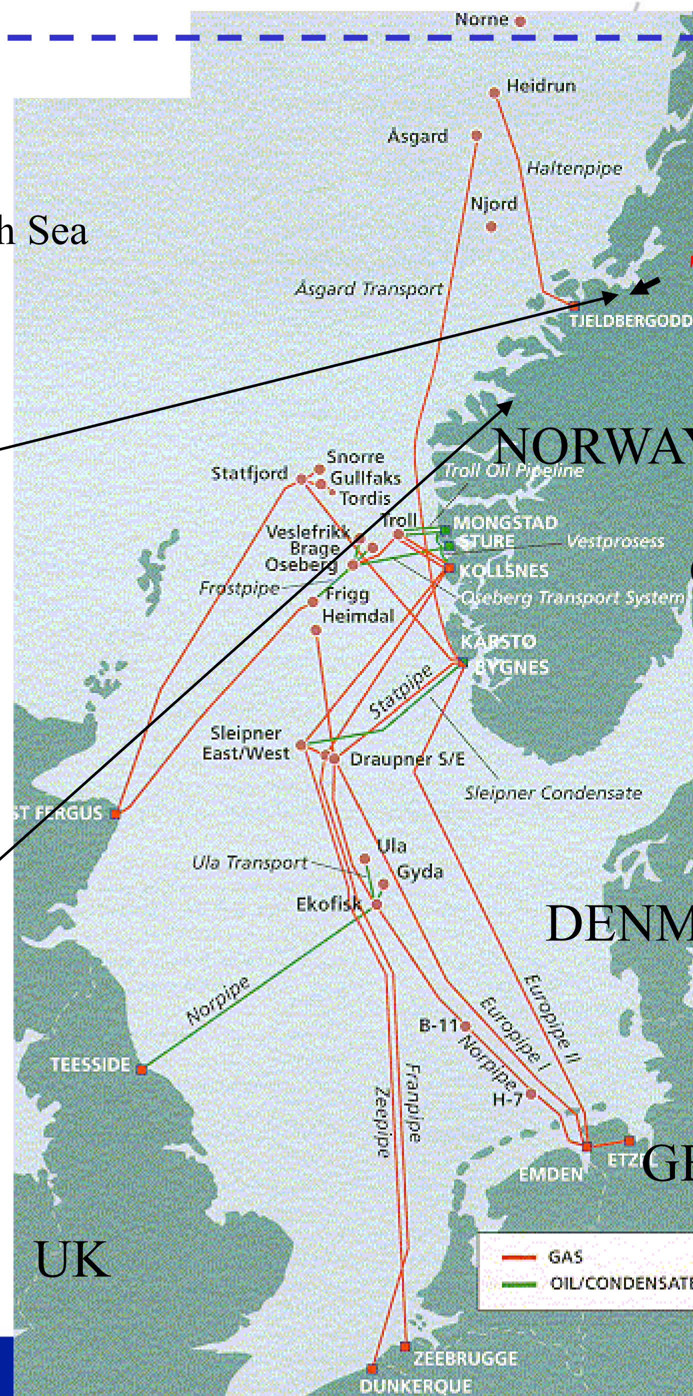

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Outline

- Introduction: Divided wall columns for 3- and 4-product separations
  - Structures
  - “V_{min} diagrams”
- Experiments: 4- Product Kaibel Column
  - Experimental Setup
  - Control Structure
  - Experimental Runs- Steady state profiles
  - Experimental data- model fitting
  - Experimental Runs- Vapor Split Experiment
- Conclusions

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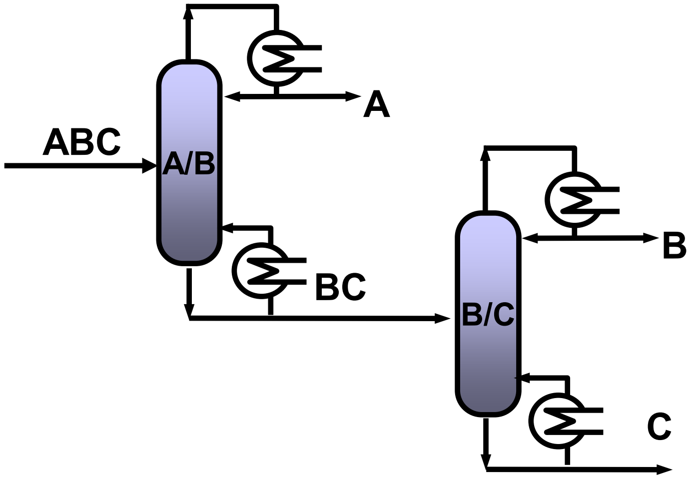
3-product separation: Conventional "direct split"



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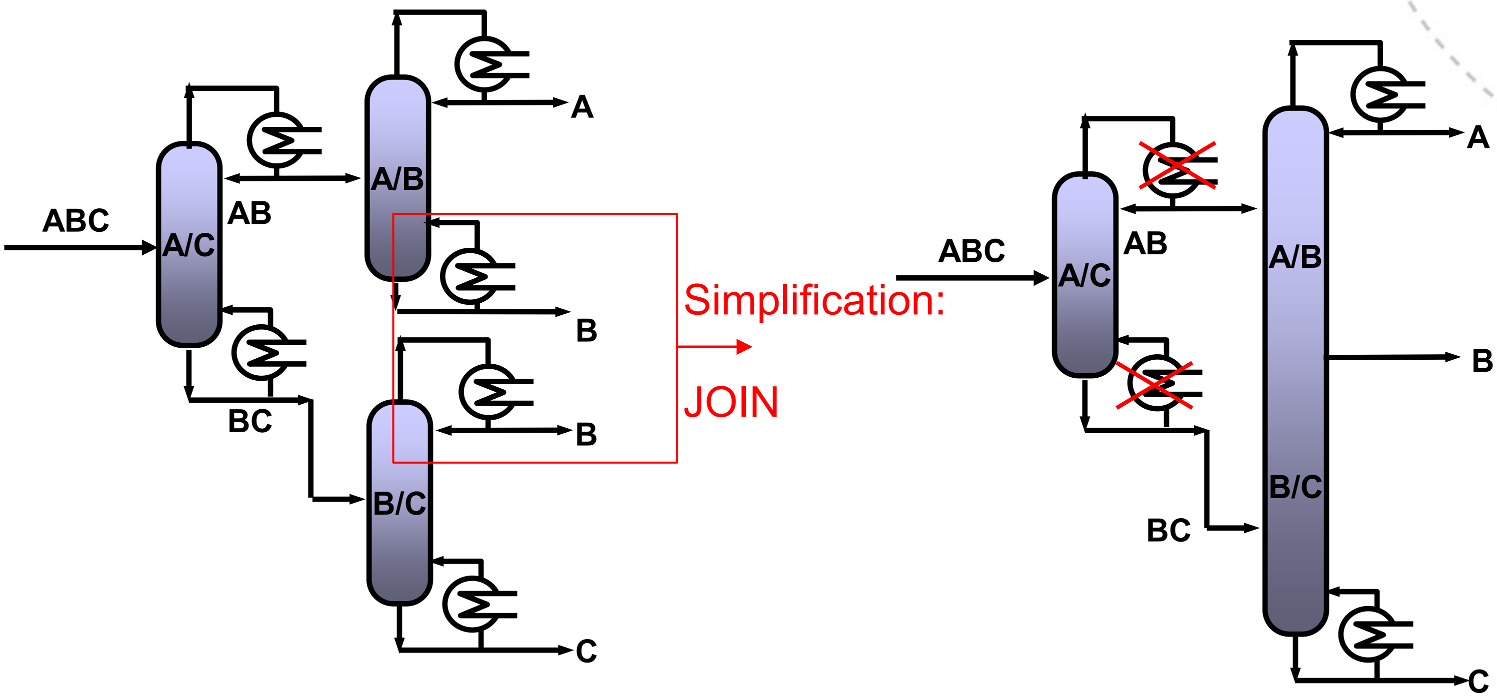
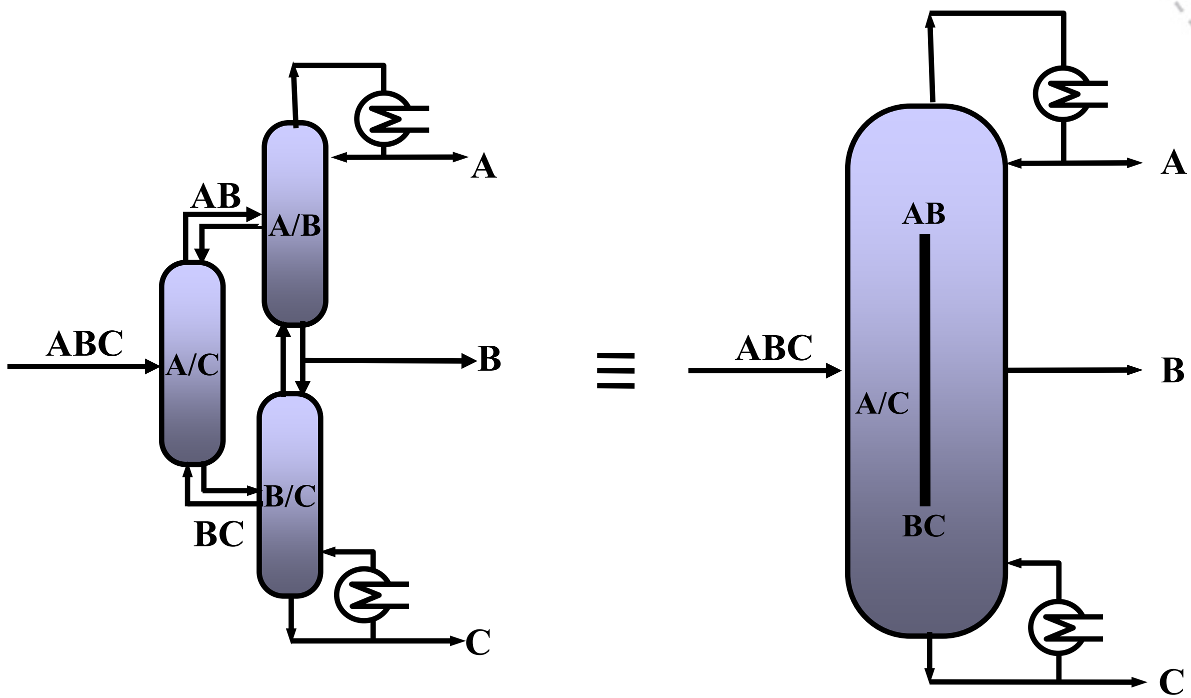
Improvement: Prefractionator (Easy split first)

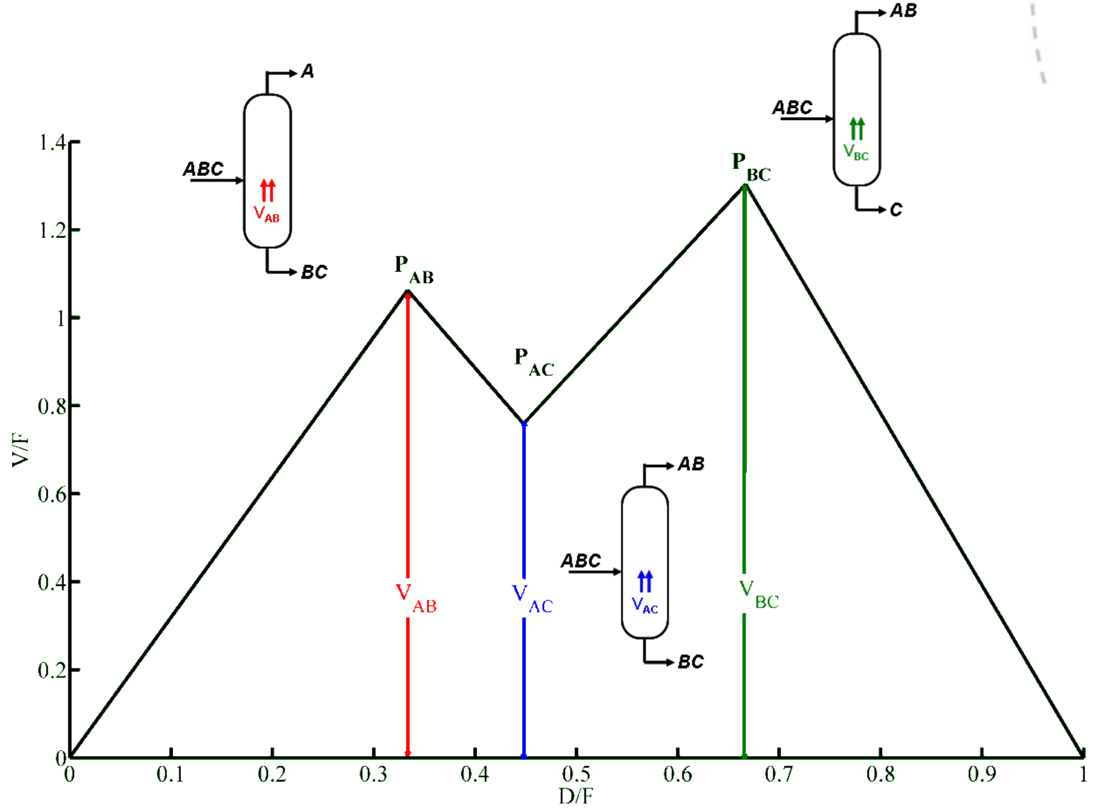


Simplification: Direct coupling ("Petlyuk") + single shell (divided wall column)



Petlyuk column

V_{min} diagram for three components



- $V_{min\,|\,Petlyuk} = \max(V_{AB}, V_{BC}) = V_{BC}$
- $V_{Prefractionator} = V_{AC}$

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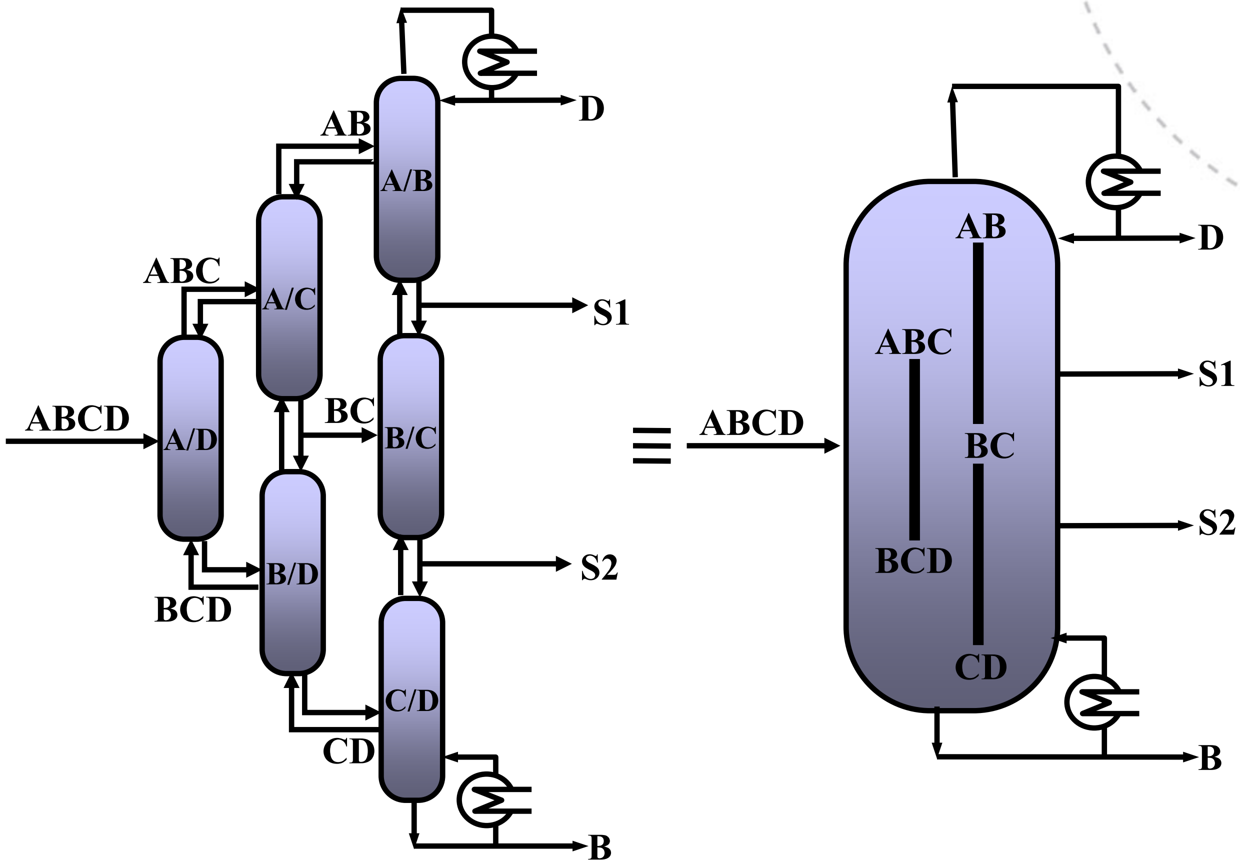
4-product separation: Extended Petlyuk



4-product extended Petlyuk column up to ~50 % energy savings

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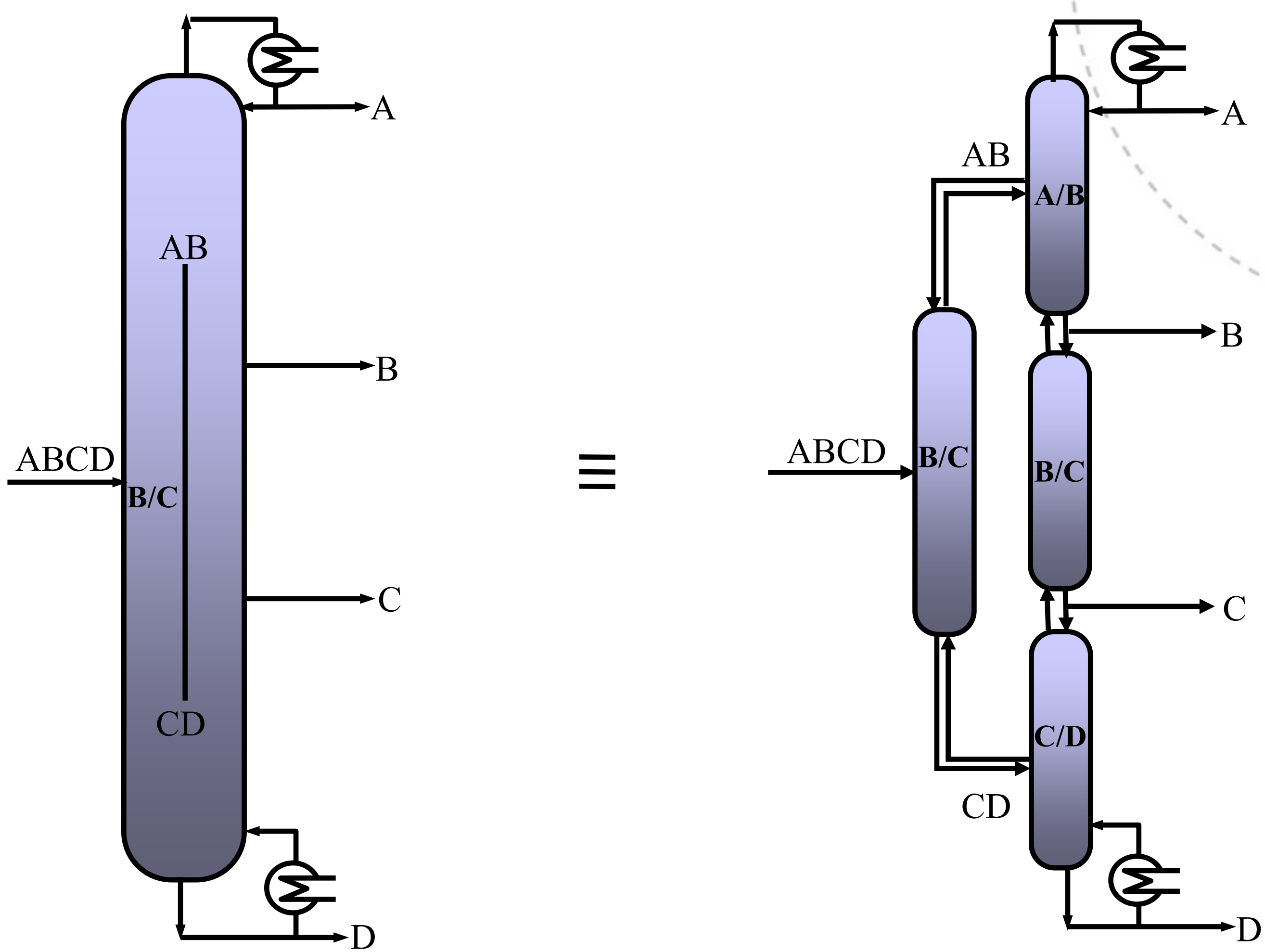
4-product separation: Simplified ("Kaibel column")



4-product extended Kaibel column up to ~30 % energy savings

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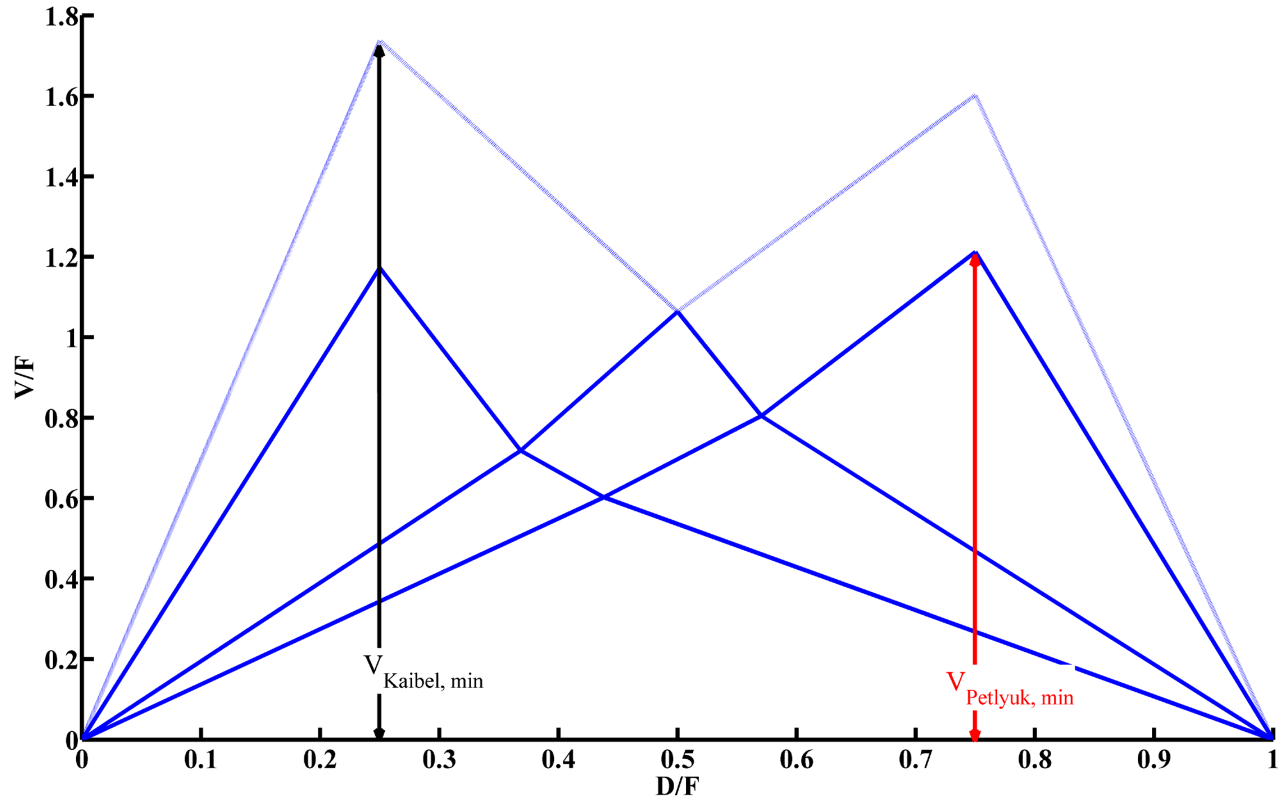
V_{min} diagram for four components



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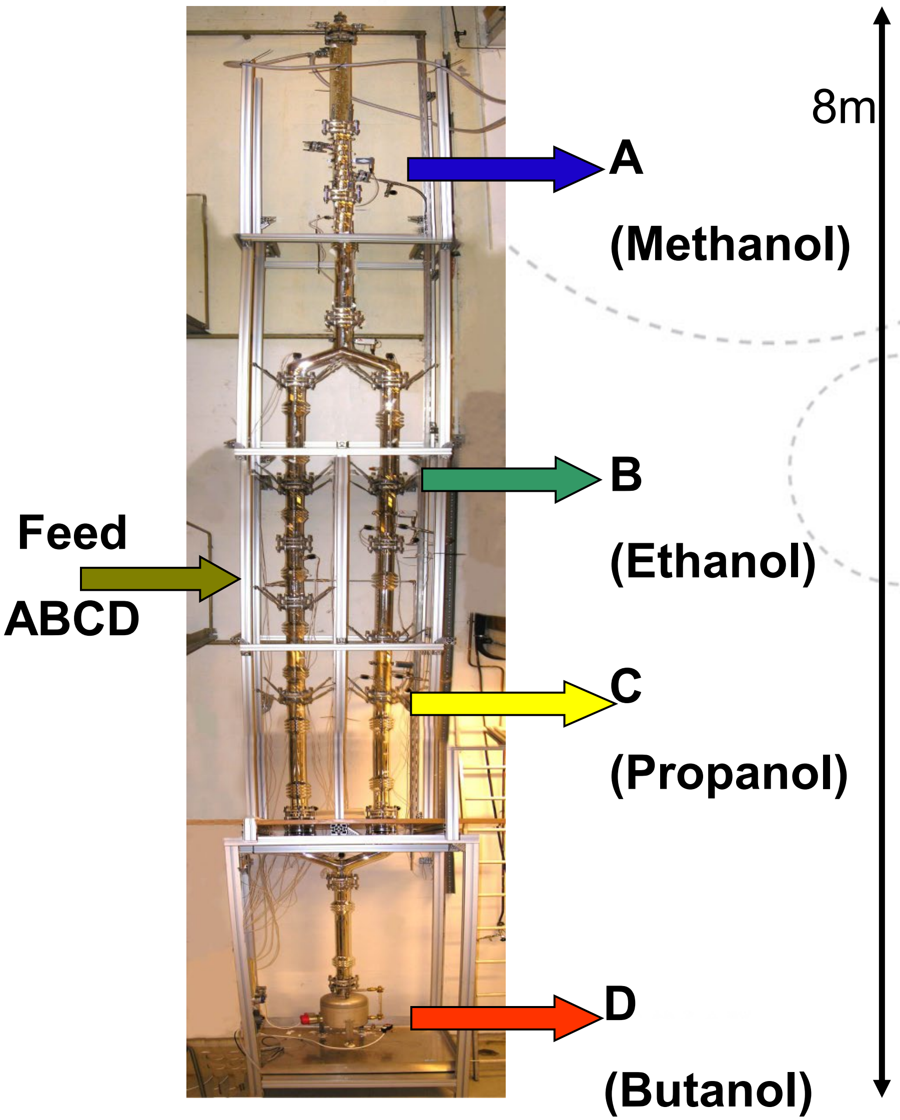
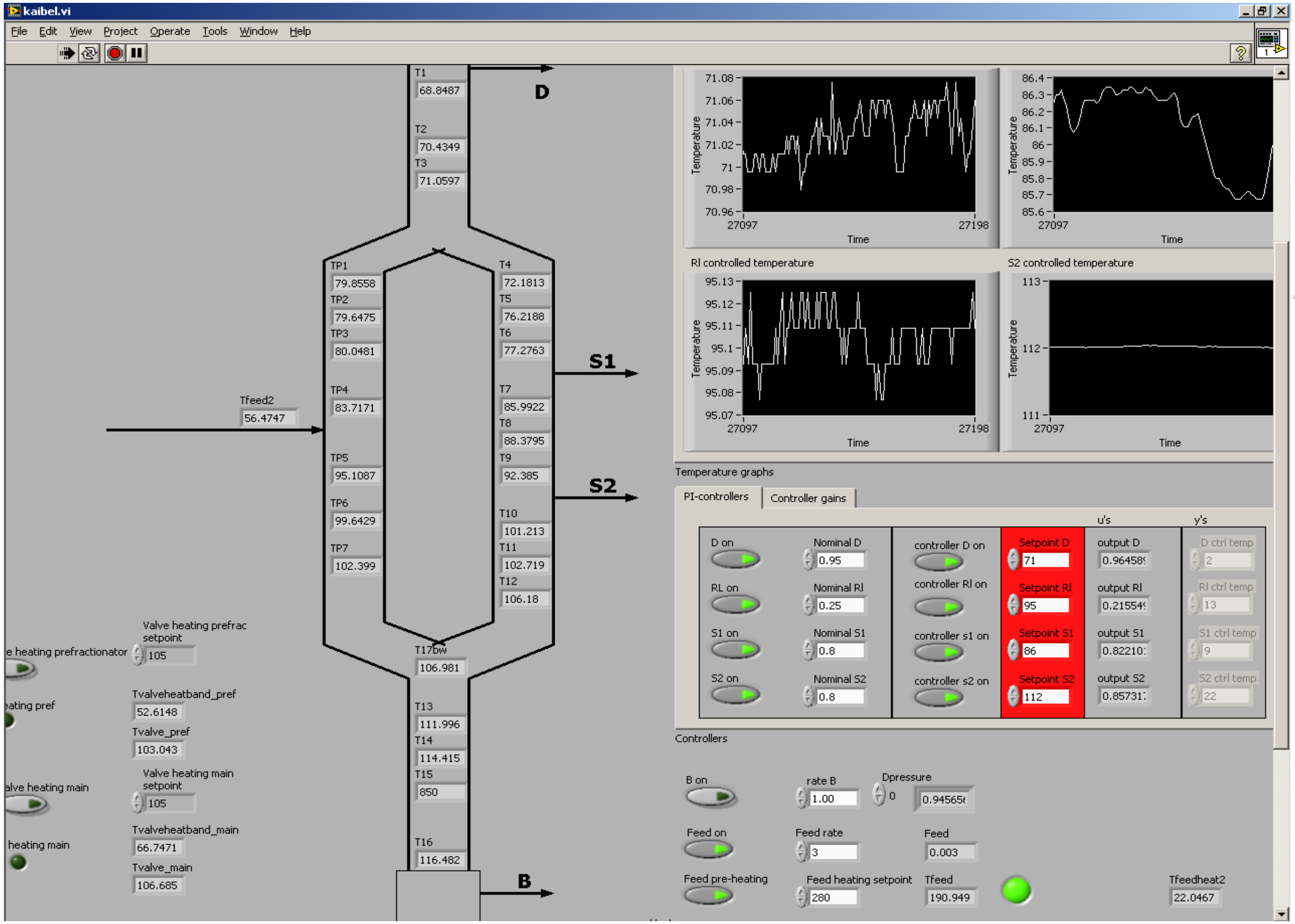
Experimental Set up

- **4 products**
- **Packed Column**
- **Magnetic funnel-liquid split & Product valves**
- **Number of theoretical stages (experimentally determined):**
  - **Prefractionator: 13**
  - **Main column : 21**

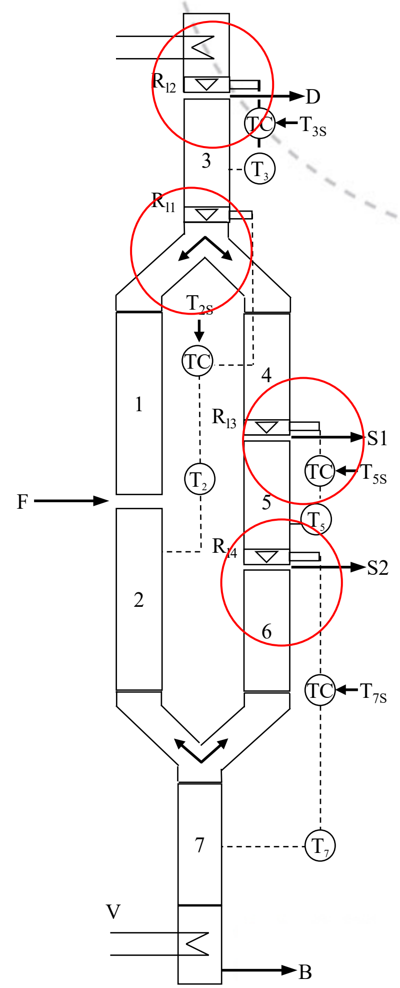


Experimental Set up (Labview Interface)…



Control Structure (As used in experiments)

- Boilup V=constant
- 4 control degrees of freedom:
  - Liquid split ratio R_{L1},
  - Reflux ratio R_{L2} (top)
  - Reflux ratio R_{L3} (middle)
  - Reflux ratio R_{L4} (bottom)
- Decentralized Control with 4 PI Temperature Controllers:
  - T_{2s} is adjusted to get large temperature change in the prefractionator
  - T_{3s}, T_{5s}, T_{7s} is adjusted to get the temperature of product stages close to the boiling points of their main components



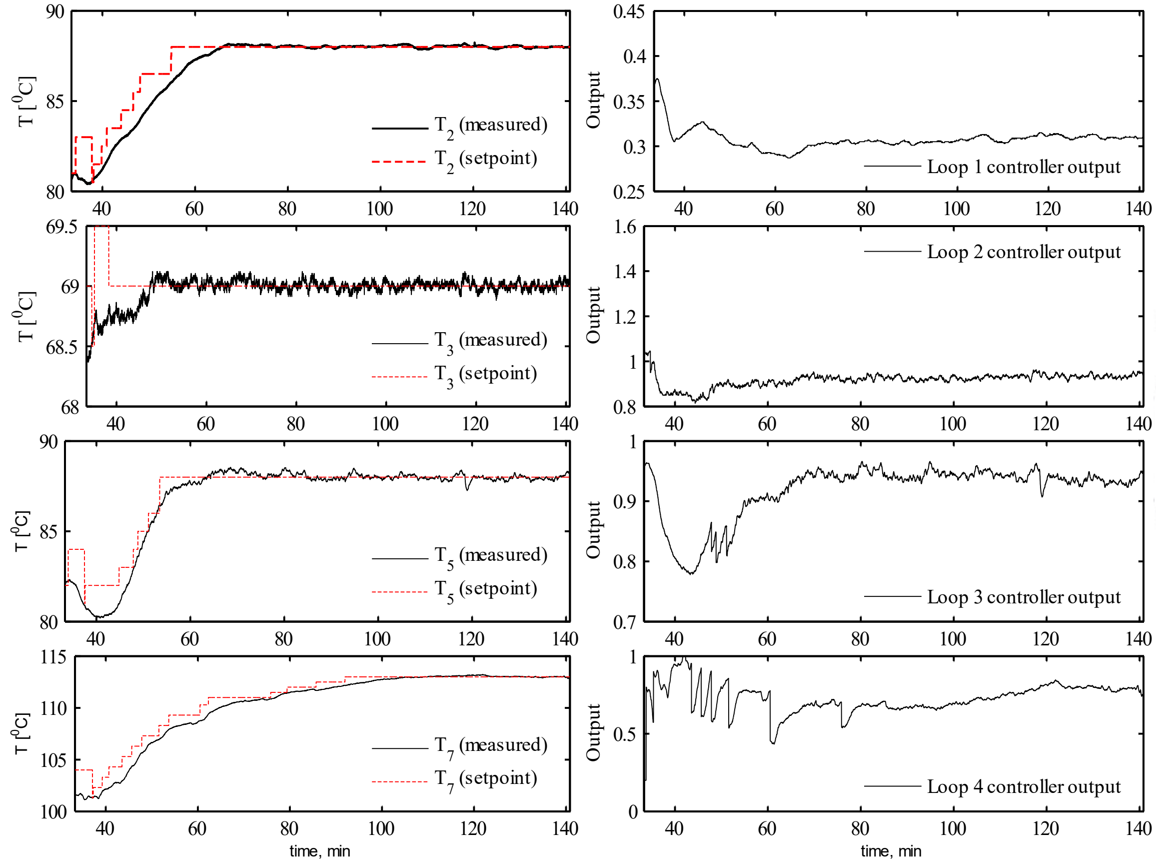
Start-up

- T_{2s} is adjusted to get large temperature change in the prefractionator

- T_{3s}, T_{5s}, T_{7s} is adjusted to get the temperature of product stages close to the boiling points of their main components

Temperatures

Reflux ratios



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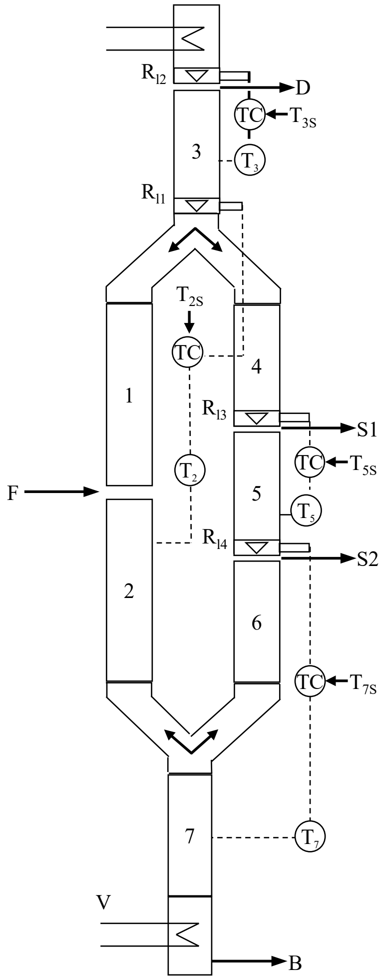
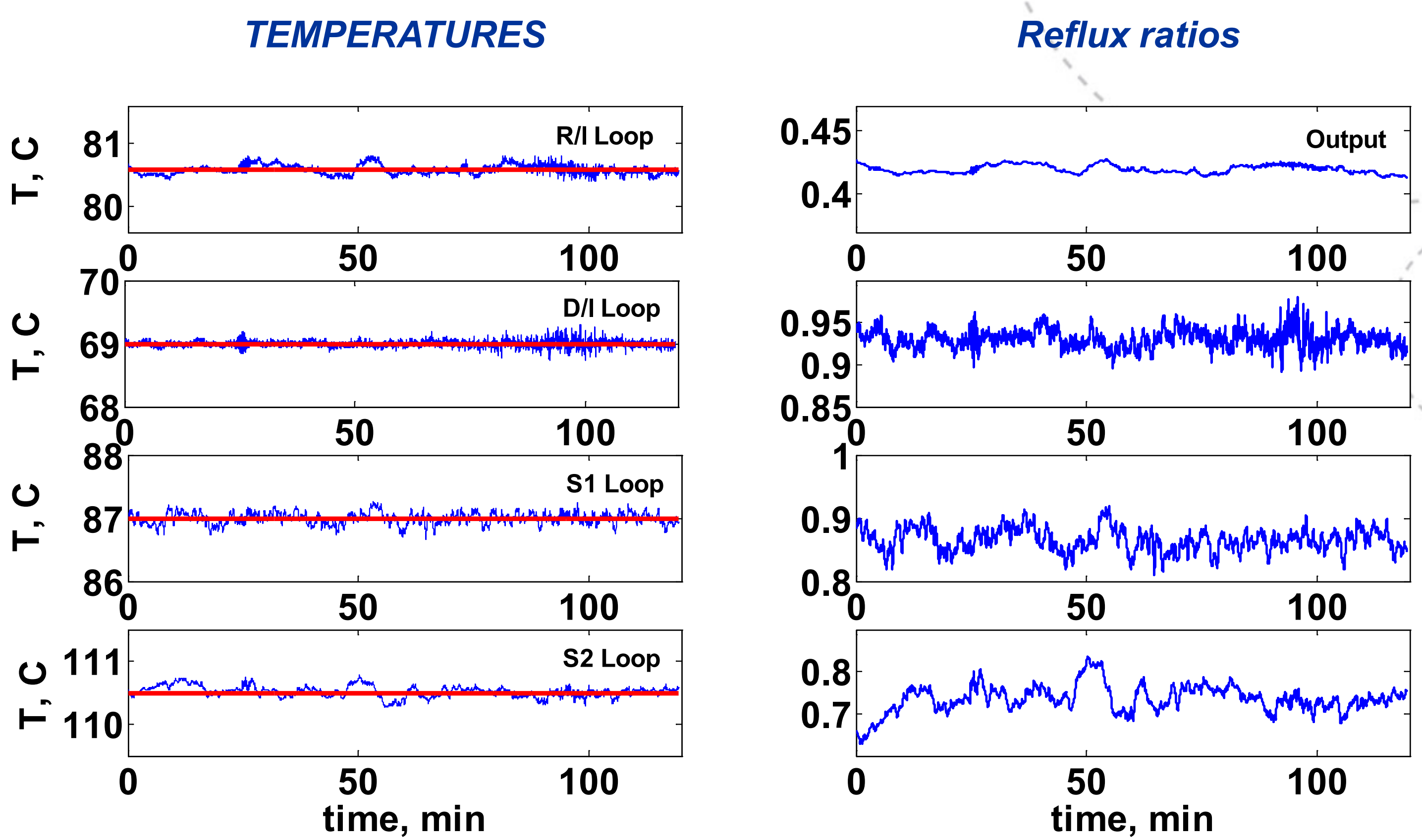
Steady Profiles with 4 temperature loops





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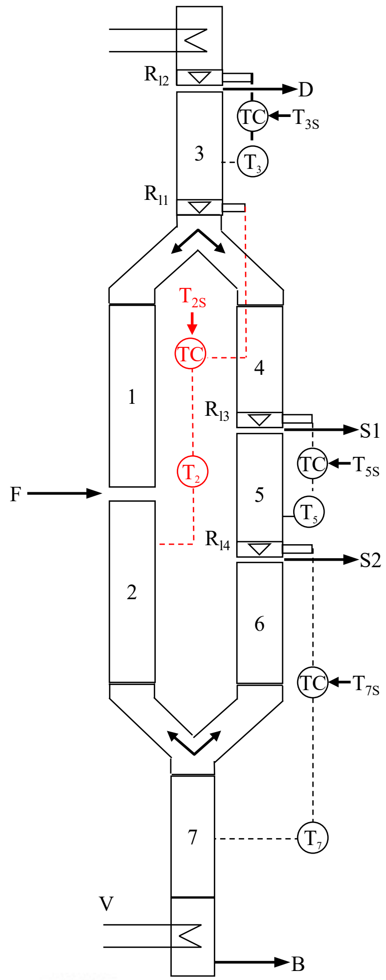
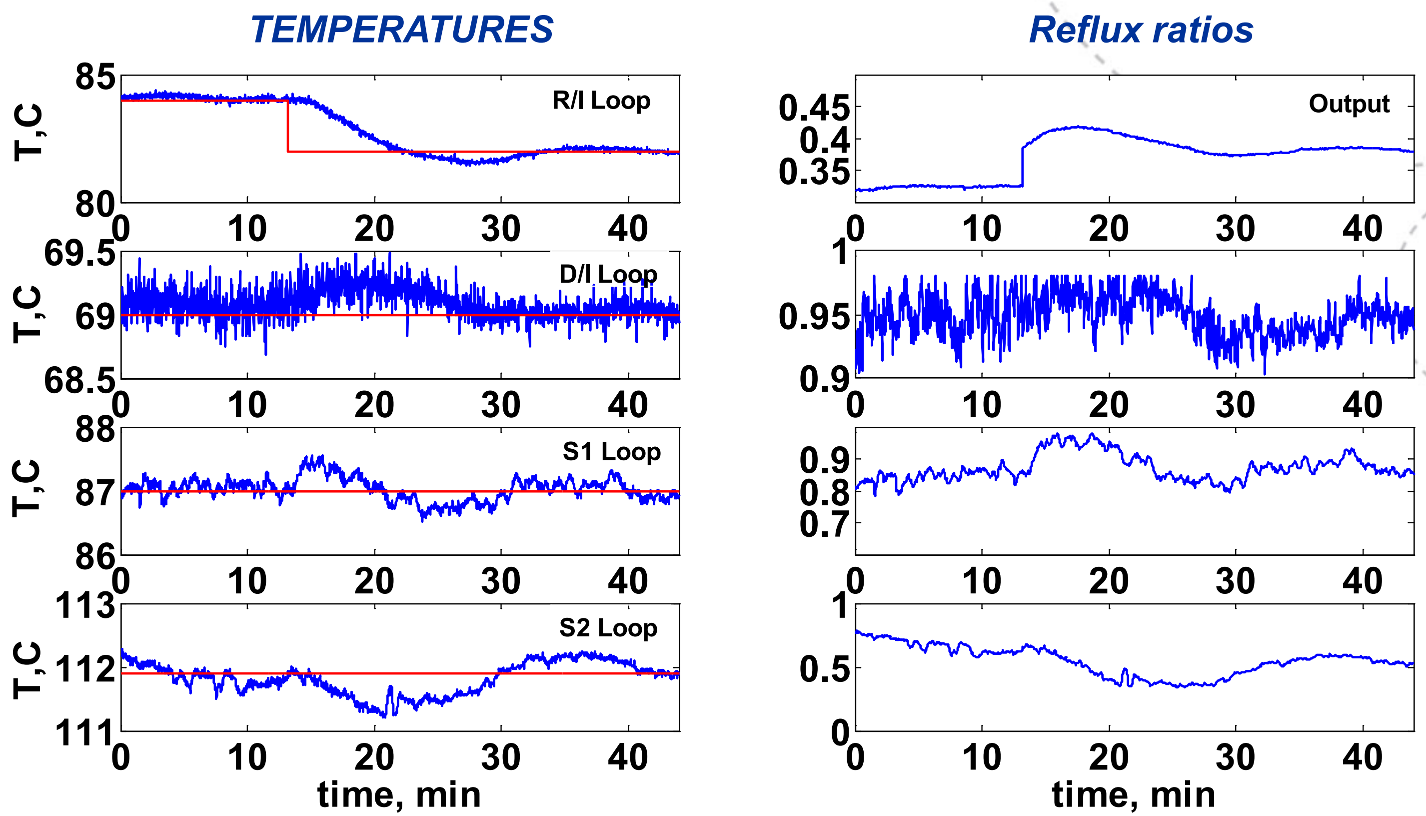
Steady Profiles with 4 temperature loops..



Liquid Split Loop -2 C



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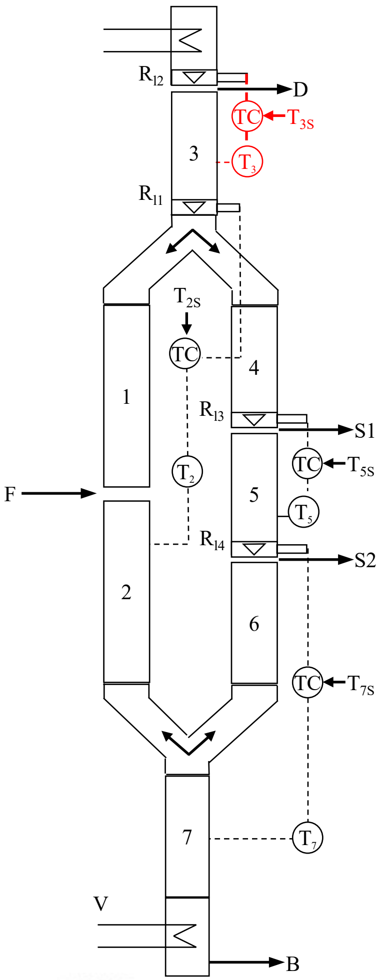
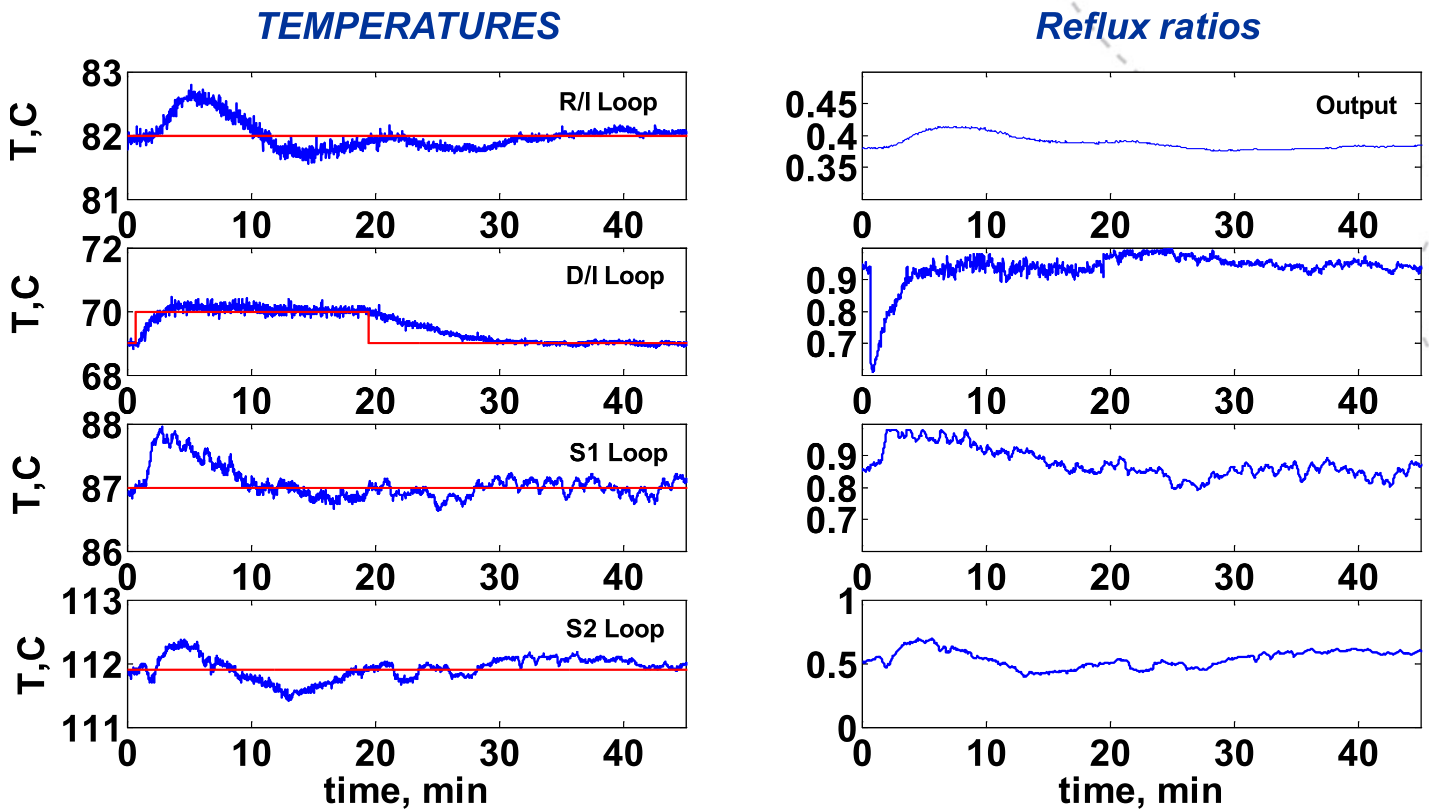
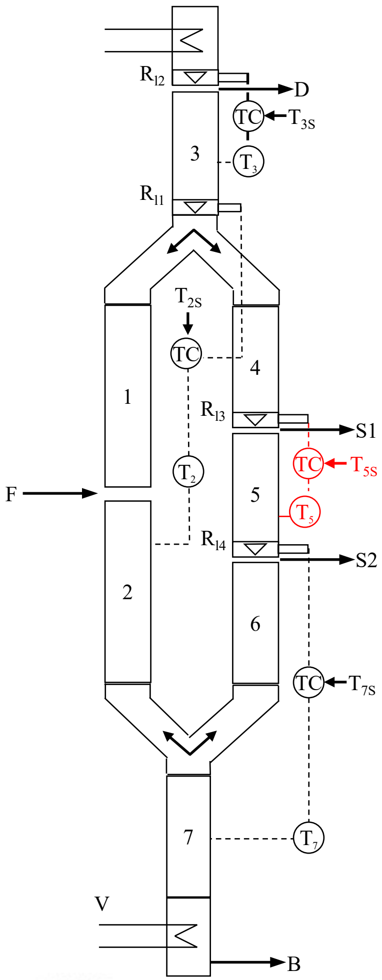
Steady Profiles with 4 temperature loops..



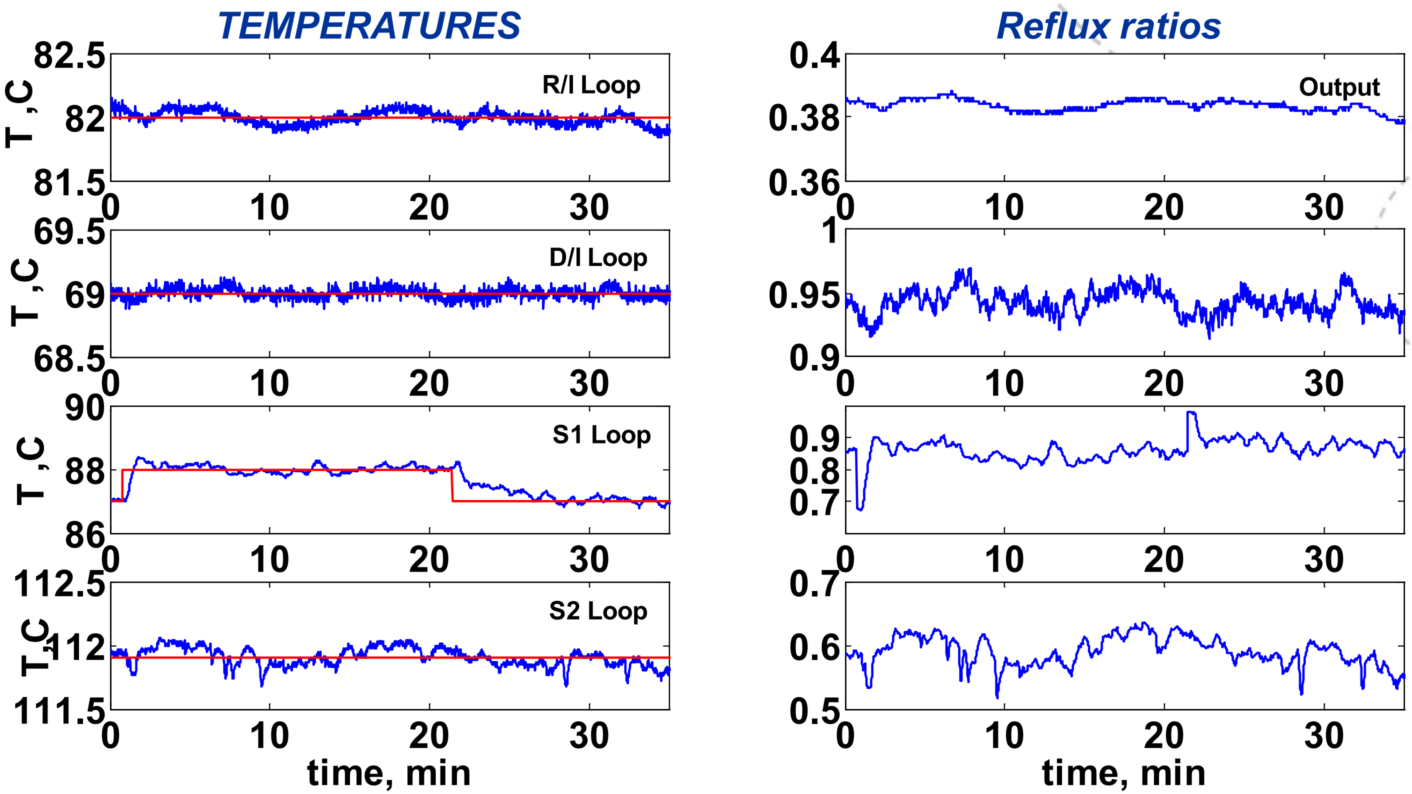
Distillate Loop ±1 C



Steady Profiles with 4 temperature loops..



S1 Loop ± 1 C



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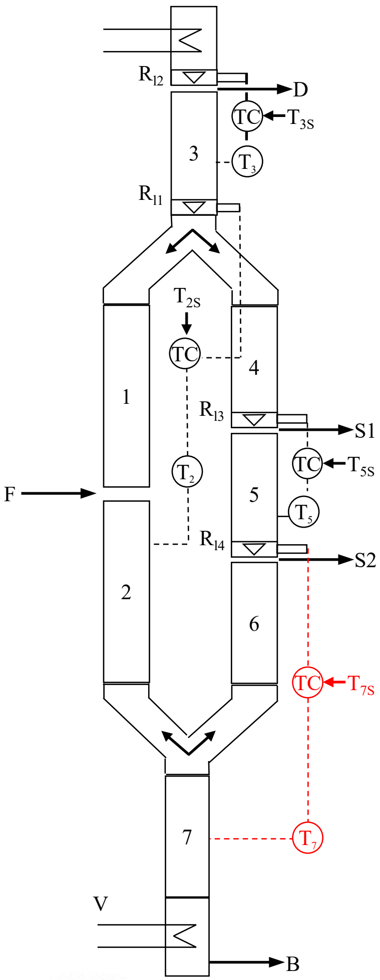
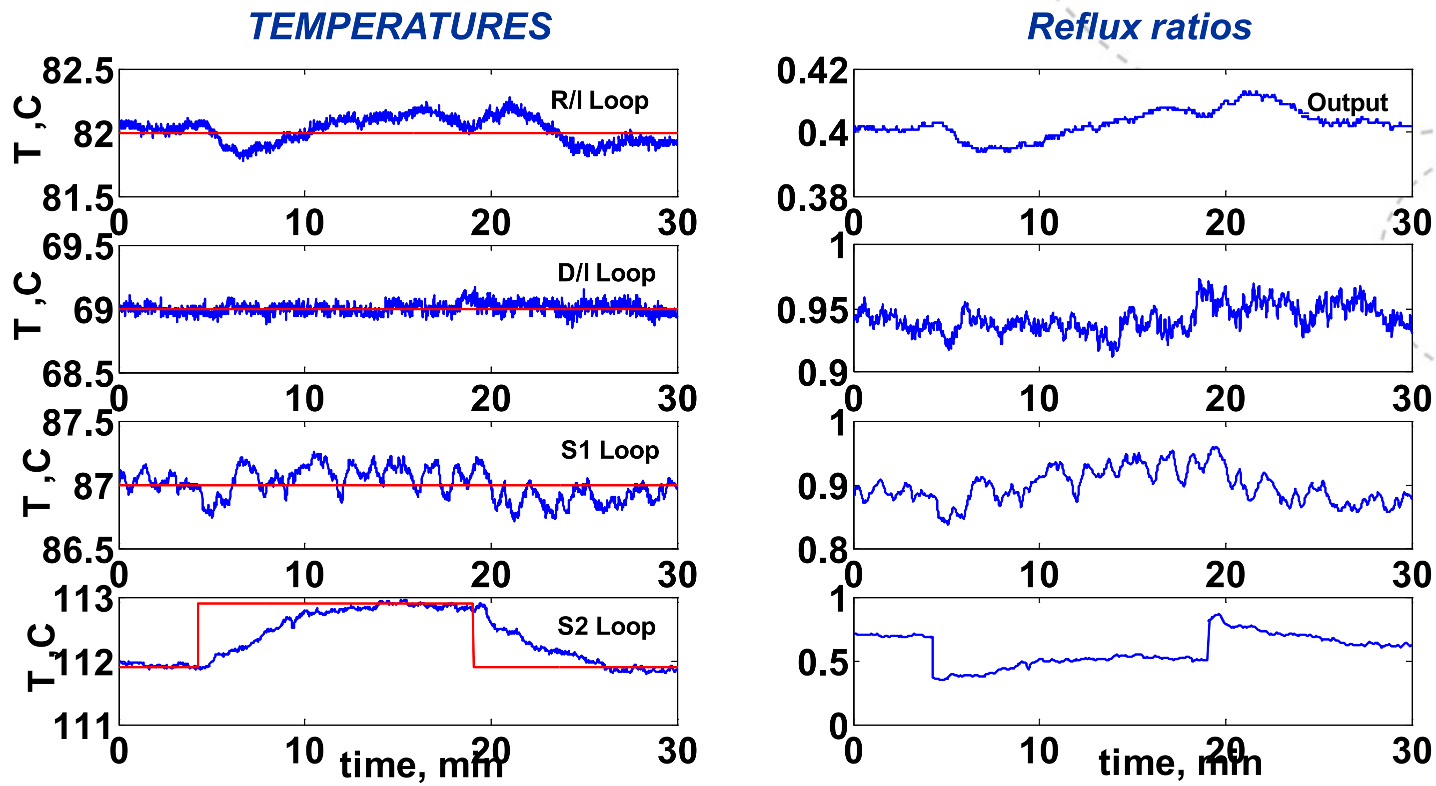
Steady Profiles with 4 temperature loops..



S2 Loop ± 1 C



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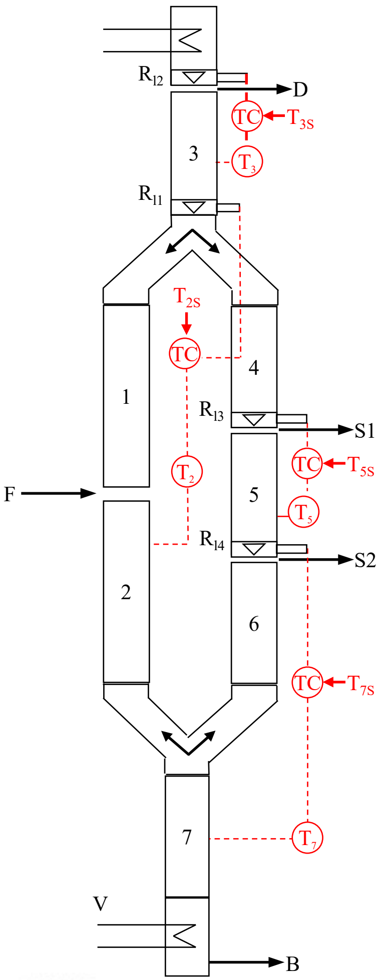
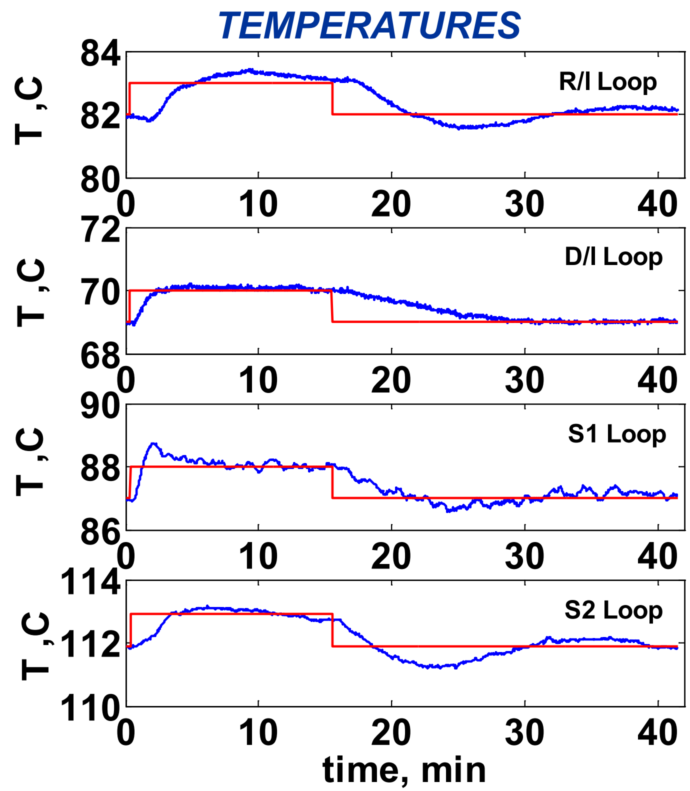
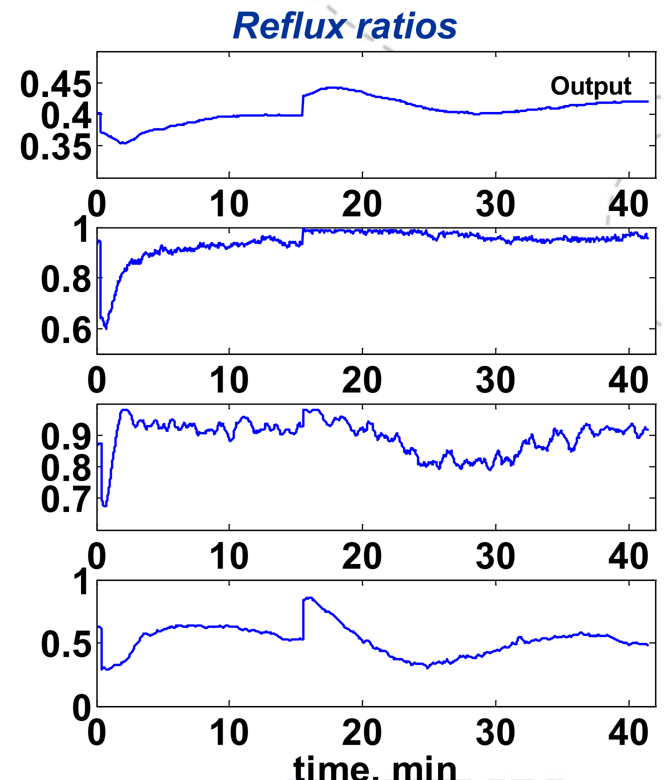
Steady Profiles with 4 temperature loops..

All Loops ± 1 C







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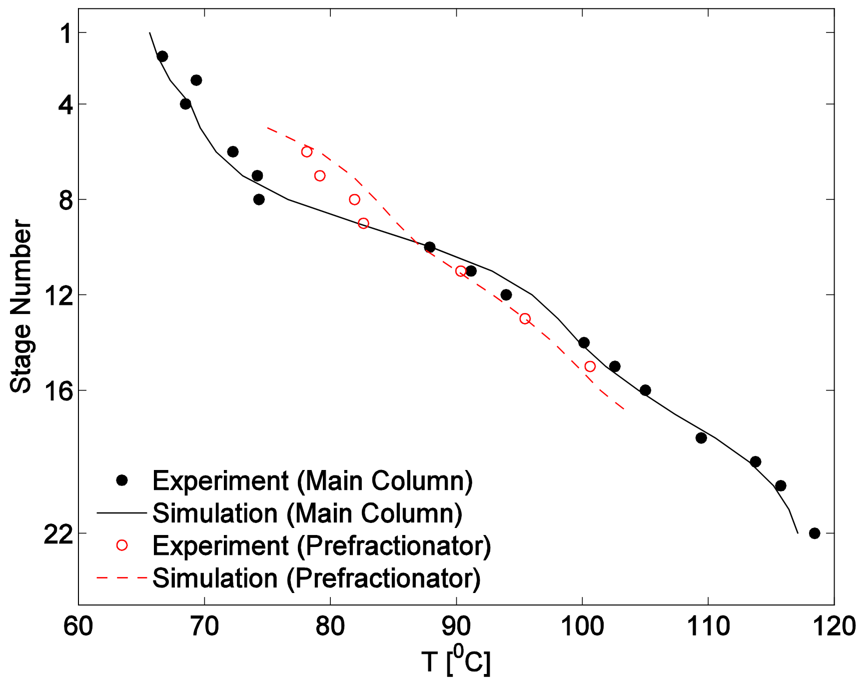
Model (lines) and experiments (points) fit well



	D		S1		S2		B	
	Simulation	Experiment	Simulation	Experiment	Simulation	Experiment	Simulation	Experiment
Methanol	**92.6%**	**92.6%**	15.4%	17.2%	0.21%	0	0	0
Ethanol	7.3%	7.3%	**51.5%**	**51.5%**	4.52%	5.38%	0	0
Propanol	0	0	32.9%	31.2%	**89.6%**	**89.6%**	3.14%	6.68%
Butanol	0	0	0	0	5.67%	5.02%	**96.86%**	**93.32%**

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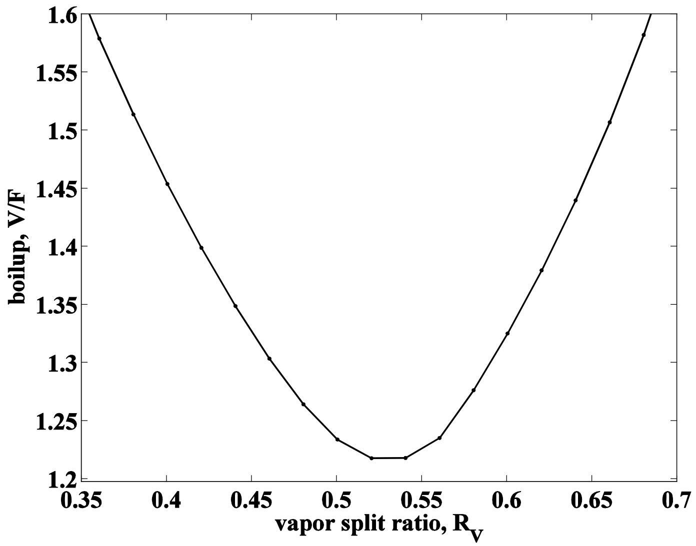
Vapor Split

- So far: Vapor split (Rv) kept constant
- But: Energy usage depends on Rv.
- Implement adjustable Rv
- But: Difficult to set Rv at desired value
  - Solution: Use Rv for temperature control (**feedback)**
  - The more precise liquid split (Rl) can be preset



V/F vs R_V for Kaibel column

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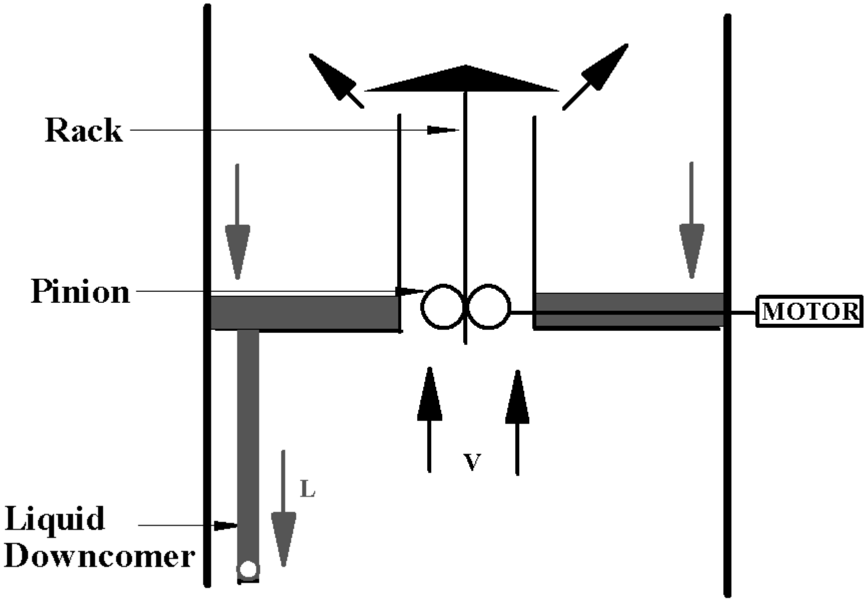
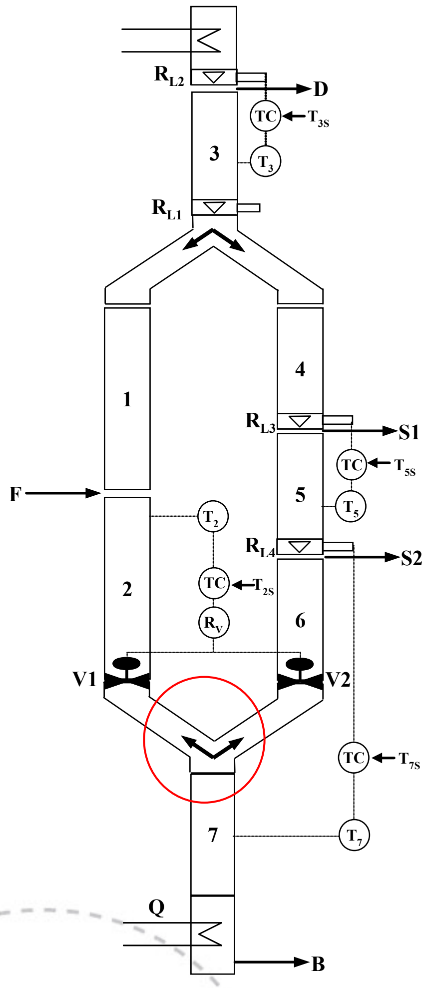
Vapor Split Experiment..

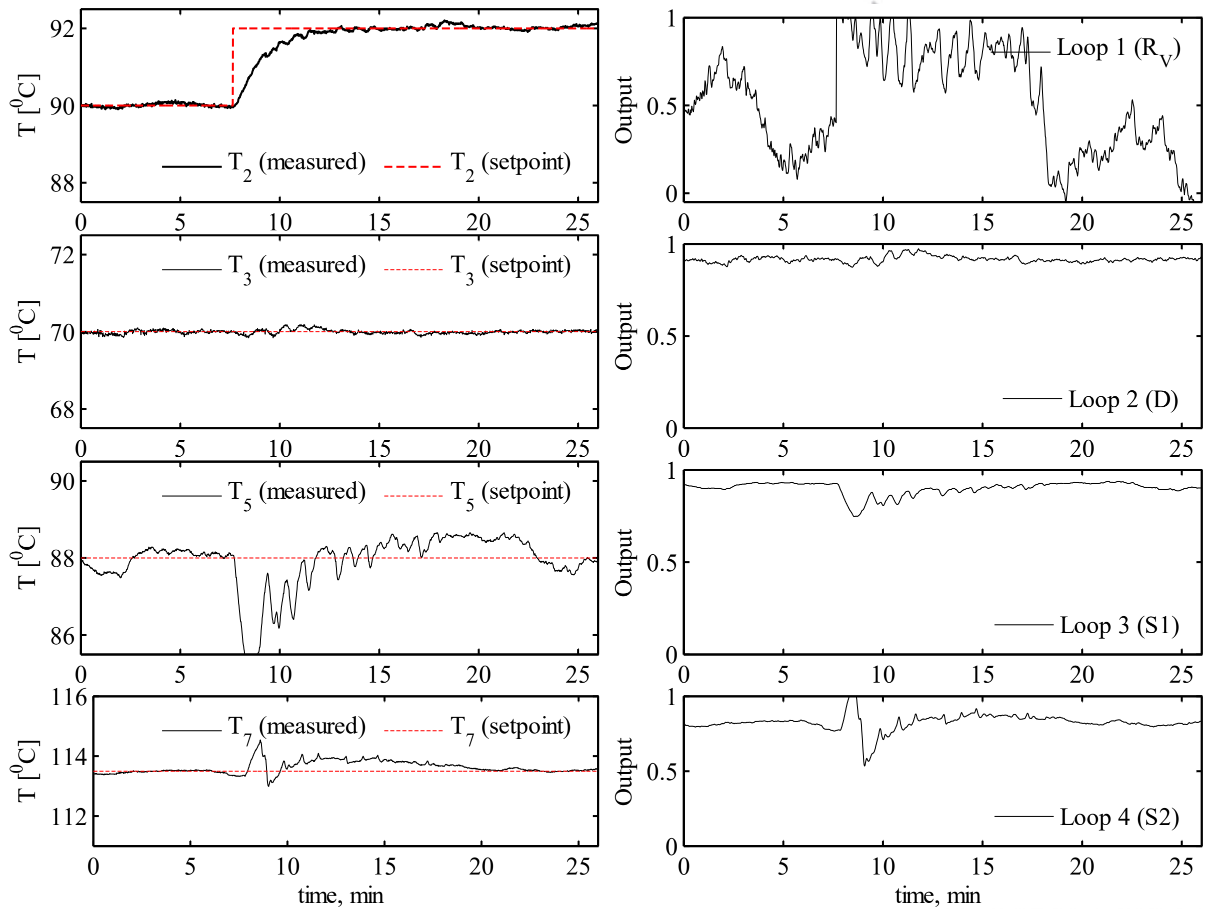


Schematic of the vapor split valve

From top left: Valve in fully open position
Top right: Rack and pinion arrangement

Vapor Split Experimental run (Kaibel Column)





Conclusions

- **Four-Product Kaibel column**
  - Experimentally demonstrated 4-point temperature control for stabilizing and startup operation
  - Experimentally demonstrated active vapor split control
  - Experimental data fits well with the model

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Outline

- Introduction
- 4- Product Kaibel Column
  - Four-product Kaibel column
  - Control Structure
  - Experimental Setup
  - Experimental Runs- Steady state profiles
  - Experimental Runs- Vapor Split Experiment
- **3- Product Petlyuk Column**
  - **Three-product Petlyuk column**
  - **The “V_{min} diagrams”**
  - **Control Structures**
  - **Close Loop Results**
- Conclusions

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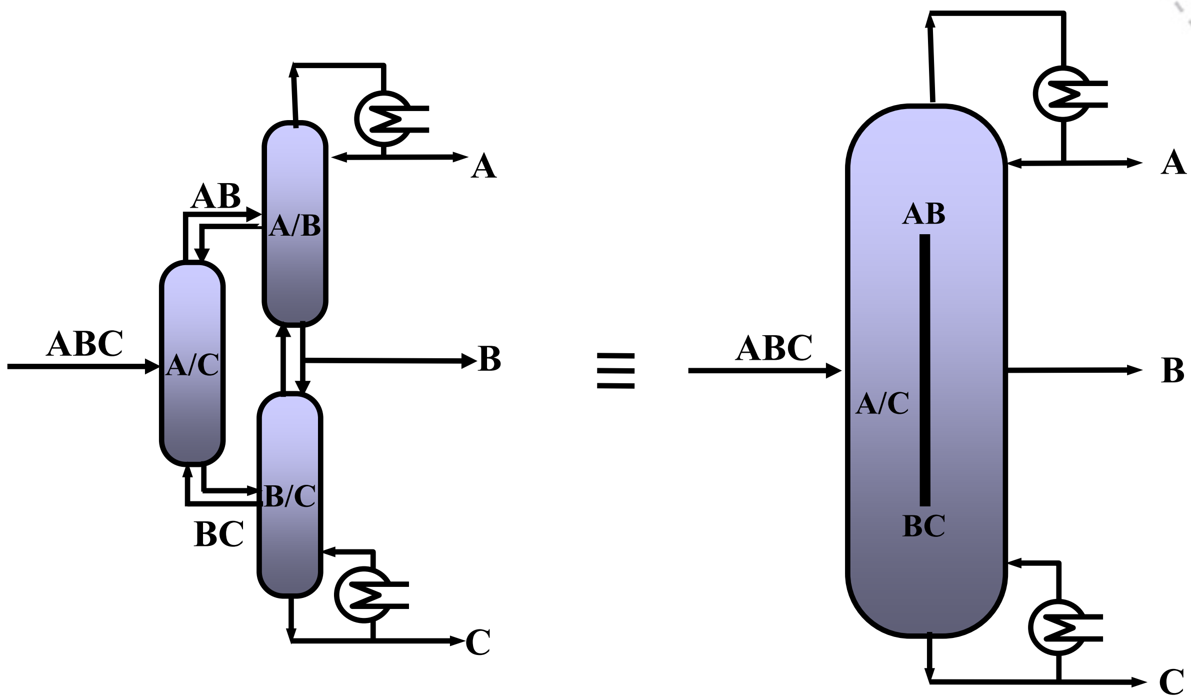
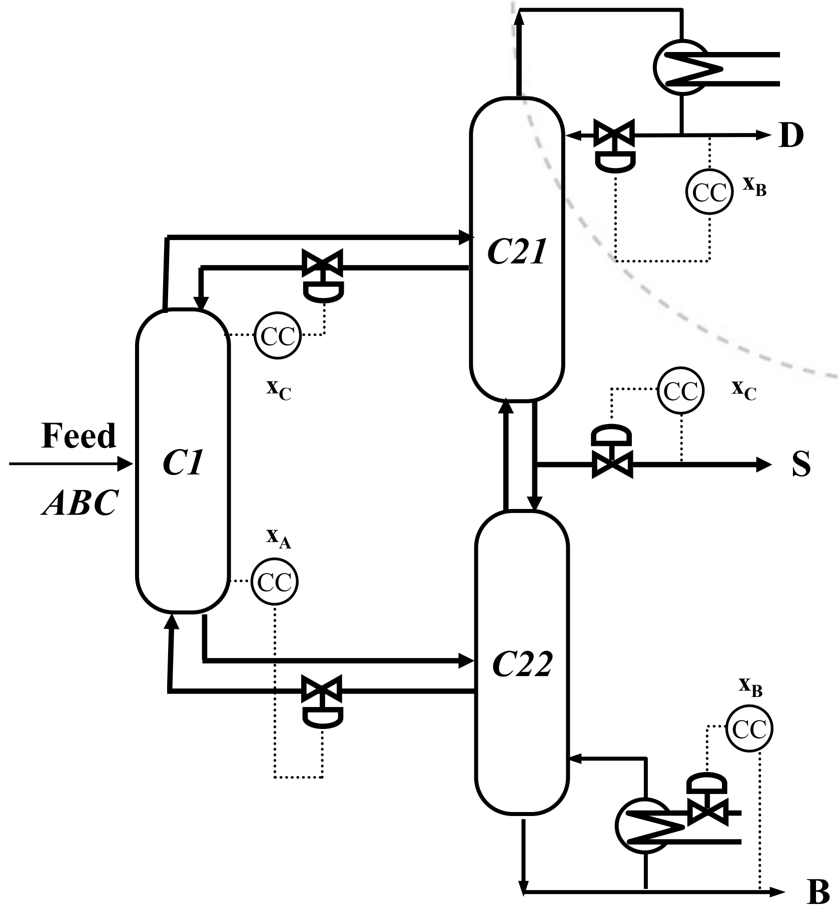
Three-product Petlyuk column

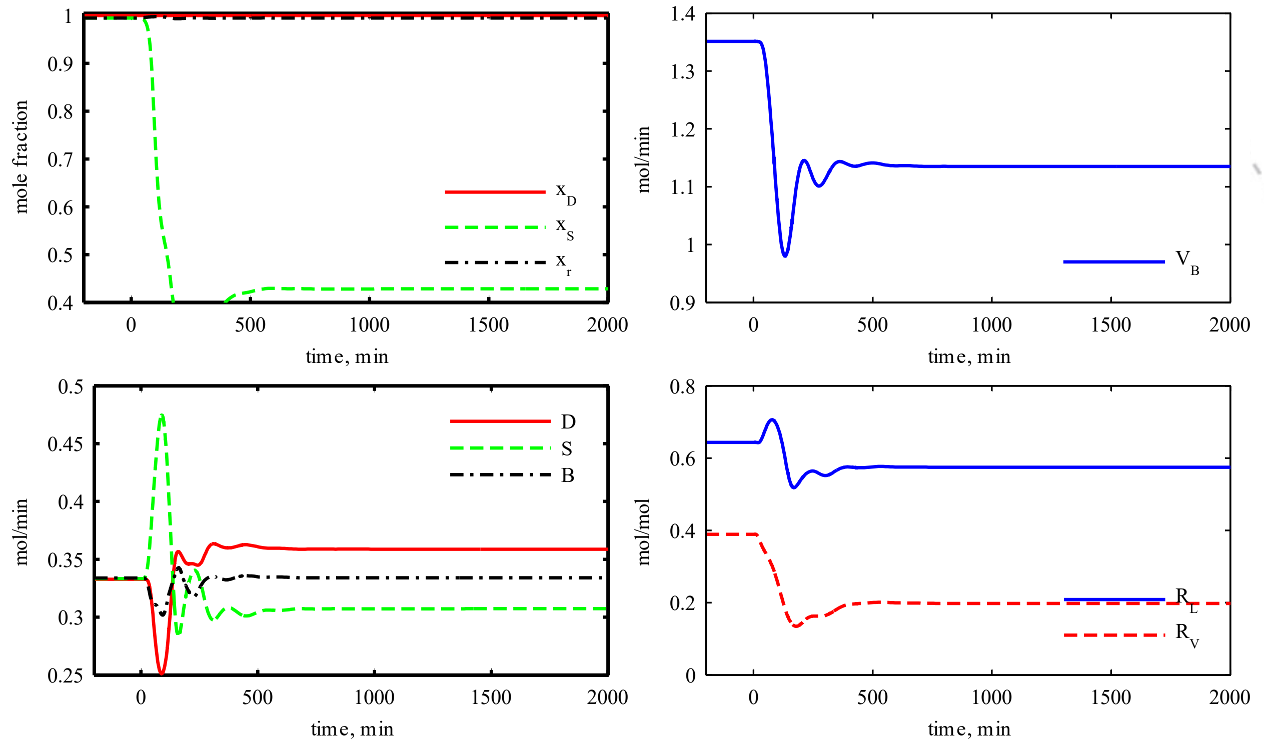


Control Structure 1

- Five degrees of freedom including vapor split
- Control key impurities using “close-by” parings
- Side product has two side impurities
  - •In CS1, S is paired with heavy key (x_C)



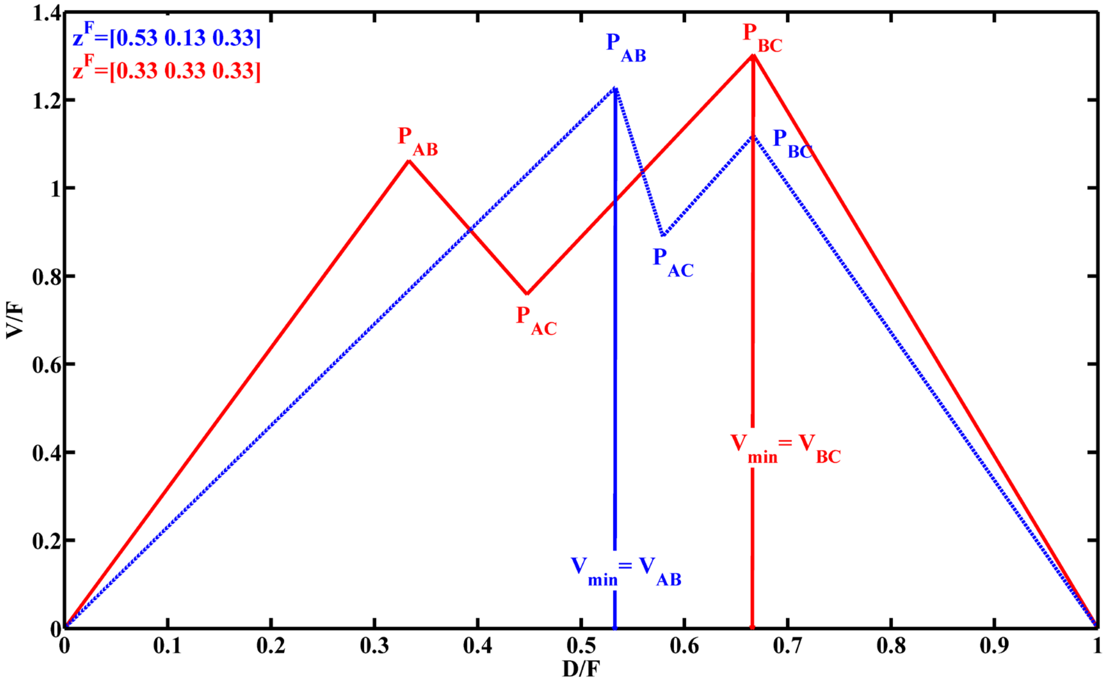
Closed-loop result from CS1



Fails for feed composition disturbance z_f=[53 13 33]

from nominal equimolar feed

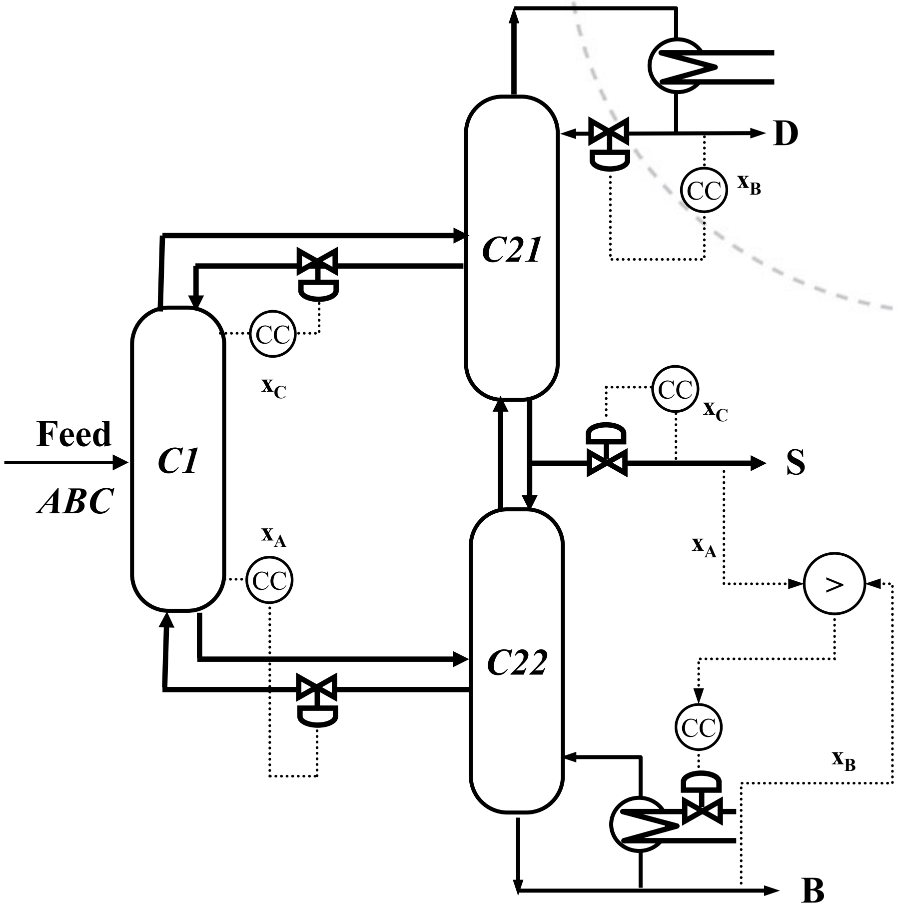
Why CS1 failed ??



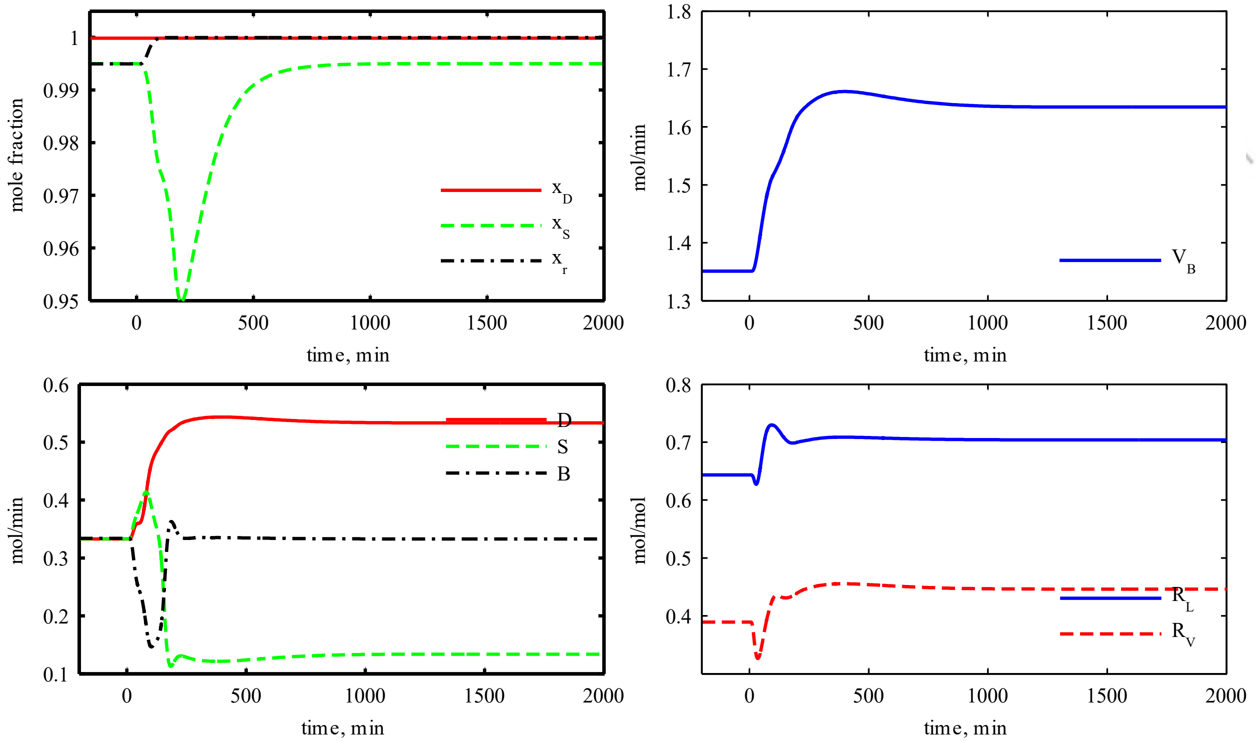
- For nominal equimolar feed, B/C is the most difficult split
- For the new feed A/B is more difficult feed and CS1 can not provide sufficient vapor in top section of main column

Control Structure 2

- Same as CS1, but boilup now has a maximum select controller with:
  - light key, x_A at S or,
  - light key, x_B at reboiler



Closed loop results from CS2



- Works for all feed composition disturbance from nominal equimolar feed
- The purity of bottom product may be over purified for some disturbances

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